PONTIFICIAE ACADEMIAE SCIENTIARVM SCRIPTA VARIA

32

SEMAINE D'ETUDE

SUR LE THEME

MATIERE ORGANIQUE ET FERTILITE DU SOL

22-27 avril 1968

PONTIFICIA
ACADEMIA
SCIENTIARVM

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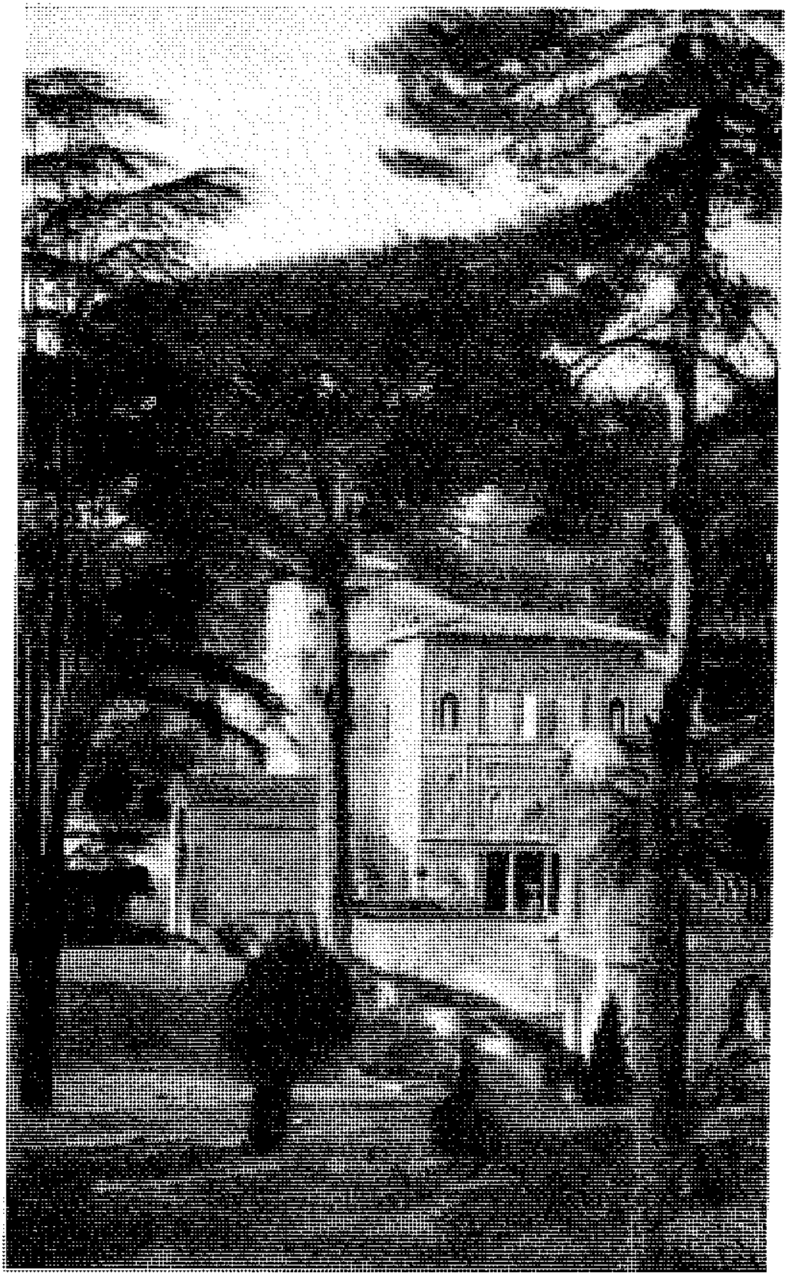

PONTIFICIAE ACADEMIAE SCIENTIARVM SCRIPTA VARIA

32

STUDY WEEK

ON

ORGANIC MATTER AND SOIL FERTILITY

april 22-27, 1968

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MATIERE ORGANIQUE
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En conformité avec le programme prévu, la Semaine d'Etude sur le thème « Matière Organique et Fertilité des Sols » a recouvert tous les aspects jugés dignes d'intérêt et en outre a fourni l'occasion pour un échange de vues entre spécialistes de matières différentes, mais qui par leur travail contribuent à la résolution de problèmes aussi complexes que ceux qui ont fait l'objet de la Semaine d'Etude.

Les groupes de travail, dont la formation était nécessaire pour pouvoir unifier les critères relatifs aux aspects partiels du problème, permirent à la Semaine d'Etude d'arriver, en sa dernière séance, à des conclusions définitives parfaitement homogènes, qui révélèrent un complet accord entre les Participants sur les points plus importants de ce problème complexe; cela déjà permet de conclure à d'importants résultats pour cette Semaine.

D'autre part les orientations discutées pendant la Semaine et les accords rejoints au cours de ses sessions contribueront sans aucun doute, selon nous, à résoudre le problème de la faim *dans le monde ou du moins à éperonner les gouvernements et les groupes d'étude et à leur fournir les directives plus aptes à l'obtention des résultats désirés en ce domaine.*

Nous sommes en train de vivre actuellement une nouvelle période de crise dans ce problème endémique que constitue l'insuffisance de la production d'aliments à l'échelle mondiale et qui se traduit si bien dans l'expression « la faim dans le monde ».

Problème et crise qui ont ému la conscience mondiale à la suite du pressant appel lancé par Sa Saintété le Pape Paul VI, qui, tout comme ses prédécesseurs, maintient deux observateurs permanents du Saint-Siège auprès de la F.A.O.

Etant donné que la Science peut et doit répondre à l'appel du Saint Siège et contribuer par son apport à préciser et à explorer les différents moyens qui doivent porter à l'expansion de la production des aliments, l'Académie Pontificale des Sciences a voulu, suivant les directives du Saint Père, prendre de son côté une part active à la solution de ce problème du point de vue scientifique.

L'Académie Pontificale des Sciences a donc tenu à souligner par cette Semaine d'Etude sur « La matière organique et la fertilité du sol » que l'un des moyens plus efficaces est sans doute l'accroissement de la productivité grâce à l'amélioration ou au moins à la conservation de la fertilité du sol, laquelle, à son tour, est en intime relation avec son contenu en matière organique.

La matière organique étant le sujet primordial des travaux présentés au cours de cette Semaine, il a été tenu compte en *premier lieu des dernières acquisitions relatives à l'origine, à la conservation et à la transformation de la matière organique dans les sols, en prenant en considération surtout les techniques les plus modernes, tant du point de vue microbiologique que du point de vue chimique.*

Dans cette perspective se trouvent tant les processus qui interviennent dans le cycle de l'azote que ceux qui concernent la matière organique dans les differents types de sols, en relation avec leur fertilité.

Les séances ultérieures ont eu pour objet les aspects plus concrets qui mettent en relation la matière organique avec la fertilité du sol: les propriétés physiques du sol, c'est-à-dire sa structure physique, et, en relation avec celle-ci, l'effet des méthodes de culture sur cette caracteristique absolument fondamentale des sols, considéré également du point de vue biologique.

Après quoi on a considéré les processus chimiques dans la matière organique, tant en relation avec le complexe matière organique-argiles que, plus concrétement, avec la transformation des groupes carboxyle.

Un argument qui, dans ce domaine, s'est révélé d'un intérêt particulier, a été l'effet de la matière organique et des phosphates sur la fixation de l'azote dans le sol par processus photochimiques. Tout cela, nous espérons, nous a permis de coordonner les différents idées relatives aux recherches actuelles dans ce domaine.

La discussion s'est poursuivie sur l'action des microorganismes sur la matière organique.

Dans ce sens ont été considérés tous les aspects mettant en rapport matière organique et fertilité, ainsi que les facteurs pouvant favoriser celle-ci.

Puis on a traité de l'action de la faune sur la formation et la décomposition de l'humus.

Cela, outre tout ce qui a été considéré dans les séances précédentes, nous a permis de discuter, en ce qui concerne la matière organique, des facteurs principaux qui peuvent influer sur l'amélioration de la fertilité des sols.

Finalement on a discuté des effets de l'application de matières organiques et de produits dérivés ou similaires, ainsi que de l'action de ceux-ci sur la croissance des plantes, ce qui a donné assurément un caractère plus concret aux résultats des discussions antérieures.

On a parlé aussi des applications aux problèmes de la fertilité, et considéré de façon spécifique les dernières découvertes concernant le développement des plantes.

On a traité de l'humus naturel et artificiel, des fertilisants préparés à partir de celui-ci et de leur effet sur la production agricole; et on a discuté des causes des effets non-accumulatifs sur le rendement et de l'intensification de l'usage de ces produits.

Nous espérons que les discussions et les échanges d'impressions qui ont eu lieu dans les différentes séances auront permis d'avoir une vision plus complète du problème dans son ensemble; nous attendons surtout que les aspects qui restent encore obscurs puissent servir de base aux futures recherches et aident *à déterminer lesquels ont une plus grande importance pratique de par leur influence sur l'accroissement de la fertilité et, en somme, sur l'augmentation de la production des sols.*

Pietro Salviucci
Chancelier de l'Académie

INTRODUCTION

Le problème de la matière organique dans le sol est d'une si grande complexité qu'il occupe l'attention d'éminents spécialistes des plus divers domaines de la science. Ainsi les chimistes et les physiciens du sol, les biochimistes, les microbiologistes, les zoologues, etc., travaillent dans leurs domaines particuliers d'activité et essaient d'obtenir des éclaircissements sur les problèmes soulevés par la formation, la transformation et la conservation de la matière organique du sol, mais avec une optique limitée et particulière, de spécialistes.

Précisément au moment où la Science est arrivée à un degré avancé de spécialisation il est capital de se rendre compte quand devient nécessaire l'échange des idées et des résultats entre les différents spécialistes qui, à partir de leurs domaines respectifs, cherchent la solution de problèmes identiques. Il nous semble que, dans la question complexe de la matière organique dans le sol, est arrivé et même dépassé le moment où la coordination des efforts réalisés dans les différentes champs de travail devient indispensable.

La réalisation de cette Semaine d'Etude promue par l'Académie Pontificale des Sciences sous le titre « Matière Organique et Fertilité du Sol » a donc été, nous l'espérons, d'une grande utilité parce que l'on a pu faire un véritable effort, et au plus haut niveau, en faveur de la nécessaire coordination.

La fertilité du sol est en relation très étroite avec son contenu en matière organique. Donc, tout ce qui pourra être réalisé en faveur de l'accumulation de matière organique dans le sol, se réflètera en une augmentation de la fertilité potentielle du sol, étant donné que nous sommes en train de vivre une nouvelle période de crise dans ce problème endémique que constitue l'insuffisante production alimentaire à l'échelle mondiale et qui est si bien résumé par l'expression « la faim dans le monde ».

Considerons à présent les caractéristiques du sol sur lesquelles agit la matière organique:

1) le type de structure, et en conséquence, le développement radiculaire, la capacité de rétention d'eau de la part du sol et, par conséquent, l'efficacité des pluies ou de l'irrigation;

2) la fixation de l'azote de l'atmosphère par les microorganismes et par voie photochimique, car dans ces deux cas la présence de la matière organique y est fondamentale. Ces deux processus d'apport d'azote aux plantes sont les plus économiques, alors que les composés produits artificiellement par l'homme, outre à revenir plus chers, sont encore, même en

l'état actuel de la technologie, produits en quantités trop faibles pour couvrir les besoins des plantes;

3) la protection du sol contre l'érosion, car celle-ci en altère la structure, et par conséquent le contenu en matière organique;

4) la vie des microorganismes qui effectuent le cycle dynamique du sol;

5) l'apport d'acides humiques et d'hormones végétales aux plantes (processus respiratoires et d'absorption d'éléments);

6) l'apport en forme directe ou indirecte de macro ou microéléments pour les plantes, qui est facilité par la matière organique même dans sa décomposition ou par l'action des produits de cette décomposition sur la fraction minérale du sol;

7) l'action compensatrice des équilibres anomaux entre anions et cations dans la solution du sol.

Ce problème est extraordinairement complexe, ce qui dérive immédiatement de la complexité même de la matière organique du sol et des mécanismes minéralogiques, chimiques, physiques et biologiques qui conditionnent ses incessantes transformations.

Voici à présent quelques-unes des lignes sur lesquelles s'est basé le programme final, qui a naturellement été prédisposé en fonction des opinions des spécialistes participant à la Semaine.

1) Origine, transformation et conservation de la matière organique dans les sols.

2) Emploi de substances organiques naturelles et de substances modèles.

3) Action réciproque des microorganismes et de la faune du sol sur la matière organique.

4) Caractéristiques de la matière organique dans les types principaux de sols et leur importance sur leur fertilité.

5) Etude conjointe par rapport aux techniques de culture, y compris l'emploi d'engrais humiques.

A partir des résultats qui ont pu être obtenus de la discussion des aspects déjà connus par les différents spécialistes y participant, la Semaine d'Etude a pu mettre en évidence les résultats obtenus, ainsi que les lacunes encore existantes, et par conséquent indiquer sur quelles lignes doivent se dérouler les recherches actuelles.

Comme résultat ultérieur on peut espérer que beaucoup d'autres chercheurs reconnaîtront l'importance des problèmes à résoudre et se sentiront induits à contribuer à leur solution.

Ainsi nous aurons contribué à éviter le sort des anciennes civilisations que disparurent précisément parce qu'elles ne connaissaient pas le rôle transcendental que la matière organique joue dans la productivité des sols.

Aujourd'hui serait encore plus déplorable de retomber dans les mêmes erreurs alors que la Science a révélé les motifs qui ont causé le déclin de ces civilisations.

VALENTIN HERNANDO FERNÁNDEZ
Sous-directeur de l'Institut d'Edaphologie et de Biologie végétale de Madrid, Participant a la Semaine d'Etude et Secrétaire technique de la même.

LA SEMAINE D'ETUDE

SUR

LA MATIERE ORGANIQUE ET LA FERTILITE DU SOL

Le but des « Semaine d'Etude » de l'Académie Pontificale des Sciences a été ainsi défini par son premier Président, S.E. Le Rev.me Père AGOSTINO GEMELLI O.F.M.

« Tandis qu'on fixait, après sa fondation, les travaux de l'Académie, un problème se présenta bien vite avec évidence: les sciences posent chaque jour des problèmes nouveaux qui donnent lieu d'ordinaire à divers essais de solution, souvent contradictoires. Il arrive ainsi constamment que parmi les représentants les plus autorisés d'une science et, en particulier, entre ceux qui se sont consacrés à l'étude d'une même question, on rencontre des opinions opposées. De pareilles divergences se maintiennent parfois pendant de longues périodes et constituent à la fois une grave difficulté pour l'enseignement des sciences et fréquemment aussi un obstacle considérable à leur développement. D'ailleurs, l'expérience montre que les méthodes actuellement pratiquées dans la discussion des problèmes scientifiques, n'ont qu'une efficacité limitée au point de vue de l'établissement d'une unité de doctrine. Il serait hautement souhaitable de promouvoir tout ce qui pourrait favoriser une entente sur les points et discussion.

« Un tel procédé semble devoir être particulièrement utile sous ce rapport: savoir établir des contacts personnels prolongés entre quelques représentants d'opinions différentes au sujet d'une question déterminée ».

Dans ce but, l'Académie Pontificale des Sciences a réalisé une nouvelle « Semaine d'Etude » ayant pour titre: « Matière organique et fertilité du sol » (¹).

Bien que ces derniers temps un travail intense ait été fourni sur les divers aspects de ce problème, il restait cependant quelques questions de détail à résoudre, et de nouvelles questions s'étaient de plus posées pendant ces dernières années.

Etant donné qu'on n'avait pas encore provoqué un débat approfondi à ce sujet et que le moment semblait propice pour le faire, l'Académie Pontificale des Sciences s'est proposée de réunir un nombre restreit de savants spécialistes de la question. Son but était de recueillir, au cours d'une discussion approfondie, les synthèses des nombreuses recherches effectuées dans ce domaine; de formuler clairement l'état des différents problèmes qui s'y rapportent; et par là de pouvoir fixer les directives de recherche les plus logiques, les plus persuasives et les plus prometteuses, étant donné l'état actuel de la science.

(¹) Cette « Semaine d'Etude » sur «Matière organique et fertilité du sol » est la dixième de la série.

La première « Semaine d'Etude » à eu lieu du 6 au 13 juin 1940; elle a été dédiée au « Problème biologique du Cancer », et a été présidée par l'Académicien Pontifical S.E. PIETRO RONDONI, Professeur de Pathologie Générale et expérimentale à l'Université de Milan; y ont participé personnellement 15 savants tandis que 3 autres ont envoyé des mémoires. Les comptes-rendus de la « Semaine d'Etude » ont été publiés dans le 7ème volume des « Scripta Varia » de l'Académie; ils représentent un volume de 364 pages.

La deuxième « Semaine d'Etude » a eu lieu du 19 au 26 novembre 1951; elle a été dédiée au « Problème des Microséismes », et a été présidée par l'Académicien Pontifical S.E. FRANCESCO VERCELLI, Directeur de l'Institut Thalassographique et de l'Observatoire Géophysique de Trieste; y ont participé personnellement 15 savants tandis que 4 autres ont envoyé des mémoires. Les comptes-rendus de la « Semaine d'Etude » ont été publiés dans le 12ème volume des « Scripta Varia » de l'Académie; ils forment un volume de 466 pages.

La troisième « Semaine d'Etude » a eu lieu du 14 avril au 2 mai 1955; elle a été dédiées au « Problème des Oligoélements dans la vie végétale et animale », et a été présidée par l'Académicien Pontifical S.E. JOSÉ MARIA ALBAREDA HERRERA, Directeur de l'Institut de Pédologie et de Physiologie

A cet effet ont été invités des experts qualifiés en agricolture, en agronomie, en biochimie, en botanique, en édaphologie, en géologie, en microbiologie, en recherche agronomique des sols et en problèmes de nutrition des plantes, etc., qui, grâce à ces études spécifiques, ont contribué à la connaissance des plus récents développements sur la matière organique et la fertilité du sol.

La présidence de cette « Semaine d'Etude » sur « Matière organique et fertilité du sol » avait été confiée par feu le Président de l'Académie Pontificale des Sciences, S.E. GEORGES LEMAÎTRE, à l'Académicien Pontifical qui eut l'idée de la réaliser, en l'occurrence, S.E. Don JOSÉ MARIA ALBAREDA HERRERA, Directeur de l'Institut d'Edaphologie et de Physiologie végétale de l'Université de Madrid et Secrétaire Général du Conseil Supérieur des Recherches Scientifiques d'Espagne, et l'organisation générale au Chancelier de l'Académie Pontificale des Sciences Prof. Dr. PIETRO SALVIUCCI.

Malheuresement l'Académicien Pontifical S.E. JOSÉ MARIA ALBAREDA HERRERA monurut et, comme la structuration scientifique de

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végétale de l'University de Madrid, Secrétaire Général du Conseil Supérieur des Recherches Scientifiques d'Espagne; y ont participé personnellement 19 savants tandis qu'un autre a envoyé un mémoire. Lec comptes-rendus de la « Semaine d'Etude » ont été publiés dans le 14ème volume des « Scripta Varia » de l'Académie; ils forment un volume de 630 pages.

La quatrième « Semaine d'Etude » a eu lieu, du 20 au 28 mai 1957; elle a été dédiée au « Problème des Populations stellaires » et a été présidée par l'Académicien Pontifical Surnuméraire le Rev.me Père DANIEL J. K. O'CONNELL, Directeur de la « Spocola Vaticana » de Castelgandolfo; y ont participé personnellement 21 savants. Les comptes-rendus de la « Semaine d'Etude » ont été publiés dans le 16ème volume des « Scripta Varia » de l'Académie; ils forment un volume de 615 pages.

La cinquième « Semaine d'Etude » a eu lieu du 23 au 31 octobre 1961; elle a été dédiée au « Problème des macromolécules d'interêt biologique avec référence spéciale aux nucléoprotéides », et a été présidée par l'Académicien Pontifical S.E. ARNE TISELIUS, Professeur de Biochemie à l'Université de Uppsala; y ont participé personnellement 18 savants. Les comptes-rendus de la « Semaine d'Etude » ont été publiés dans le 22ème volume des « Scripta Varia » de l'Académie; ils forment un volume de 544 pages.

La sixième « Semaine d'Etude » a eu lieu du 1 au 6 octobre 1962; elle a été dédiée au « Problème du rayonnement cosmique dans l'espace inter-la Semaine était déja bien avancée, elle put être terminée par le Prof. VALENTIN HERNANDO FERNANDEZ, le plus intime collaborateur du feu l'Académicien ALBAREDA HERRERA.

L'actuel Président de l'Académie Pontificale des Sciences, S.E. le Rév.me Père DANIEL J.K. O'CONNELL confia alors la Présidence de la Semaine d'Etude à l'Académicien Pontifical S.E. Don MANUEL LORA TAMAYO, Professeur de Chimie organique à l'Université de Madrid, en raison de son amitié personnelle avec le disparu et de la similarité de leurs domaines d'étude, et nomma Secretaire technique de la dite Semaine M. le Prof. Dr. VALENTIN HERNANDO FERNÁNDEZ, Sousdirecteur de l'Institut de Sciences des sols et Biologia Vegetale de Madrid.

Ont été invités à la réunion les savants suivants:

Prof. Dr. MARTIN ALEXANDER, Professeur de Microbiologie au Département d'Agronomie de l'Université Cornell - *Ithaca, N. Y.* (USA).

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planétaire », et devait être présidée par l'Académicien Pontifical S.E. VICTOR FRANCIS HESS, Professeur émérite de Physique à l'Université Fordham de New York; malheureusement l'Académicien VICTOR FRANCIS HESS n'a pas pu, en raison de son état de santé, être présent et la « Semaine d'Etude » a été présidée par l'Académicien Pontifical S.E. GEORGES LEMAÎTRE, Professeur de Mécanique et de Méthodologie matèmatique à l'Université de Louvain et Président de l'Académie. Y ont participé personnellement 24 savants. Les comptes-rendus de la « Semaine d'Etude » ont été publiés dans le 25ème volume des « Scripta Varia » de l'Académie; ils forment un volume de 626 pages.

La septième « Semaine d'Etude » a eu lieu du 7 au 13 octobre 1963; elle a été dédiée à « Le rôle de l'analyse économétrique dans la formulation de plans de développement », et a été présidée par l'Académicien Pontifical S.E. MARCELLO BOLDRINI, Professeur de Statistique à l'Université de Rome; y ont participé personnellement 18 savants. Les comptes-rendus de la « Semaine d'Etude » ont été publiés dans le 28ème volume des « Scripta Varia » de l'Académie; ils forment une oeuvre de 1260 pages en deux volumes.

La huitième « Semaine d'Etude » a eu lieu du 28 septembre au 3 octobre 1964; elle a été dédiée au « Cerveau et expérience consciente », et a été présidée par l'Académicien Pontifical S.E. Sir JOHN CAREW ECCLES, Prof. Dr. LEONARD DAVID BAVER, Professeur d'Agronomie à l'Université de l'Etat d'Ohio. - *Columbus, Ohio* (U.S.A.).

Prof. Dr. RICHARD BRADFIELD, Consultant spécial pour l'Agricolture près la Fondation Rockefeller. - *New York, N. Y.* 10020 (U.S.A.).

Prof. Dr. LUIS BRAMAO, Chef de l'Office des Ressources du Sol à la FAO - *Rome* (Italie).

Prof. Dr. JOHN McCOLL BREMNER, Professeur d'Agronomie et Biochimie à l'Université de l'Etat d'Iowa. - *Ames, Iowa* (U.S.A.).

Prof. Dr. FRANCIS EVERETT BROADBENT, Professeur de Microbiologie à l'Université de Californie. - *Davis, Calif.* (U.S.A.).

Prof. Dr. RAYMOND CHAMINADE, Directeur de Recherches à l'Institut National de la Recherche Agronomique; Chef de la Di-

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Professeur de Physiologie à l'Université de Canberra; y ont participé personnellement 18 savants. Les comptes-rendus de la « Semaine d'Etude » ont été publiés dans le 30ème volume des « Scripta Varia » de l'Académie; ils forment un volume de 885 pages.

La neuvième « Semaine d'Etude » a eu lieu du 18 au 23 avril 1966; elle a été dédiée aux « Forces moléculaires », et devait être présidée par l'Académicien Pontifical S.E. PIETER DEBYE, Président du Department of Chemistry de la Cornell University de Ithaca, N.Y.; malheureusement l'Académicien PIETER DEBYE n'a pas pu, en raison de son état de santé, être présent et la « Semaine d'Etude » a été présidée par l'Académicien Pontifical S.E. SAN-ICHIRO MIZUSHIMA, Professeur émérite de Chimie à l'Université de Tokyo et Directeur de l'Institut des Recherches scientifiques « Yawata ». Y ont participé personnellement 17 savants. Les comptes-rendus de la « Semaine d'Etude » ont été publiés dans le 31ème volume des « Scripta Varia » de l'Académie; ils forment un volume de 824 pages.

L'organisation générale de chaque « Semaine d'Etude » a été confiée au Chancelier de l'Académie Pontificale des Sciences, le Dr. PIETRO SALVIUCCI. Toutes les réunions se sont tenues au Siège de l'Académie à la « Casina di Pio IV » dans le Jardins du Vatican.

vision des Sols à l'Institut de Recherches Agronomiques tropicales; Professeur à l'Institut National Agronomique. - 78, *Versailles* (France).

Prof. Dr. Nil Ratan Dhar, Directeur honoraire de l'Institut d'Edaphologie Sheila Dhar de l'Université d'Allahabad. - *Allahabad, Uttar Pradesh* (Inde).

Prof. Dr. Wolfgang Arthur Julius Flaig, Directeur Général de l'Institut de Biochimie du Sol de l'Office Fédéral de Recherche Agronomique. - *Brunswick-Völkenrode* (Rép. Féd. Allemande).

Prof. Dr. Herbert Franz, Directeur de l'Institut de Géologie et Edaphologie de l'Université Agricole de Vienne. - 1180 *Wien XVIII* (Autriche).

Prof. Dr. Giovanni Haussmann, Directeur Supérieur de la Station expérimentale de Culture des Prairies de Lodi. - *Lodi* (Italie).

Prof. Dr. Stephane Henin, Chef du Département Agronomie à l'Institut National de la Recherche Agronomique. - *Versailles* (France).

Prof. Dr. Valentín Hernando Fernández, Chercheur au Conseil Supérieur de la Recherche Scientifique; Sous-directeur de l'Institut de Science des Sols et Biologie Végétale. - *Madrid* (Espagne).

Prof. Dr. Hans Jenny, Professeur émérite, réengagé pour l'enseignement et la recherche scientifique au Département des Sols et de la Nutrition des Plantes de l'Université de Californie. - *Berkeley, Calif.* (U.S.A.).

Prof. Dr. Lydia Asenovna Khristeva, Professeur de Physiologie-des-Plantes et Botanique, et Directrice Scientifique du Laboratoire des engrais humiques à l'Institut d'Agriculture de Dniepropetrosk. - *Dniepropetrovsk, RSS d'Ukraine* (URSS).

Prof. Dr. MARIA MIKHAILOVNA KONONOVA, Directrice du laboratoire de biochimie de l'Institut du Sol Dokuchayev. - *Moscou* (URSS).

Prof. Dr. VICTOR A. KOVDA, Professeur de Science des Sols et Chef de la Sous-Faculté de Science des Sols de l'Université d'Etat de Moscou. - *Moscou* (URSS).

S.E. Prof. Dr. MANUEL LORA TAMAYO, Académicien Pontifical, Professeur de Chimie Organique à la Faculté des Sciences de l'Université de Madrid. - *Madrid* (Espagne).

Prof. Dr. ARTHUR GEOFFREY NORMAN, Vice-Président de l'Université du Michigan chargé de la recherche. - *Ann Arbor, Mich.* (U.S.A.).

Prof. Dr. ARTURO PRIMAVESI, Directeur de l'Institut « Solos e Culturas » de l'Université Fédérale de Santa Maria. - *Santa Maria, RGS* (Brésil).

Prof. Dr. ELWYN THOMAS REESE, U. S. Army Natick Laboratories. - *Natick, Mass.* (U.S.A.).

Prof. Dr. HERBERT WILLIAM REUSZER, Professeur Associé d'Agronomie à l'Université Purdue. - *Lafayette, Ind.* (U.S.A.).

Prof. Dr. RAYMOND JOHN SWABY, Chef de la section Microbiologie des Sols à la Division des Sols du CSIRO. - *Adelaide* (Australie).

Prof. Dr. SELMAN ABRAHAM WAKSMAN, Professeur Emérite de Microbiologie et Directeur Emérite de l'Institut de Microbiologie de l'Université d'Etat du New Jersey. - *New Brunswick, N. J.* (U.S.A.).

Tous les invités, à l'exception des Professeurs L.A. KHRISTEVA, M.M. KONONOVA et V.A. KOVDA, qui n'ont pas pu intervenir, ont participé à la Semaine.

Le « Règlement des Semaine d'Etude » sélon lequel le nombre des Participants doit être rigoureusement limité, a malheureusement empêché d'inviter d'autres illustres savants.

Ont aussi participé à la réunion: en qualité d'interprète et chef du Secrétariat Mlle JOSÉPHINE LUCAS; en qualité de sténographes polyglotte de séance Mlle DENISE CARS, Mlle JUDITH PICKFORD, Mlle DEBORAH REYNOLDS, Mlle HETHER SAUNDERS et Mlle MARJORIE TAYLOR; en qualité de sténodactylographes polyglottes chargées des Procès-verbaux: Mlle RITA MAURO BALOCCO et Mlle EITHNA RYAN; en qualité de traductrice simultanée Mme VALERIA ZINGAROPOLI; en qualité de technicien pour l'enregistrement et la projection, Mr. MAURO ERCOLE, assisté par des opérateurs de Radio-Vatican. Le Bureau de Presse était confié au Dr. FRANCESCO SALVIUCCI, Coadjuteur du Chancelier de l'Académie.

Le Comité de Réception pour les Dames était ainsi composé: Mme HÉLÈNE LOTTI, Mme MARIÙ PUNZO, et les Comtesses ISABELLA et KARINA CALVI DI COENZO.

Le soir du dimanche 21 a eu lieu dans les salons de l'Hôtel Reale une rencontre amicale, au cours de laquelle les Participants ont eu l'occasion de prendre contact entre eux et avec l'équipe technique du Secrétariat, afin de faciliter le cas échéant l'organisation pratique de la Semaine et prendre d'éventuels accords préliminaires.

Au cours de ladite rencontre a en effet été approuvé le programme définitif de la Semaine, dont à la page LXX.

A l'ouverture des travaux de la Semaine d'Etude, le matin du lundi 22, le Président de l'Académie a eu pour les participants quelques mots de bienvenue.

Ensuite le Professeur SELMAN A. WAKSMAN, « Chairman » de la première séance, prononça l'allocution suivante:

« Gentlemen, in welcoming you here at this meeting of Soil Organic Matter and Soil Fertility I want to make at first two comments. It was exactly forty-four years ago that I participated in a meeting here in Rome held in what used to be the International Institute of Agriculture. At that meeting the basis was laid for the Organisation of the International Society of Soil Science. A representative group of soil scientists gathered here in Rome; organic matter occupied some place during the discussions at those meetings. In those forty-four years, which is practically nearly half a century, our knowledge of soil organic matter had received much consideration. Our present meeting, under such high auspices as the Pontifical Academy of Sciences, adds much significance to this problem. I want therefore to express on behalf of all you our most sincere appreciation to the Pontifical Academy that has given such important consideration to a subject of tremendous importance in soil fertility.

« I would further like to say a few words on behalf of our friend who has passed away unfortunately before this meeting and who has laboured so hard in bringing this meeting about, Professor ALBAREDA. Professor ALBAREDA indeed was a man as one might say, « un homme de bonne volonté », a man of goodwill. He meant well, worked hard for the field in which he was rightly interested, the science of the soil, and especially in the subject which we are going to consider this week, namely the role of the organic matter in the fertility of the soil. It would therefore be only proper if these meetings are dedicated to Professor ALBAREDA.

« Now please remember the conditions under which we are meeting this week. The address is to last not more than thirty minutes and there will be a discussion of not more than fifteen minutes for the particular paper ».

Le samedi 27 avril a eu lieu au Siège de l'Académie Pontificale des Sciences, en présence également des participants à la Semaine d'Etude, une séance extraordinaire de l'Académie, au cours de laquelle le Professeur HANS JENNY, participant à la Semaine d'Etude, a tenu une conférence des plus intéressantes sur le thème « Image of soils in landscape painting of the ages ». Abondamment illustrée par de nombreuses projections de reproductions de toiles célèbres, cette conférence a permis de donner à l'assistance un aperçu général, du point de vue pictural, des différents aspects du sol comme l'ont interprété les peintres des diverses époques, de Duccio de Boninsegna à Dubuffet et autres artistes encore vivants.

Le texte de la conférence est reproduit à la fin du présent volume.

Le même jour, à 11 h 30, tous les participants ont été reçus en Audience Solennelle par le Souverain Pontife, qui leur adressa un discours, dont le texte, ainsi que la chronique de l'Audience, sont reproduits dans les pages suivantes.

Pendant la Semaine, qui se déroula jusqu'au samedi 27 les travaux scientifiques se poursuivirent sans interruption. Les discussions des différentes rapports se déroulèrent groupées selon l'affinité des sujets.

Les séances se tiennent deux fois par jour, le matin de 9 h. 30 à 12 h. 30 et l'après midi de 16 h. à 19 h.; chaque séance fut présidée par l'un des Participants à la réunion.

La réussite de la « Semaine d'Etude » a pleinement satisfait les illustres Participants, qui, à la fin de leurs travaux, ont tenu à exprimer au Saint Père leur profonde gratitude et leur très sincère admiration pour cette manifestation scientifique si réussie, en envoyant à l'Auguste Pontife, animateur et mécène de l'Académie, le télegramme suivant:

« SA SAINTETÉ LE PAPE PAUL VI - *Cité du Vatican. — Nous tous remercions Votre Sainteté pour l'obligeante invitation et pour l'aimable accueil et en particulier nous Vous exprimons notre vive gratitude pour l'atmosphère de totale liberté dans laquelle nous avons pu suivre nos travaux scientifiques en exprimant nos différentes idées sans aucune restriction. Nous espérons que notre Semaine d'Etude sur "La matière organique et la fertilité du sol" que nous venons de tenir dans Votre Maison ouverte à tous les hommes de bonne volonté, puisse faire progresser notre science dans le sens désiré par Votre Sainteté en soulagement de l'humanité et en faveur surtout de la lutte contre la faim.* — ALEXANDER, BAVER, BRADFIELD, BRAMAO, BREMNER, BROADBENT, CHAMINADE, DHAR, FLAIG, FRANZ, HAUSSMANN, HENIN, HERNANDO FERNÁNDEZ, JENNY, LORA TAMAYO, NORMAN, PRIMAVESI, REESE, REUSZER, SWABY, WAKSMAN ».

A ce télégramme d'hommage et de remerciement, le Saint Père a daigné répondre par le message suivant, signé de Son Eminence le Cardinal Secrétaire d'Etat:

« *Professeur* PIETRO SALVIUCCI, *Chancelier Académie Pontificale des Sciences - Casina Pio IV, Città del Vaticano. — Sa Sainteté, très sensible délicat message participants Semaine d'Etude sur "Matière organique et fertilité du sol", remercie profondement pour geste nous charge bien vouloir faire joindre tous signataires expression renouvelée Sa paternelle bienveillance et vifs encouragements pour engagement au service bien commun humanité.* — Cardinal CICOGNANI ».

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Les pages qui suivent contiennent, à la suite du compte rendu de l'Audience du Saint-Père et du « Règlement des Semaines d'Etude », les rapports originaux présentés à la Réunion, et les discussions qui les ont suivis.

Les « Conclusions » de la « Semaine d'Etude » se trouvent à la fin du présent volume.

Pendant la Semaine les Participants ont visité, avec l'assistance du Prof. FILIPPO MAGI et du Dr. DEOCLECIO REDIG DE CAMPOS de la Direction Générale des Monuments de la Cité du Vatican, les Musées Pio-Clementino, Chiaramonti, Etrusque, Egyptien; le Braccio Nuovo; les Galeries des tapisseries, des cartes géographiques; les Chambres et les Loggia de Raphaël, la Chapelle de Fra Angelico, la Chapelle Sixtine, l'Appartement Borgia et la Pinacothèque Vaticane.

À la fin de la Semaine d'Etude, les Participants ont visité la Résidence Pontificale à Castel-Gandolfo, où ils ont été invités à une réception donnée à la Villa Barberini par les Observateurs permanents du Saint-Siège auprès de la F.A.O., Monseigneur LUIGI LIGUTTI et Monsieur EMILIO BONOMELLI, Directeur des Villas Pontificales qui, dans une atmosphère de cordialité, se sont longuement attardés avec eux, exprimant leur satisfaction pour l'excellent réussite des travaux.

Enfin, le soir du samedi 27 avril, un dîner d'adieu a été offert par l'Académie, selon la coutume, aux savants participant à la « Semaine d'Etude ».

L'AUDIENCE

ET

LE DISCOURS DU SAINT-PERE

Le matin du samedi 27 avril, le Saint Père a accordé dans la Salle du Consistoire du Palais Apostolique Vatican, une Audience Solennelle à l'Académie Pontificale des Sciences à l'occasion de la « Semaine d'Etude » tenue par l'Académie sur le thème « Matière organique et fertilité du sol ». A la dite Audience ont participé aussi de nombreuses hautes personnalités.

Etaient présents Leurs Eminences les Cardinaux: CICOGNANI, Académicien Pontifical, ALOISI MASELLA, CENTO, SLIPYI, OTTAVIANI, CONFALONIERI, ZERBA, BERAN, VILLOT, BELTRAMI, STAFFA, SAMORÉ et BRENNAN.

De nombreux Académiciens Pontificaux sont intervenus, et précisément Leurs Excellences: le Rév.me Père DANIEL JOSEPH KELLY O'CONNELL Président, CHARLES HERBERT BEST, MARCELLO BOLDRINI, HERMAN ALEXANDER BRÜCK, EDUARDO CRUZ COKE, PAUL ADRIEN MAURICE DIRAC, ERNESTO GHERZI, GIORDANO GIACOMELLO, GERHARD HERZBERG, CORNEILLE HEYMANS, SVEN HÖRSTADIUS, ALBERTO HURTADO, JEAN LECOMTE, PIERRE LEPINE, LOUIS LEPRINCE-RINGUET, MANUEL LORA TAMAYO, SAN-ICHIRO PAULO MIZUSHIMA, PAUL NIEHANS, JAN HENDRIK OORT, SALIMUZZAMAN SIDDIQUI; l'Académicien surnuméraire: Mgr. MARTINO GIUSTI; le Chancelier de l'Académie, Prof. PIETRO SALVIUCCI et le Coadjuteur Dr. FRANCESCO SALVIUCCI.

Parmi le groupe d'Académiciens l'on pouvait voir les Participants à la Semaine d'Etude sur le thème « Matière organique et fertilité du sol »: MM. les Professeurs MARTIN ALEXANDER, LEONARD DAVID BAVER, RICHARD BRADFIELD, LUIS BRAMAO, JOHN McCOLL BREMNER, FRANCIS EVERETT BROADBENT, RAYMOND CHAMINADE, NIL RATAN DHAR, WOLFANG ARTHUR JULIUS FLAIG, HERBERT FRANZ, GIOVANNI HAUSSMANN, STEPHANE HENIN, VALENTÍN HERNANDO FERNANDEZ, HANS JENNY, ARTHUR GEOFFREY NORMAN, ARTURO PRIMAVESI, ELWIN THOMAS REESE, HERBERT WILLIAM REUSZER, RAYMOND JOHN SWABY, SELMAN ABRAHAM WAKSMAN.

A l'Audience assistait en outre S.E. Mgr. GIUSEPPE SCHRÖFFER, Secrétaire de la Sacrée Congrégation pour l'Education Catholique.

Outre le Corps Diplomatique au complet étaient présents S.E. Monseigneur GIOVANNI BENELLI, Substitut de la Secrétairerie d'Etat, et Monseigneur SOTERO SANZ VILLALBA, Assesseur de la Secrétairerie d'Etat; les Membres du Corps Diplomatique furent reçus par M. MARIO BELARDO.

Parmi les invités citons en outre le Comte PAOLO DALLA TORRE DEL TEMPIO DI SANGUINETTO, Directeur des Musées et Galeries Pontificales.

Une déférente manifestation d'hommage a accueilli l'arrivée du Saint Père.

Après avoir gagné le trône, le Saint Père donna son assentiment au Président de l'Académie, S.E. le Rév.me Père DANIEL J.K. O'CONNELL qui s'adressa alors au Souverain Pontife en ces termes:

« Très Saint-Père, j'ai l'honneur de présenter à Votre Sainteté les hommages des membres de Votre Académie des Sciences réunis pour les travaux scientifiques de leur Session Plénière.

« Mon illustre prédécesseur, Monseigneur GEORGES LEMAÎTRE, dont nous pleurons la mort, a travaillé sans cesse pour faire progresser les buts de l'Académie. Nous devons à son initiative plusieurs Semaines d'Etude très bien réussies. Ce son en effet ces Semaines d'Etude qui constituent le plus fécond travail scientifique de l'Académie Pontificale. Un groupe restreint de savants illustres discutent intensivement quelques problèmes soigneusement choisis, de grande importance actuelle. Les comptes rendus des discussions sont de haute valeur pour l'avancement de la science, et ils sont estimés beaucoup par les spécialistes. Il se fait aussi que les résultats d'une Semaine marquent une étape décisive dans l'évolution de l'une ou l'autre science, et que le volume des actes soit utilisé comme manuel autoritaire pour les études avancées.

« L'Académicien ALBAREDA HERRERA fut chargé de l'organisation de la Semaine d'Etude sur le thème "Matière organique et fertilité du sol", qui vient de se terminer sous la présidence de l'Académicien MANUEL LORA TAMAYO. Au moment de sa mort imprévue, ALBAREDA HERRERA laissa l'organisation bien avancée, et heureusement son collaborateur, le Professeur HERNANDO FERNANDEZ, pouvait continuer la préparation de la Semaine, dont l'importance est assurément très actuelle dans cette période de l'histoire des peuples.

« Au nom des Académiciens, et des autres savants qui ont participé à la Semaine, je veux exprimer notre gratitude pour la munificence avec laquelle Votre Sainteté nous permet de poursuivre nos travaux ».

Le Saint Père daigna répondre par le discours que nous reproduisons plus loin.

Le Saint-Père s'entretint ensuite, après avoir reçu l'hommage des Cardinaux, avec le Président de l'Académie, S.E. le Rév.me Père DANIEL J.K. O'CONNELL, les Académiciens Pontificaux, le Chancelier

PIETRO SALVIUCCI et les Participants à la « Sémaine d'Etude », trouvant pour chacun d'aimables paroles de félicitations et de souhaits, pour eux, leurs familles et leur activité scientifique.

L'assistance exprima enfin ses remerciements au Saint-Père, sa reconnaissance émue et sa profonde gratitude, et le plus chaleureux hommage se manifesta de nouveau au moment où, l'Audience terminée, le Souverain Pontife quitta la Salle du Consistoire.

Chers Messieurs,

Nous saluons avec joie en vos personnes, Messieurs, le corps des savants distingués qui — présents ou absents d'ici en ce jour — constituent Notre Académie pontificale des Sciences, avec, à sa tête, son nouveau et docte Président, le Révérend Père O'Connell, et Nous sommes heureux d'avoir cette occasion de rendre un solennel hommage à votre haute valeur dans le domaine scientifique. Les diverses contributions que vous apportez au progrès des sciences vous font le plus grand hon-

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Dear Gentlemen,

In your persons, Gentlemen, We are happy to greet the organization of distinguished savants, both present here today and absent, constituting Our Pontifical Academy of Science, headed by its new and learned President, the Reverend Daniel O'Connell; and We are glad to have this opportunity of rendering public homage to your high standing in the scientific domain. The various contributions you render to the progress of science do you great honour, and that honour reflects upon the Holy See which assembled your organization in the first place. We begin, therefore, by felicitating and by thanking you.

Different circumstances, among them the sad death of your President, Monsignor Georges Lemaître, have prevented your Academy from abounding in external manifestations in recent times.

neur, et cet honneur rejaillit sur le Saint-Siège qui a pris l'initiative de vous réunir. Soyez donc, avant tout, félicités et remerciés.

Diverses circonstances, dont la mort, douloureusement ressentie, de votre Président, Monseigneur George Lemaître, n'ont pas permis à votre Académie, en ces derniers temps, d'abonder en manifestations extérieures. Personne, certes, ne sera tenté d'interpréter cette apparente et accidentelle diminution d'activité comme un signe de moindre vitalité d'une institution qui s'est desormais acquis dans le monde la réputation et la célébrité qu'elle mérite. Nous temons en tout cas, pour Notre part, à confirmer solennellement ici l'estime et la confiance qui Nous animent à son égard.

L'idée qui a présidé à la fondation de l'Académie pontificale des Sciences, vous le savez, était de donner, par les personnes qui la composent et par les activités qu'elle déploie, une preuve de l'amour et du respect de l'Eglise catholique pour le monde scientifique contemporain. Ce dessein primitif, Nous tenons à

Certainly, no one will be tempted to interpret this merely apparent and accidental decrease of activity as a sign of lessened vitality in an institution which has, by now, acquired throughout the world the fame and celebrity it merits. For Our part, We desire here and now to give solemn confirmation to the esteem and confidence We feel for you.

As you are aware, the idea which inspired the foundation of the Pontifical Academy of Science was that of giving, by means of the persons composing it and the activities it promotes, a proof of the love and respect which the Catholic Church nourishes for the contemporary scientific world. We wish now to renew Our assurance to you, that this primeval purpose is more alive than ever in the conscience and plans of the Apostolic See. Its duty will be to preserve the full vigour of the Academy. Its intention is to give witness, in this way, to the veneration the Catholic Church professes *vous en renouveler l'assurance, est plus que jamais vivant dans la conscience et dans les perspectives du Siège Apostolique. Celui-ci se fera un devoir de conserver à l'Académie sa pleine vitalité. Il entend rendre témoignage, par son moyen, du culte que l'Eglise catholique professe pour la recherche scientifique, de la liberté qu'elle reconnaît à celle-ci dans son domaine spécifique, de la confiance avec laquelle elle envisage ses conquêtes présentes et futures. Si la science, en effet, au lieu d'être considérée, dans la vie de l'homme, comme une sorte de corps, êtranger, y est, au contraire, convenablement insérée, l'Eglise estime qu'elle peut conduire au progrès, non seulement spéculatif et technique, mais moral, et même — sans aucun besoin de recouir à des processus artificiels — au progrès religieux et chrétien de l'humanité.*

C'est assez dire avec quelle respectueuse attention l'Eglise considére la mission du savant. Vous êtes à ses geux les chercheurs et les explorateurs des mystérieuses réalités de la création: autant dire ceux, qui remplissent au plus haut degré la

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for scientific research, the liberty She acknowledges in such research within its specific domain, the confidence with which She envisages its present and future achievements. In fact, if science, instead of being thought a sort of foreign body in the life of man, is properly inserted into his life, the Church believes that it can contribute to the progress, not only speculative and technical, but moral and even, without here having recourse to artificial processes, to the religious and Christian progress of mankind.

This should suffice to show respectful attention with which the Church considers the mission of the scientist. In her eyes, you are the seekers and explorers of the mysterious realities of creation; in other words, those who fulfil in the highest degree the task which God entrusted to man when He created him: that of conquering the earth, of uncovering the secrets of nature. For nature is full of secrets, and it cannot be doubted that those who strive to discover *tâche que Dieu a confiée à l'homme en le créant: conquérir la terre, mettre au pour les secrets de la nature. Car la nature est pleine de secrets, et on ne peut douter que ceux qui s'emploient à les découvrir — au prix de quelles patientes et minutieuses recherches, vous le savez mieux que Nous! — ne répondent à un dessein original et à une volonté certaine du Créateur.*

Lorsque Nous arrêtons Notre esprit sur votre activité de savants, elle Nous apparaît comme se développant à partir d'une double prémisse, qui constitue comme le prédestal de ce degré supérieur d'excellence humaine auquel vous élève l'exercice de votre profession de chercheurs.

C'est d'abord l'usage systématique et perfectionné de l'intelligence. Si vous êtes, peut-on dire, plus pleinement hommes que d'autres, c'est en effet, en premier lieu, parce que vous avec développé à un haut degré les possibilités de ce qu'il y a de plus noble et de plus semblable à Dieu dans l'homme: la pensée, la capacité de « devenir toutes choses » — le « fieri

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them — and you know better than We do, what patient and painstaking research this entails! — are responding to the Creator's original purpose and clear will.

When We fix Our attention upon your activity as scientists, it seems to Us to develop from a twofold premise, which constitutes as it were the pedestal of that superior degree of human excellence to which you are raised by the exercise of your vocation as searchers.

First of all, there is the systematic and perfected use of your intelligence. If you are, in a way, more fully men than other men, it is in the first place because you have developed to a high degree the potentialities of what is noblest and likest to God in man: that is, thought, the ability to become all things — the « fieri omnia » described by classical philosophy — that unique and incomparable privilege of the human intellect, the thinking being's power to conquer reality, assimilate it into himself, to turn it into a truth which *omnia » de la philosophie classique — ce privilège unique et incomparable de l'intelligence humaine, ce pouvoir que possède l'être pensant de conquérir la réalité, de se l'assimiler, d'en faire une vérité qui devient son bien propre, tout en étant en puissance, par son universalité, le bien de tous.*

A cette utilisation supérieure de la plus haute faculté de l'être humain, vient s'ajouter, chez le savant — c'est la seconde prémisse — son insertion dans la tradition scientifique. Il recueille, assimile, approfondit et perfectionne ce qu'il y a de valable dans l'immense héritage d'étude et de réflexion de ceux qui l'ont précédé; et il utilise ce patrimoine du savoir humain acquis jusqu'à lui comme une base de départ, d'où il s'élance hardiment vers de nouvelles conquêtes, au profit de sa génération et de celles qui la suivront.

En vérité, l'homme de science mérite bien l'honneur et la reconnaissance, et c'est pour Nous un besoin du coeur, en même temps qu'un devoir, de rendre hommage en vos personnes, Messieurs, aux représentants hautement qualifiés de la cul-

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becomes his own possession even though, by its universality, it remain potentially the possession of all.

To this superior utilization of the highest faculty of the human being, there is added in the scientist — and this is the second premise — his entry into the scientific tradition. He collects, assimilates, deepens and perfects all that is of value in the vast heritage of the study and reflexion of those who proceeded him; and he makes use of this patrimony of human knowledge amassed before him as a point of departure, to leap boldly forth towards new conquests, for the profit of his own generation and of those that follow.

Verily, then, men of science deserve honour and gratitude, and it is a heartfelt need, as well a duty, for Us to pay homage to your persons, Gentlemen, to such highly qualified representatives of modern culture and of its inspiring genius. We are well aware that, *ture moderne et du génie qui l'inspire. Nous avons conscience, en agissant ainsi, d'interpréter fidèlement la pensée de l'Eglise à votre sujet: pensée qu'elle a souvent exprimée en ces dernières décades, notamment par la voix de Nos prédécesseurs Pie XI et Pie XII, et qu'elle vient de proclamer à nouveau avec éclat lors du récent Concile oecuménique. Comment laisserions-Nous passer une occasion comme celle-ci sans rappeler que cette solennelle assemblée a voulu apporter tout le poids de son autorité é réaffirmer l'attitude positive de l'Eglise en face de la science?*

Voici dans quelle lumière le Concile envisage votre vocation de chercheurs: « Celui qui s'efforce, dit-il, avec persévérance et humilité, de pénétrer les secrets des choses, celui-là, même s'il n'en a pas conscience, est comme conduit par la main de Dieu, qui soutient tous les êtres et les fait ce qu'ils sont ». Ces mots se lisent dans la Constitution sur l'Eglise dans le monde de ce temps, *qui consacre un chapitre entier au problème de la culture. Analysant les développements de celle-ci, le*

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in doing so, We are faithfully interpreting the mind of the Church concerning you, a mind which She has often expressed in recent years, especially by the voice of Our Predecessor Pope Pius XII, a mind which She proclaimed again and proudly on the occasion of the recent Ecumenical Council. How could We let pass an occasion like this, without recalling that the conciliar assembly willed to lend the full weight of its authority to the reaffirmation of the Church's positive attitude towards science?

Here is the aspect under which the Council envisages your calling as searchers: « Whoever labours to penetrate the secrets of reality with a humble and steady mind is, even unawares, being led by the hand of God, Who holds all things in existence, and gives them their identity ». These words occur in the *Constitution on the Church in the Modern World,* which dedicates a whole chapter to the problem of culture. Analysing the development of *document conciliaire n'hésite pas à prendre acte, avec une haute satisfaction, des acquisitions positives dues au progrès actuel des sciences et des techniques, et il mentionne explicitement « le goût des sciences et la fidélité sans défaillance à la vérité dans les recherches scientifiques, la nécessité de travailler en équipe dans des groupes spécialisés, le sens de la solidarité internationale, la conscience de plus en plus nette de la responsabilité que les savants ont d'aider et même de protéger les hommes, la volonté de procurer à tous des conditions de vie plus favorables, à ceux-là surtout qui sont privés de responsabilité ou qui souffrent d'indigence culturelle* » (Const. Gaudium et spes, *nn.* 36 *et* 57). *Le document conciliaire met certes en garde les chrétiens contre le péril d'un humanisme purement terrestre; mais il leur montre en même temps comment la foi qu'ils professent, « loin de la diminuer, accroît plutôt la gravité de l'obligation qui est la leur de travailler avec tous les hommes à la construction d'un monde plus humain* » (ibid., *n.* 57).

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culture, the Council document does not hesitate to note with satisfaction the positive acquisitions made by the present progress of science and of technique, and makes explicit mention of « scientific study and strict fidelity towards truth in scientific research, the necessity of working together with others in technical groups, a sense of international solidarity, an ever clearer awareness of the responsibility of experts to aid men and even to protect them, the desire to make the conditions of life more favourable for all, especially for those who are deprived of the opportunity to exercise responsibility or who are culturally poor » (*Constitution 'Gaudium et Spes'*, Nos. 36 *and* 57). The conciliar document, of course, warns Christians against the perils of a purely earthly humanism; but at the same time shows them how the faith they profess « in no way decreases, but rather increases, the weight of their obligation to work with all men in constructing a more human world » (*ibid.*, No. 57).

Nous sommes loin, Monsieurs, sous le voyez, des disputes souvent mesquines et presque toujours stériles dans lesquelles se complaisaient jadis certains esprits, enclins à considérer l'Eglise et le progrès des connaissances humaines comme deux adversaires en lutte ouverte.

Ce n'est pas que l'ancienne question, sans cesse renaissante, des rapport de la science et de la foi, ait perdu toute actualité et tout intérêt. Et il Nous aurait été agréable, si Nous avions disposé d'un temps moins limité, de profiter d'une circonstance comme celle-ci pour Nous en entretenir avec vous. Nous aurions aimé vous décrire l'éclairage nouveau sous lequel elle Nous semble se présenter aujourd'hui: celui d'une distinction plus nette des plans auxquels chacune d'elles — science et foi — suivant ses propres méthodes, déroule le fil de ses connaissances, la complexité globale de la pensée rendant possible une heureuse synthèse des deux ordres de connaissance.

Vous Nous auriez alors montré sans doute — pour l'avoir

As you see, Gentlemen, We are here far from the frequently petty and almost always sterile disputes which once gave pleasure to certain minds, inclined as they were to consider the Church, and the advance of human knowledge, as two openly struggling adversaries.

This does not mean that the ancient and ever reviving question of the relationships between science and faith has lost all meaning and interest. If the time at Our disposal were less limited, We should have liked to profit by an occasion like this to meditate the matter further with you. We should have liked to describe to you the new illumination which seems to shine on it today: that, namely, of a clearer distinction of the levels on which, separately, science and faith follow their proper methods, develop their knowledge; while the encompassing complexity of thought makes a happy synthesis of both orders of knowledge possible.

éprouvé par une expérience directe — comment la recherche scientifique, venant à absorber parfois toutes les capacités de connaissance du cehrcheur, semble apporter une satisfaction suffisante et définitive à l'activité intellectuelle et spirituelle de l'homme; comment elle reussit à annuler non seulement la connaissance, mais même l'aspiration vers la connaissance de Dieu; à tel point que l'athéisme finit par apparaître à certains savants comme une position logique, donnant satisfaction à la pensée et justifiant la réalité.

Et à Notre tour Nous aurions été tenté de renverser ce fragile édifice du progrès intellectuel moderne et d'affirmer — non sans faire appel, là encore, à votre expérience, mais à une expérience plus profonde — que la science prépare et postule un ordre de pensée qui la transcende et qui la justife: car elle n'explique pas tout; elle ne peut explorer que ce qui existe, ce qu'un Autre, infiniment plus grand qu'elle, a livré avec prodigalité à l'étude des enfants des hommes. Et si elle est fidèle

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In that case, you would undoubtedly have demonstrated to Us, as having experienced it directly, how scientific research, by absorbing as it can all the knowing capacity of the seeker, can seem to provide sufficient satisfaction and repletion for the intellectual and spiritual activity of man; how it can succeed in annulling, not only the knowledge, but even the desire of knowledge of God; to such a degree that finally atheism appears to some scientists to be a logical position, satisfying thought and justifying reality.

Then We, in turn, would be tempted to overthrow this fragile edifice of modern intellectual progress by affirming — and by calling again on your experience but on a deeper level — that science prepares for and presupposes an order of thought which transcends and justifies it, for science cannot explain everything; it can only what exists, what some Other, infinitely greater than science, has prodigally delivered over to the study of the sons of men. For if science *à maintenir ses recherches et ses certitudes dans son domaine propre, qui est celui de l'observable et du mesurable, plus elle progressera dans ses investigations, plus aussi elle éprouvera le besoin et comme l'intuition de l'immensité du monde divin qui la domine et qui reflète en elle quelque chose de lui.*

Mais limitons-Nous a considérer plutôt un autre. aspect du monde scientifique, celui que votre réunion met en une si belle et si louable évidence, et demandons-Nous: quel doit être l'usage l'emploi pratique et utile, que la science, ou pour mieux dire les hommes de science, et leurs brillants élèves les techniciens, doivent faire des conquêtes de la science? Il n'y a qu'une réponse possible: tout doit tendre au bien de l'humanité.

Est-ce à vous, Messieurs, en vérité, qu'il faut rappeler que le spectre des plus terribles calamités, capables de bouleverser et de réduire en cendres toute la terre habitée, sort précisément des laboratoires les plus perfectionnés des sciences physiques modernes? Pourrions-Nous Nous taire devant de telles perspec-

is faithful in restricting research and certitudes within its proper sphere, that of the observable and measurable, so much the more will it progress in its investigations, and so much the more will it feel the need, as it were the intuition, of the immensity of that divine world which dominates it, and bestows upon it some reflection of itself.

We shall instead limit Ourself to considering rather another aspec tof the scientific world, to which your assembly so handsomely and laudably testifies, by asking: What use, what practical and useful employment should science, or rather men of science, and their brilliant pupils the technicians, make of the conquests of science? To this query only one reply is possible: Everything must tend towards the good of all mankind.

It is certainly not necessary to remind you, Gentlemen, that the spectre of most terrible calamities, capable of overwhelming and *tives? Car si grande que puisse être en ce domaine la responsabilité des hommes politiques, elle laisse intacte celle des hommes de science. Et c'est pourquoi Nous ne cesserons de prier et de supplier, et vous Nous en fournissez une occasion singulièrement propice. Que l'on ait le courage des renoncements nécessaires! Que toute mesure soit prise, tout engagement assumé, dans le but de prévenir et de conjurer la fabrication et l'emploi des armes nucléaires, des attaques bactériologiques et de tout autre moyen qui tirerait du progrès scientifique la puissance diabolique d'infliger à des populations entières, étrangères même à d'éventuels conflits, le fléau d'horribles dévastations! Que l'humanité se ressaisisse! Qu'elle sache trouver en elle-même, dans ses chefs, dans ses maîtres, la force et la sagesse de rejeter loin d'elle l'usage maléfique de la science destructrice! Qu'elle aille plutôt demander à la science le secret de se faire du bien à elle-même!*

Elle le fait, du reste, pour son honneur et à l'avantage de

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razing the whole inhabited earth, rises in fact from the most advanced laboratories of modern physical science? Can We remain silent before such prospects? No matter how great is the responsibility of politicians in this regard, yet the full responsibility of men of science also remains. For this reason, We shall never cease to pray and implore, as you now provide Us with a most propitious occasion to do. May necessary renunciations be made with courage! Let every measure be taken and every obligation assumed, in order to prevent and avert the manufacture and use of nuclear arms, of bacteriological warfare, of every other means deriving from scientific progress the diabolic power of inflicting upon entire nations, even those uninvolved in possible conflicts, the scourge of horrible devastation! May mankind return to its senses! May men find in themselves, in their leaders, their teachers, the strength and the *tous. Et vous-mêmes, Messieurs, par cette semaine d'étude qui vous rassemble, en témoignez magnifiquement. Votre thème: « Matière organique et fertilité des sols » est tout entier orienté vers le bien des hommes, mieux, vers ce développement intégral et solidaire de l'humanité que Nous appelions de Nos voeux, voici un an, dans Notre Encyclique* Populorum progressio. *Rendre la terre féconde, lui faire produire du pain pour touse ses habitants, lutter contre la sterilité des zones désertiques, multiplier partout les fruits des cultures agricoles, tirer de la fatigue de l'homme des résultats plus faciles et plus abondants, rendre possible la victoire sur la faim, qui afflige, encore aujourd'hui, des populations entières, donner subsister aux générations humaines sans cesse croissantes: voilà votre conquête, voilà votre art, votre mission, votre couronne.*

Nous sommes fiers de vous, Messieurs, heureux de vos études et de vos contributions au bien-être de l'humanité. Aussi est-ce de grand coeur que Nous vous exprimons. Nos louanges

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wisdom to forswear the evil use of destructive science! May they rather seek from science the secret of doing good to themselves!

This is what sciences is doing, indeed, to its own honour and for the advantage of all. You yourselves, Gentlemen, bear magnificent witness to this with the study week you are observing. Your theme, which is « Organic Matter and the Fertility of Soil », is completely directed towards the good of men, may rather, towards the integral and mutual development of mankind which We invoked, just a year ago, in Our Encyclical Letter « *Populorum progressio* ». To make the earth fruitful, producing bread for all its dwellers, to struggle against the sterility of desert wastes, to multiply agricultural products, to derive from man's labour easier and more abundant results, to make possible a victory over hunger which today still affects entire nations, to give hope and the means of subsistence to *et Nos voeux. Et au nom de ce Dieu si grand et si mystérieux dont vous explorez des oeuvres, du Dieu créateur du monde et rédempteur de l'homme, de ce Dieu qu'en toute humilité, mais en toute vérité, Nous représentons, Nous vous donnons à tous Notre Bénédiction Apostolique.*

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the ever increasing generations of men — such is your conquest, such your art, your mission, your crown!

We are proud of you, Gentlemen, and glad of your studies and your contributions to mankind's well-being. With all Our heart do We express to you Our praise and Our good wishes. And, in the name of that God, so great and so mysterious, Whose works you explore; that God Who created the world and redeemed men; that God Whom in all humility but also in all truth We represent, We impart to you all Our Apostolic Blessing.

LES « SEMAINES D'ETUDE »

ET

LEUR REGLEMENT

Lorsque l'Académie Pontificale des Sciences fut fondée par le Souverain Pontife Pie XI, de vénérée mémoire, par son « Motu Proprio » du 28 octobre 1936 « In multis solaciis », cette initiative suscita dans les milieux scientifiques un mouvement général de sympathie et d'admiration. Cette institution unique au monde, qui groupait en une même assemblée des représentants de toutes les Nations civilisées, était appelée, en effet, à de hautes destinées dans le développement de la pensée scientifique.

D'autre part, cette oeuvre de coopération fut accueillie avec un véritable soulagement par tous ceux que plongeait dans le désarroi le plus profond la période qui suivit la guerre 1914-18. On voyait, en effet, s'altérer profondément les caractères d'objectivité et de

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A general movement of sympathy and admiration was aroused in scientific circles when, in 1936, the Pontifical Academy of Sciences was founded by His Holiness Pope Pius XI, of venerable memory, by means of his « Motu Proprio » of October 28, « In multis solaciis ». This institution, the only one of its kind in the world, which brought the representatives of all civilized nations into touch with each other, was, in fact, called upon to play a leading role in the development of scientific thought.

This work of cooperation was, moreover, welcomed with a sense of real relief by all those who were plunged in a deep state of confusion in the period following the 1914-18 war.

Signs of drastic changes were, in fact, discernible in the objective and disinterested nature of scientific work and even a tendency to make science subject to pragmatic aims.

In his immortal « Motu Proprio » of October 28, 1936, Pope Pius XI, désintéressement propres au travail scientifique, et s'affirmer même une tendance à asservir la science à des fins pragmatiques.

Tout au contraire, dans l'immortel « Motu Proprio » du 28 octobre 1936, le Pape Pie XI proclamait solennellement la dignité de la recherche de la vérité pour elle-même, et, élevant sa pensée au-dessus de toute préoccupation utilitaire, affirmait qu'il ne demandait rien d'autre aux nouveaux « Académiciens Pontificaux » que de se consacrer, avec une ferveur toujours plus grande, au progrès de la science et, par là, au culte de la vérité: « C'est Notre souhait ardent et Notre ferme espérance: que par cet Institut, à la fois Nôtre et leur, les "Académiciens Pontificaux" contribuent toujours plus et mieux au progrès des sciences. Nous ne leur demandons pas autre chose; car en ce dessein généreux et ce noble labeur consiste le service, qu'en faveur de la vérité, nous attendons de leur part» (*).

(*) « Nobis autem in votis expectationeque est, fore ut "Pontificii Academici" vel per hoc Nostrum suumque studiorum Institutum, ad scientiarum progressionem fovendam amplius excelsiusque procedant; ac nihil praeterea aliud petimus, quandoquidem hoc eximio praeclaroque labore famulatus ille nititur servientium veritati, quem ab iisdem postulamus ».

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on the contrary, solemnly proclaimed the dignity of the search for truth for its own salce and, raising his thoughts above all preoccupations of an utilitarian nature, asserted that all be asked of the new « Pontifical Academy » and its members was that they should dedicate themselves, with increasing fervour, to the furthering of the progress of science and, consequently, to the cult of truth: « It is Our ardent wish and firm hope that, by means of this Institute, which is both Ours and theirs, the "Pontifical Academicians" will contribute to an increasingly great extent to the progress of science. We ask nothing more than that from them because the service in favour of truth that We expect from them consists in this generous intention and noble work » (*).

(*) « Nobis autem in votis expectationeque est, fore ut "Pontificii Academici" vel per hoc Nostrum suumque studiorum Institutum, ad scientiarum progressionem fovendam amplius excelsiusque procedant; ac nihil praeterea aliud petimus, quandoquidem hoc eximio praeclaroque labore famulatus ille nititur servientium veritati, quem ab iisdem postulamus ».

La consécration pratique de cette idée, par la nomination d'un certain nombre de non-catholiques parmi les nouveaux Académiciens Pontificaux a fait une profonde impression sur beaucoup d'esprits, comme l'ont montré les réactions de la presse internationale de l'époque et de nombreux témoignages individuels d'hommes de science et des plus grands savants du monde.

Beaucoup de préjugés à l'égard de l'Eglise ont été fortement ébranlés par ce geste du Souverain Pontife qui a obligé à reconnaître la place éminente réservée aux valeurs purement intellectuelles dans l'Eglise Catholique.

Pour toutes ces raisons, la fondation de l'Académie Pontificale des Sciences a été hautement appréciée dans le monde scientifique et y a fait naître de grands espoirs quant aux possibilités d'action d'une institution si opportune.

Elle est placée sous la dépendance directe du Souverain Pontife et composée de soixante-dix « Académiciens Pontificaux » nommés par le Pape sur proposition du Corps Académique et choisis sans

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By including a certain number of non-Catholics amongst the new Pontifical Academicians, the practical application of this idea made a deep impression on many persons, as is proved by the reaction of the international press of the time and by the innumerable individual tributes paid by scientists and by the greatest scholars of the world.

Many prejudices against the Church were very deeply shaken by this gesture on the part of the Sovereign Pontiff, since it called attention to the lofty place reserved for purely intellectual values in the Catholic Church.

For all these reasons, the foundation of the Pontifical Academy of Sciences was greatly appreciated by the scientific world and aroused high hopes as to the prospects open to such a timely institution.

The Academy is directly subject to the Sovereign Pontiff, and it is composed of seventy « Pontifical Academicians », nominated by the Holy Father himself, proposed by the Academical Body and chosen aucune discrimination parmi le plus insignes spécialistes des sciences mathématiques et experimentales de tout pays.

L'Académie Pontificale des Sciences est actuellement unique en son genre, étant la seule Académie scientifique à caractère supranational et à classe unique existant dans le monde.

Elle a pour but d'honorer la science pure, où qu'elle se trouve, d'en assurer la liberté, d'en favoriser les recherches qui constituent la base indispensable du progrès des sciences appliquées.

Le Saint-Père Pie XII, qui avait collaboré avec son Prédécesseur au projet et à la fondation de l'Académie et qui l'avait représenté comme Légat personnel lors de l'inauguration solennelle, ne se borna pas à maintenir à son égard ses sentiments de haute estime par sa présence à de solennelles séances académiques, où il daigna prononcer ses discours d'une haute portée scientifique; il a tenu en outre à lui donner un nouveau témoignage de son auguste satisfaction en accordant à ses membres le titre d'Excellence par le Bref Apostolique du 25 novembre 1940.

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without any discrimination from amongst the most famous experts in mathematical and experimental sciences in all countries.

At the present time the Pontifical Academy of Sciences is unique, in the sense that it is the only Academy of Sciences in the world which is super-national and which has only one class amongst its Members.

It has for its purpose to pay honour to pure science wherever it exists to ensure its liberty and to further its researches, which are the necessary basis for the progress of applied sciences.

His Holiness Pope Pius XII, who had helped his predecessor to draw up the plan and to found the Academy, and who had represented him as his personal Legate at the time of its solemn inauguration, did not confine himself to the expression of lofty sentiments when attending solemn academic gatherings, where he deigned to make speeches of great scientific importance, but he also afforded proof of his august satisfaction by granting the title of Excellency to the members of the Academy, by an Apostolic Brief of November 25, 1940.

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Les sciences posent chaque jour des problèmes nouveaux qui donnent lieu d'ordinaire à divers essais de solution, souvent contradictoires. Il arrive ainsi constamment que, parmi les représentants les plus autorisés d'une science, et en particulier parmi ceux qui se sont consacrés à l'étude d'une même question, on rencontre des opinions opposées. Pareilles divergences se maintiennent parfois durant de longues périodes et constituent à la fois une grave difficulté pour l'enseignement des sciences et fréquemment aussi un obstacle considérable à leur développement.

Par ailleurs, l'expérience montre que les méthodes actuellement pratiquées dans la discussion des problèmes scientifiques n'ont qu'une efficacité limitée au point de vue de l'établissement d'une unité de doctrine.

Il serait dès lors hautement souhaitable de promouvoir tout ce qui pourrait favoriser un accord sur les points en discussion.

Un procédé semble devoir être particulièrement utile sous ce rapport: à savoir, l'établissement de contacts personnels prolongés

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Every day science raises new problems, which usually give rise to various, and often contradictory, solutions. Consequently it often happens that amongst the most authoritative representatives of a given branch of science, and particularly amongst those who are engaged in studying the same question, one meets with contrasting opinions. Divergences of this kind often exist over long periods of time and are a serious obstacle not only to the teaching of science but also to its development.

Experience shows, moreover, that the methods at present in use in the discussion of scientific problems have only a limited efficacy in so far as concerns doctrinal unity.

It would, therefore, be highly desirable if everything that could favour agreement on controversial points were to be promoted.

One process that would seem to be particularly useful from this point of view would be the establishment of prolonged personal contacts entre quelques représentants d'opinions différentes au sujet d'une question déterminée.

En effet, le contact personnel entre hommes de science constitue, sans aucun doute, le moyen le plus efficace de résoudre les controverses scientifiques.

Dans ce but, l'Académie Pontificale des Sciences a décidé de convoquer de pareilles rencontres. Pour la partie scientifique ces rencontres seront présidées par un Académicien Pontifical versé dans la même discipline tandis que l'organisation générale en sera réalisée par le Chancelier de l'Académie.

Ces rencontres, qu'on a appelées « Semaine d'Etude » ont été réglées de la manière suivante:

RÈGLEMENT DES SEMAINES D'ÉTUDE

1. - L'Académie invite quelques illustres savants, parmi ceux qui, ayant étudié spécialement une question déterminée, sont arrivés à des conclusions différentes, à se rencontrer à Rome, à son siège, la

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between some of the representatives of different trends of thought on a given subject.

Personal contacts amongst scientists are, in fact, the most efficacious means of solving scientific controversies.

With this aim in mind, the Pontifical Academy of Sciences decided to organize meetings of this description. These meetings, for the scientific part, will be presided by an Academician versed in the same discipline while the general organization of these will be realized by the Chancellor of the Academy.

These meetings, known as « Study Weeks », were planned on the following lines:

STANDING RULES FOR « STUDY WEEKS »

1. - The Academy invites a number of illustrious scholars — comprising those who have especially studied a given question and have

« Casina di Pio IV », à l'intérieur de l'Etat de la Cité du Vatican, afin d'y procéder en commun, en dehors de toute autre préoccupation, à un examen général de toutes les données du problème.

2. - Le but essentiel de ces discussions est de chercher à formuler de façon précise les raisons qui sont à la base de la divergence des opinions. Les savants conviés aux réunions s'engageraient d'avance à concentrer leurs efforts dans cette direction.

3. - Un examen critique de ces raisons aboutira soit à un accord sur une solution déterminée, soit à la constatation qu'à l'état actuel des connaissances, il est impossible d'établir une unité de doctrine au sujet du problème envisagé.

Dans ce dernier cas, les savants invités auront pour tâche:

a) de préciser les motifs pour lesquels un accord s'avère présentement irréalisable;

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arrived at different conclusions — to meet in Rome at its headquarters, the « Casina di Pio IV », situated in the Vatican City, so as to make a joint examination, free from all other preoccupations, of all data concerning the problem.

2. - The chief aim of these discussions is to endeavour to formulate precisely the reasons which are at the root of the differences of opinion. The scholars invited to these meetings undertake in advance to concentrate their efforts on this.

3. - A critical examination of these reasons should lead, either to agreement on a given solution or else to the conclusion that, on the basis of the information actually available, it is impossible to establish doctrinal unity on the problem envisaged.

In the latter event the scholars concerned will be called upon:

a) to define the reasons why agreement appears to be impossible for the present;

b) de définir le genre de recherches qu'il serait souhaitable d'entreprendre en vue de résoudre la question.

4. - L'invitation ne sera adressée par l'Académie qu'à un très petit nombre de représentants de chaque science: ceux-ci seront choisis exclusivement parmi les spécialistes de la question considérée, qu'ils soient membres ou non de l'Académie.

5. - Les discussions auront un caractère strictement privé; elles prendront la forme de conversations particulières.

Des interprètes polyglottes, des sténographes, des rapporteurs, etc., seront mis à la disposition des savants réunis.

6. - Les « Conclusions » des discussions seront publiées sous la forme d'une « Note Collective Finale » (à laquelle pourront éventuellement être jointes des annotations individuelles), mentionnant:

a) les points sur lesquels un accord aurait été réalisé;

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b) to specify the kind of research work it would be desirable to undertake with a view to solving the problem.

4. - The invitation will be addressed by the Academy to only a small number of representatives of each branch of science: those will be exclusively selected from amongst the specialists of the question being considered, either members of the Academy or no.

5. - The debates will be strictly private and will take the form of personal talks.

Polyglot interpreters, stenographers, reporters, etc. will be placed at the disposal of the participants.

6. - The « Conclusions » arrived at will be published in the form of a « Collective Note » (to which may eventually be added individual notes) mentioning:

a) the points on which agreement was reached;

b) les points sur lesquels un accord n'aurait pas paru réalisable;

c) les raisons pour lesquelles l'accord n'aurait pu être réalisé;

d) des suggestions relatives aux recherches paraissant les plus aptes à résoudre les difficultés.

7. - Les « Conclusions » seront ausitôt imprimées et communiquées, par les soins de l'Académie Pontificale des Sciences, à tous les centres scientifiques qu'elles seraient de nature à intéresser.

8. - L'Académie préparera, donc, la publication d'un volume officiel des Actes de la Semaine d'Étude contenant la chronique des journées, les rapports des participants avec les discussions correspondantes et la Note Collective Finale.

Le volume fera partie des publications officielles de l'Académie: il sera envoyé aux Institutions Scientifiques avec lesquelles l'Académie même entretient des relations d'échange et toute personne pourra se le procurer.

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b) the points on which it was impossible to reach agreement;

c) the reasons why it was not possible to reach agreement;

d) suggestions regarding the research work which appears most suitable for arriving at a solution of the difficulties.

7. - The « Conclusions » reached will be immediately printed and transmitted, by the Pontifical Academy of Sciences, to all the scientific centres which might be interested therein.

8. - The Academy will publish an official volume of the Proceedings of the Study Week, containing an account of the sessions, the papers presented by the participants, together with the relevant discussions. and the final « Collective Note ».

This volume will form part of the official publications of the Academy and will be sent to the scientific institutions with which the Academy maintains exchanges. It can be acquired by anyone.

En vue d'étendre sa diffusion, le volume pourra aussi être confié à une organisation éditoriale pour être mis en vente, le Copyright demeurant toujours réservé à l'Académie.

9. - Toutefois, chaque participant reste libre de faire imprimer son propre rapport partout où il le juge convenable et à n'importe quel moment.

10. - L'Académie offrira en hommage à chaque participant une copie du volume officiel des Actes de la Semaine d'Étude, et des Extraits de son propre rapport suivant le nombre de copies qu'il souhaiterait avoir.

11. - Toutes les frais de voyage et de séjour à Rome des personnalités invitées seront à la charge de l'Académie Pontificale des Sciences. L'hospitalité sera assurée dans l'un des principaux hôtels de Rome.

The volume may also be entrusted to a publisher, with a view to ensuring a wider distribution, but the Copyright will always be reserved to the Academy.

9. - Each participant remains free to print his own contribution wherever and whenever he thinks fit.

10. - The Academy will present to each participant a copy of the official volume of the Proceedings of the Study Week, as well as such number of reprints of his own communication as he may desire.

11. - All travelling expenses, and accommodation in one of the best hotels in Rome, of the persons invited to the meetings will be borne by the Pontifical Academy of Sciences.

L'Académie se fera un plaisir d'offrir la même hospitalité aux épouses des savants invités, à l'exclusion toutefois des frais de voyage.

12. - La participation à la Semaine d'Étude comporte de la part de chacun l'acceptation de toutes les clauses du présent Règlement.

The Academy will be pleased to offer similar accommodation to the wives of the scholars who are invited, but not their travelling expenses.

12. Participation in the Study Week implies on the part of each member the acceptance of all the clauses in these regulations.

PROGRAMME DES SEANCES DE LA SEMAINE D'ETUDE

LUNDI 22 AVRIL

I. MATIÈRE ORGANIQUE, AZOTE ET TYPES DE SOL

Matin : Président : WAKSMAN

1. JENNY : *Interplay of soil organic matter and soil fertility with state factors and soil properties.* - Discussion.
2. BRAMAO : *Characteristics of organic matter in the major soils of the world and its importance on fertility.* - Discussion.
3. BROADBENT : *Turnover of nitrogen in soil organic matter.* - Discussion.

Après-midi : Président : JENNY

1. NORMAN : *The use of the isotopes in soil organic matter.* - Discussion.
2. BRADFIELD : *The role of organic matter in soil management and the maintenance of soil fertility.* - Discussion.

Débat.

MARDI 23 AVRIL

II. MATIÈRE ORGANIQUE ET PROCESSUS CHIMIQUES

Matin : Président : FLAIG

1. BREMNER : *Role of organic matter in the nitrogen economy in soils.* - Discussion.
2. REUSZER : *Observations on the soil organic matter fraction decarboxylated by acids.* - Discussion.
3. DHAR : *The value of organic matter, phosphates and sunlight nitrogen fixation and fertility improved in world soils.* - Discussion.
4. KONONOVA : *Humus of the main soil types and soil fertility.*

III. MATIÈRE ORGANIQUE ET PROPRIÉTÉS PHYSIQUES

Après-midi : Président : HENIN

1. BAVER : *The effect of organic matter on soil structure.* - Discussion.
2. HAUSSMANN : *The culture technique from the standpoint of conservation and implementation of organic matter in the soil, in the light of modern research.* - Discussion.

Débat.

MERCREDI 24 AVRIL

IV. TRANSFORMATIONS PRODUCED BY DIFFERENT AGENTS ON THE ORGANIC MATTER IN THE SOIL

Matin: Président: NORMAN

1. WAKSMAN: *Microbes, organic matter and soil fertility.* - Discussion.
2. KOVDA: *Biological cycles of chemical elements and soil formation.*
3. ALEXANDER: *Degradation of natural and synthetic organic compounds in soil.* - Discussion.
4. REESE: *Microbial transformation of soil polysaccarides.* - Discussion.

Après-midi: Président: ALEXANDER

1. SWABY: *Stability of soil organic matter and its significance in practical agriculture.* - Discussion.
2. FRANZ: *La différente composition des zoocénoses terricoles causée par les différences climatiques et sa réaction à la formation de l'humus.* - Discussion.

Débat.

JEUDI 25 AVRIL

V. THE EFFECT OF ORGANIC MATTER AND RELATED PRODUCTS ON PLANT GROWING

Matin: Président: SWABY

1. PRIMAVESI: *Organic matter and soil productivity in the tropic and subtropics.* - Discussion.
2. KHRISTEWA: *About the nature of physiologically active substances of the soil humus and of organic fertilizers and their agricultural importance.*
3. FLAIG: *Iptake of organic substances from soil organic matter by plant and their influence on metabolism.* - Discussion.
4. CHAMINADE: *Effet spécifique de la matière organique sur la nutrition des végétaux.* - Discussion.

Après-midi: Président: CHAMINADE

1. HERNANDO: *The action of humic acid of different sources on the development on plant and their effect on increasing concentration of the nutrient solution* - Discussion.
2. HENIN: *Elements pour une politique d'emploi des matières organiques.* - Discussion.

Débat.

VENDREDI 26 AVRIL

Président: BRADFIELD
Secrétaire: BROADBENT

Débat général final.

Conclusions.

TRAVAUX SCIENTIFIQUES
ET
DISCUSSIONS

I

MATIERE ORGANIQUE, AZOTE ET TYPES DE SOL

INTERPLAY OF SOIL ORGANIC MATTER AND SOIL FERTILITY WITH STATE FACTORS AND SOIL PROPERTIES

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INTRODUCTION

This paper is theoretical in that it attempts to combine conceptually and experimentally researches in soil fertility with those in soil genesis. To polarize the issue around personalities, DOKUCHAEV composed the first soil forming factor equation, LIEBIG assessed crop yields in terms of soil chemistry and plant nutrition, and HILGARD, standing between them, linked soil fertility problems to rocks, vegetation and climate. Our study is a modern hybrid of all three. It is based on a California collection of soil individuals that is highly stratified according to genetic factors and that was subjected to a large scale fertility experiment and was analysed chemically and mineralogically. The results suggest that interpretation of soil fertility studies is broadened and made more meaningful by integrating them with state factors (soil forming factors).

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THE STUDY AREA, ITS STATE FACTORS AND SOIL PROPERTIES

The soils were collected to a depth of 20 cm in random fashion along a moisture traverse in California extending from the deserts of latitude 35° N to the high rainfall zone of latitude 41° N. This area had been previously sampled by HARRADINE and by KLEMMEDSON [9] and was resampled by JENNY and SALEM. The present study is essentially confined to KLEMMEDSON's 97 soil samples on which additional work was performed.

As to *topography,* the exposures of the sampling sites were always south-east, hence invariant. The slopes (Sl) varied between 0 and 30%. All soils were well drained and free from influences of ground water tables.

Two kinds of *parent materials* (Pm) were selected. Acid igneous rocks (Ai), mostly granodiorites, and basic igneous rocks (Bi), mainly basalts and andesites. The two rock provinces were treated as dichotomous variables.

The *biotic factor,* the flora (Fl), was confined to *Pinus ponderosa* (Pi) and to « grass » (Gr) which included a variety of species of *Gramineae,* herbs and some desert shrubs. The forests had in part been selectively logged and the natural grasslands had been grazed, but neither had ever been cultivated.

The *climate* has hot, dry summers and cool, moist winters. Mean annual precipitation (P) of the sites ranged widely, from about 8 to 200 cm; mean annual temperature (T) was confined to 10-16°C.

The primary factors P and T were supplemented by potential evapotranspiration (Pet) and actual evapotranspiration (Aet) for which the available water holding capacity of all soils was assumed to be 15.24 cm (6.0 in.). ARKLEY's [1] leaching value (Li) was obtained by subtracting each mean monthly Pet from each mean monthly P. The 12 months summation of the positive values of P minus Pet is Li.

Although not usually considered state factors, *elevation* (El) and *latitude* (Lat) were included because they might act climatically as seasonal modifiers of P and T.

The *age* t of the landscape is unknown, but the soils must be old as all collection sites were situated far beyond the area of possible disturbance by Pleistocene glaciers. The topography appears stabilized, man-made erosion is not noticeable and the profiles have the features of mature soils. Since nitrogen and carbon are believed to reach equilibrium in a few thousand years [7], we shall start with the assumption that soil organic matter is at steady state and hence time invariant.

On nearly all of the 97 soils 25 *properties* having pedogenic significance were determined by conventional methods. They are identified by symbols as follows: *C*, organic carbon, by dry combustion followed by CO_2 absorption, and corrected for free carbonates; *N*, total nitrogen according to KJELDAHL; *aci*, exchange acidity (me/100g) by leaching soil with $BaCl_2$ - triethanolamine at pH 8.1, according to MEHLICH. In the MEHLICH extract K and Na were determined by flame photometry, and *Ca* and *Mg* by atomic absorption spectrophotometry. In pastes pH was measured with glass electrode. Texture was analysed by pipette method as *clay*, *sa* (sand), and *si* (silt); *ME*, the moisture equivalent, by centrifuge method. Coarse and fine fraction are denoted by *cof* and *fin*, oven-dry moisture by *ov*.

Dr. I. BARSHAD [2] determined the clay minerals in per cent, specifically *fel* (feldspar), *cry* (crystobalite), *qtz* (quartz), *mia* (mica), *ver* (vermiculite), *mon* (montmorillonite), *kao* (kaolinite), *hal* (halloysite), *gib* (gibbsite) and *iro* (iron oxides).

Derived properties are *C/N*, *sba*, the sum of bases as Ca + Mg + K + Na, in me/100g, *cec*, the sum of cations (sba + aci), and *pac*, the percentage acidity given by 100 aci/cec. There are thus 29 soil properties.

On all 97 soils an elaborate pot test experiment was conducted. It is described in an ensuing section. The full treatment yields and the relative yields have the symbols FY and RY, respectively.

THE PEDOGENIC EQUATION AND ITS EVALUATION

Soil and the organisms in it and on it comprise the *soil ecosystem.* In this study the ecosystem properties pertain to certain aspects of vegetation but mainly to the 29 soil properties $s_1, s_2, s_3 \ldots$. Among these the organic components N, C, C/N and their close relatives aci and pac are singled out for special emphasis.

The state factors [8] of the ecosystem, which determine its states, are its initial state L_o, here particularized as Pm, Sl, Fl, El and Lat, and the influx variables P_x — always measured in the environment — represented by P, T, Li, Pet and Aet. As mentioned, the age of the system (time factor) is tentatively left undetermined. The resulting, somewhat bulky sequence of equations is

$$(1) \qquad \mathrm{FY}, \mathrm{RY} = f \left\{ \begin{matrix} \mathrm{N, C, C/N} \\ \mathrm{aci, pac} \\ s_1, s_2, s_3 \ldots \end{matrix} \right\} = f \left\{ \begin{matrix} \mathrm{P, T, Li, Pet, Aet} \\ \mathrm{El, Lat, Pm, Sl, Fl} \end{matrix} \right\}$$

Proceeding from right to left, our inquiry is directed to the relations among the state factors themselves, to the dependencies of soil properties on state factors, followed by relations among the soil properties themselves, and to the dependencies of crop yields on state factors and soil properties.

The evaluation of equation [1] relies on recent developments in multivariate statistical analysis which are geared to fast electronic computers [10, 11, 12, 13].

Variabilities of soil properties are characterized by variances. The dependency of one variable (Y) on another (X_1) is expressed by the least square regression equation

$$(2) \qquad Y = a + b_1 X_1$$

where a is the intercept and b_1 the slope coefficient. Individual values of Y or X_1 are designated as Y_i and X_{1i}, sometimes called scores. Means are denoted by $\bar{Y}$ and $\bar{X}_1$. The overall association of Y and X_1 is measured by the *correlation coefficient* r which is zero in absence of a trend and $+1$ or -1 for perfect collinearity.

For several predictor variables X_1, X_2, X_3, ... the linear multiple regression equation reads

$$Y = a + b_1X_1 + b_2X_2 + b_3X_3 + \ldots. \tag{3}$$

The multiple correlation coefficient R is a measure of the success of regression. It lies between 0 and 1. The square of R or r is known as coefficient of discrimination R^2, r^2. It expresses the portion of the variability of Y that can be explained by the variations in X_1, X_2, X_3, ... Much of the ensuing discussion rests on the interpretation of R^2. As the number of X variables increases, R^2 tends to rise, but simultaneously degrees of freedom are lost, and if the gain in R^2 is small its adjusted value R_A^2 may actually decline. As we are not particularly interested in valid numerical predictions of Y from the X's but rather in the contributions of the individual X's in explaining the variance of Y, more emphasis will be placed on R^2 than R_A^2.

When the independent variables X_1, X_2, X_3 ... are highly self-correlated (collinear) the slope coefficients b become unstable, even meaningless as to sign. Regressing for example N against P (in.) and T (°F) gives

$$N = 0.350 + 0.0012\ P - 0.0055\ T \tag{4}$$

with $R^2 = 0.324$. Introducing Li (in.), which is highly collinear with P, results in

$$(5) \qquad N = 0.375 + 0.0037\ P - 0.0062\ T - 0.0029\ Li$$

The slope coefficient of P has tripled and that of Li is negative, which is absurd from the viewpoint of soil leaching. R^2 remains essentially unchanged as 0.327.

The handicap of self-correlation can be overcome by computing *principal components*. To illustrate, consider the correlation of aci and C of the 14 soil samples in Fig. 1, left. The solid, inclined line with angle θ (76.73°) passes through the center point which has $\overline{aci}$ equal to 6.656 me/100g and $\bar{C}$ equal to 2.133% as its coordinates. The line is the first principal axis (1P axis), constructed by minimizing the sum of the squares of the projections *normal* to this axis. The right-angle line through the center point is the second principal axis (2P axis).

Rotating the original coordinate axes through angle $(90-\theta)^\circ$ to the unconventional right, for the sake of simplified pictorial presentation, produces the new coordinate system of Fig. 1, right. The new coordinates of the observation points are known as the first and second principal components (1PC, 2PC). For point P_i with aci of 12.64 me/100g (X_{1i}) and C of 4.11% (X_{2i}) the two component individuals (or scores) are

$$1PC_i = X_{1i}\ \sin\ \theta + X_{2i}\ \cos\ \theta = 13.25$$
$$2PC_i = X_{2i}\ \sin\ \theta - X_{1i}\ \cos\ \theta = \ \ 1.09$$

The 14 points give 14 individual values of 1PC and 2PC each. Their variances λ_1 and λ_2 (eigenvalues) are 10.485 for 1PC and 0.122 for 2PC. Since λ_1 is nearly equal to the ag-

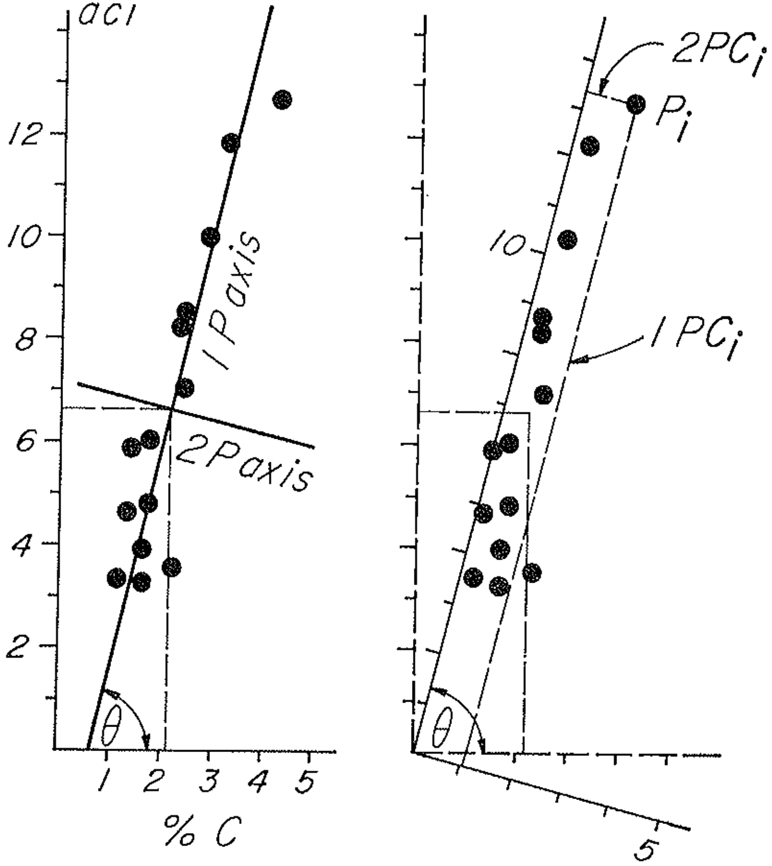

FIG. 1 — Illustration of converting original variables (aci, C) to first and second principal components (l.c. PC, 2PC).

gregate variances of aci (9.929) and C (0.669), the first principal component 1PC may be considered a numerical blend or composite of the original variables. It has no special name and may have ackward units. Parsimony has been achieved by replacing the two variables aci and C by one (1PC).

Three variables have three PC's and *n* variables have *n* PC's. Often one or two or very few component axes suffice to characterize an entire *cluster* of variables.

If the individuals of the components (the scores) are correlated with the individuals of the original variables the resulting *r*'s are the component weights or loadings. Frequently, it is helpful to rotate the principal axes and arrive at easier identifications with the original soil properties. It was done in this paper by varimax transformation of the loading matrix. The new variables, here labelled PCV, may be used in place of Y and the X's in eq. (3).

The PCV regression technique gives for the aforementioned $N = f\ (P, T, Li)$ the equation

$$N = 0.346 + 0.0006\ P - 0.0054\ T + 0.0007\ Li \tag{6}$$

which is to be compared with eq. (5). The insertion of Li left R^2 unchanged (0.32). The slope coefficient of Li is now positive and about the same as that of P, as it should be. Moreover, the sum of the P and Li slopes in eq. (6) matches that of P in eq. (4), again as would be expected from the high collinearity of P and Li.

CORRELATION AMONG STATE FACTORS

In Table 1 the correlation coefficients among P, T, Pm and Sl are very low. For practical purposes these factors are independent of each other. Importantly, the low *r*'s guarantee that the distribution of Ai- and Bi-rocks has no climatic bias. As expected, temperature varies with El and Lat, and for the trivariate combination $T = f$ (El, Lat) the multiple correlation coefficient is high, $R = 0.892$. One could replace T by El and

Lat. From chemical and biological points of view T is the preferred variable.

Correlations of P and T with the derived climatic measures are either very low or very high. Surprising is the close association of P and Li ($r=0.997$), the more so as P is merely an annual sum, whereas Li contains monthly combinations of climatic data. Also high are r for T versus Pet, and Aet versus log P. As the members of these pairs may be used here interchangeably, P and T are given preference. Pet, Aet and Li will be used as modifiers of P and T.

TABLE I — *Correlations among state factors. (For complete independence* $r=0$, *for perfect association and « identity »* $r=\pm 1$).

		Primary state factors			
		P	T	Pm	Sl
Primary state factors	P	1	− .20	− .08	.20
	T		1	.23	− .09
	Pm			1	.25
	Sl				1
Derived climatic variables	Pet	− .27	.98		
	Aet (1)	.84	− .03		
	Li	.997	− .24		

(1) For Aet and log P, $r = 0.97$.

Plant life deserves special comment as it occurs on both sides of the state factor equation; on the right as flora, that is, the pool of species as genotypes, on the left as vegetation, the species as phenotypes. As judged from the configuration of the landscape the seeds of pines and grasses may reach any site of the transect. For this reason the flora chosen is the invariant biotic factor.

The correlation coefficient of vegetation with P amounts to 0.728 for all soils. It expresses the predominance of pines over grasslands in the humid portion of the transect.

DEPENDENCE OF SOIL PROPERTIES ON STATE FACTORS

Before attempting to solve the general regression equation in which all state factors are variables, it is pertinent to assess the dichotomous factors parent material (Pm) and flora (Fl).

Since *parent material* is neither correlated with P, T and Sl (as in Table 1), nor with Fl ($r = -0.139$), the Ai and Bi soils may be compared directly, as in Table 2. The texture fractions sand, silt and clay are essentially uncorrelated with state factors (e.g. all r's for clays are less than 0.229) and, therefore, the marked texture variation between Ai- and Bi-soils may be considered a direct reflection of the differences in Ai- and Bi-rocks. In fact, regressing a soil property with sand and clay equals that with Pm, though not entirely so. The sum of bases and the suite of clay minerals likewise are characteristically different, as are many other properties, but, since these also vary with climate they lack a one to one correspondance with the two rock types.

Since the distribution of *pine forests* and *grasslands* is strongly P-dependent, pine soils and grass soils cannot be compared directly, save in the arid-humid transition zone (56-76 cm) where both occur in the same climate as random patches of pines surrounded by grassy areas.

[1] *Jenny* - pag. 10

TABLE 2 — *Mean values of properties of soils derived from acid igneous (Ai) and basic igneous (Bi) rocks. (All Ai - Bi differences are significantly different at the 1% level or less.)*

Soil properties	Ai-soils	Bi-soils
clay, %	11.6	21.2
silt, %	21.2	33.0
sand, %	58.0	34.5
C %	1.74	2.80
N %	0.074	0.121
bases (sba) me/100g	5.33	10.86
1 PC of clay minerals	ver mia qtz mon	mont mia gib hal

The data in Table 3 include KLEMMEDSON'S samples and additional ones collected by the authors. Compared to pine soils, the grasslands have low C/N ratios, 12-13 versus 25-28, and this highly significant differentiation is brought about by C rather than N. The r-value for C/N with Fl is high, 0.809. Parent material does not modify C/N, confirming the results in Table 2. Carbon and aci are much higher in pine soils than in grass soils, at the 1% level of significance for Ai- and Bi-soils together. As in Table 2, the Bi-soils have a high base (sba) status, but vegetation does not cause a differentiation at the 10% level of significance.

TABLE 3 — *Effect of vegetation and parent material on means of soil properties in the arid-humid transition zone* ($P = 23\text{-}30'' = 58\text{-}76$ *cm*).

	Grasslands		Pine Forests		Grass with isolated pines
	Ai-soils $n = 10$ (¹)	Bi-soils $n = 4$	Ai-soils $n = 8$	Bi-soils $n = 5$	Ai-soils $n = 6$
P	25.9	26.0	28.4	25.2	25.3
C/N	12.7	12.5	25.8	27.9	14.6
aci	2.55	4.45	8.77	13.00	2.49
C	1.03	1.31	2.98	3.20	1.11
sba	6.28	16.91	7.19	18.27	7.63

(¹) n = number of samples.

The last column in Table 3 has pertinent eco-pedological significance. It describes the situation under isolated, 100-200 year old pine trees surrounded by grassland. Intrinsically, the soils are grassland soils with a slight displacement toward pine soils, which, however, is statistically of low significance. The lesson is conveyed that a single pine tree does not make a pine soil, rather a permanent cluster of pine trees is needed that imprints its marks throughout centuries and millennia. The soil criteria may have diagnostic significance for deciphering vegetational history.

To illustrate the *regression procedure* with dichotomous variables consider the 40 Bi-soils in Fig. 2. The dashed line re-

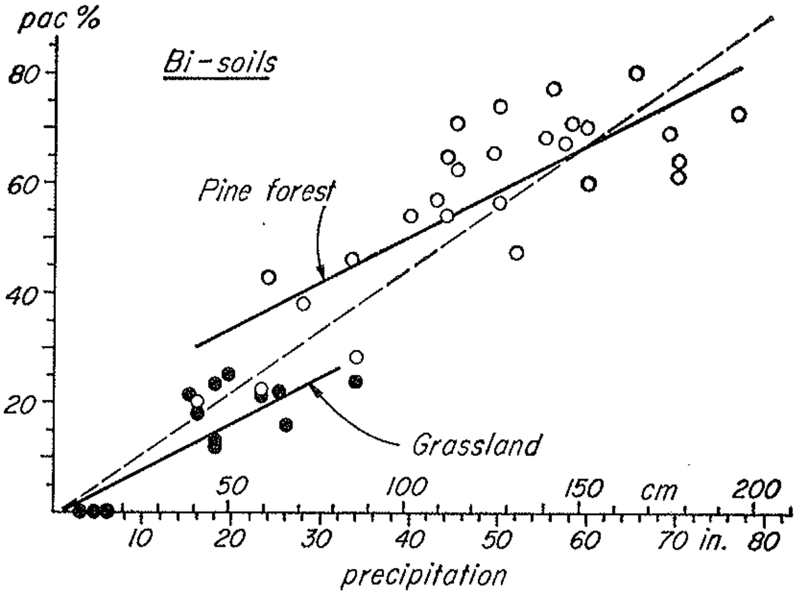

FIG. 2 — Dependency of percentage acidity (pac) on mean annual precipitation and vegetation groups.

lates aci to P, regardless of the kind of vegetation. The equation is

$$pac = 0.592 + 1.128 \ P$$

with $r^2 = 0.834$ and $r = 0.913$. This r^2 registers the direct effect of P on aci and includes the indirect effect of vegetation which is correlated to P with a r value of 0.736.

Introducing the flora (Fl) as pac - f (P, Fl), its value for pines is set as 1.000 and for grassland as - 2.0769, which is the ratio of the 27 pine soils to the 13 grass soils to give a mean value for Fl = 0. The equation is

$$pac = 10.997 + 0.841 \ P + 5.582 \ Fl$$

with an improved R^2 of 0.883 or $R = 0.940$. This new R^2 expresses the combined influence of P and Fl. Under favorable circumstances the difference $0.883 - 0.834 = 0.049$ may be assigned to Fl directly. Replacing Fl by the pine and grassland value, brings forth the two equations

$$\begin{aligned} &\text{pines:} && \text{pac} = 16.579 + 0.841\ P \\ &\text{grassland:} && \text{pac} = -0.596 + 0.841\ P \end{aligned}$$

Recognizing that pine and grass curves could have slightly different slopes, we formulate

$$\text{pac} = 10.964 + 0.848\ P + 5.827\ \text{Fl} - 0.0115\ \text{Fl}\ P$$

There is no significant improvement in R^2. The pine and grassland equations are

$$\begin{aligned} &\text{pine:} && \text{pac} = 16.790 + 0.834\ P \\ &\text{grassland:} && \text{pac} = -1.138 + 0.872\ P \end{aligned}$$

The dependency of the organic soil constituents N, C, aci, pac on the state factors, summarized in Table 4, was evaluated in the following manner. Choosing N as an example, it was first regressed with P, then with P + T, then with P + T + Pm, and so forth. Within each of the first six constellations listed in Table 4 the individual R^2 contributions were nearly invariant and the slope coefficients of the factors remained fairly stable, hence the state factors could be assessed separately by conventional regression.

The four organic criteria N, C, aci, paci behave highly individualistically. They are discussed under the following headings:

Climate (P, T). Nitrogen is least affected by rainfall; only 22.8% of the entire N variance is explained by P. Percentage

TABLE 4 — *Variability of soil properties assigned to state factors. (% R^2 values obtained by stepwise conventional regression).*

		N	C	aci	pac	C/N (1)
1	P	22.8	45.2	45.5	80.9	20
2	T	5.4	9.5	3.6	0.3	2
3	Pm	16.3	6.0	17.4	2.0	1
4	Sl	1.2	1.3	3.5	0.3	6
5	Fl	0.2	3.9	4.4	8.9	40
6	Lat	5.9	3.1	1.9	0.4	7
	Sum	51.8	69.0	76.3	92.8	77
	R	0.720	0.831	0.874	0.963	0.878
7	Min	63.4	74.2	79.7	2.6	80.7
8	cl	5.2	1.3	0.7	0.2	1.6
	Total sum	68.6	75.5	80.4	95.6	82.3
	R	0.823	0.870	0.897	0.978	0.907

(1) Computed by PCV regression.

acidity (pac) is at the other extreme, with $R^2 = 80.9\%$. Carbon and aci occupy intermediate positions. For N and C relating to T, r is negative, as had been observed in many previous investigations.

Parent material (Pm). Nitrogen and aci react strongly to variations in parent material, C much less so, pac hardly at all:

Parent material exerts its role mainly through soil texture and clay mineralogy.

Slope (Sl). Owing to careful topographic controls during field sampling, the slope effect is small, except for C/N.

Flora (Fl). The role of species is highly specific, being near zero for N and 8.9% for percentage acidity (pac). It would seem that biologic N fixation which in the long run controls the steady state of N is but slightly affected by vegetation, whereas C, whose source is photosynthesis, is much more so. This is corroborated by the C/N ratio to be discussed presently.

Latitude (Lat). Carbon and particularly N have significant negative coefficients with latitude. It implies that for any chosen pair of P and T coordinates soil organic matter increases toward lower latitudes. The reason is obscure. Lat may mitigate mean annual P and T, or register systematic biotic variation. At any rate, the trend is in accord with observations made in India and Latin America and leads to the prediction that the soils having the highest climatically controlled humus content should be found at the equator at high elevations (e.g. Mt. Kilimanjaro).

The sums of the columns of the six factor allocations divulge variance explanations of 52% for N and a spectacular 92.8% for pac. The row of the conventional R values indicates — exclusive of N — that all multiple correlation are highly successful.

The *C/N ratio* could not be regressed conventionally because high interaction and collinearity forfeited the consistency of the individual factors. Thus, C/N correlated with P alone to the extent of $R^2=44.7\%$, but when Fl was inserted it reduced the P share to only 0.4% and amassed for itself 73% units of the total R^2 sum of 77.0%. The C/N column was obtained by PCV regression which successfully masters the interaction problem. Precipitation explains 20% of the va-

[1] *Jenny* - pag. 16

riance and this comprises both the direct effect of P on C/N and the climatic control of vegetation. The species effect on C/N, as flora Fl, adds 40% to R^2.

Let us divert for a moment from organic matter and look at the regimen of clay minerals. It responds to all state factors. Montmorillonite prevails at low rainfall [2], for its correlation with P is negative, with r equal -0.534. Kaolinate and halloysite are negatively correlated with each other, $r=-0.800$, and its IPC regressed with P and T gives $R^2=11.3\%$ which rises to 61.4% upon the addition of Pm. The first PC of all clays taken together is affected by climate to the extent of $R^2=31.9\%$ and by all factors as $R^2=82.5\%$ a remarkably high value for an inert mineral soil constituent.

Granting that soil organic matter is vastly more dynamic than clay alteration, we may be justified in considering the clay matrix as a stable physical and chemical frame work for biochemical reactions, a sort of parent material for the organic substances. Accordingly, the clays are introduced as factor No. 7 in the regression chain of Table 4.

Owing to the dependency of clay minerals on climate it is not possible to isolate their share in the regression coefficient. Only the total contribution is listed in Table 4. Nitrogen reacts most strongly, the rise in R^2 being 11.6%. The others have their R^2's augmented by 3-5%.

Derived climatic variables. If Li, Pet and Aet are added for completeness sake, also El, a further slight increase in R^2 is produced for N, but barely for the other variables.

Looking at the *total sum of R^2* in Table 4, the factors explain 68.6% of the variance of N and an amazing 95.6% ($R_A^2=94.4\%$) for pac. C/N is also very high, followed by aci and C.

Clusters of highly correlated soil properties, such as the acidity dyad pH*pac or the organic matter triad N*C*C/N — where the stars indicate that the properties have been correlated — may likewise be coordinated with state factors. It results in economy of functions. One function, with the first principal component of the cluster as the dependent variable, takes the place of two or three. High R^2 values may be achieved (Table 5) but not quite as high as the highest R^2 of the top ranking partner in a cluster.

TABLE 5 — *Ordination of first principal components of dyads and triads with state factors. R^2 values (%); all soils.*

Cluster (¹)	Climate alone (P, T)	All State Factors
N*C	44.6	64.1
pH*pac	76.8	91.2
N*C*C/N	49.0	74.0
N*C*aci	48.9	74.4

(1) The stars indicate that the properties are closely correlated.

Ordination of soil properties confined *within Ai-* and *Bi-rock provinces* was carried out with PCV technique. The R^2 values for the constellation P, T, Sl, Fl and Lat are reported in Table 6. They are high, and are even higher if texture is included as a criterion of composition variability within the Ai- and Bi-rocks. As expected, the ranking of the clay minerals differs in the two materials.

Not shown are the standardized slope coefficients which record the thrust of the individual state factors. Among the Ai-soils the flora contribution to R^2 is 3% for N, 26% for C

TABLE 6 — *Variance of selected properties of Ai- and Bi-soils explained as R^2 by the state factors P, T, Sl, Fl and Lat, according to the PCV method. (The R^2's in parenthesis express the inclusion of soil texture (sand, clay) as a state factor to characterize the mineralogical variability within the Ai- and Bi-rocks).*

Ai-soils		Bi-soils	
Soil property	R^2	Soil property	R^2
pac	94 (95)	pac	89 (93)
C/N	82 (83)	sba	77 (78)
pH	80 (82)	aci	74 (75)
aci	68 (85)	C/N	73 (73)
C	67 (78)	C	69 (69)
mica	66 (73)	ME	66 (77)
verm	65 (65)	pH	65 (66)
sba	35 (67)	mica	64 (67)
ME	28 (84)	mon	60 (67)
N	25 (45)	N	53 (57)

and 43% for C/N. At a given climate Fl also modifies the proportions of the clay minerals mica, kao, ver and mon. Among the Bi-soils the flora contributions to total R^2 are 16% for mon, 27% for hal and 38% for kao.

All these R^2 values furnish a beautiful numerical confirmation of the ideas of HILGARD and especially of Dokuchaev's equation (4). We believe that the data in Tables 4, 5 and 6 constitute its first complete solution.

Our findings are seemingly in conflict with a recent trend of thought that denies the validity of soil forming factor equations. It is contended that most soils are paleosoils or fossil soils that owe their existence to previous climates. It cannot be overlooked, however, that the high correlation in Tables 4, 5 and 6 pertain to present-day climate, slopes, vegetation, etc. Either there has not been a pedologically measurable change in climate in the study area, or the soil features assayed here readjusted themselves to modern climate. In this light the expression paleosoil is ambiguous without the explicit specification of the kind of properties one has in mind. Evidentely, organic soil constituents reflect todays state factors.

INTERACTION OF NITROGEN AND CARBON WITH SOIL PROPERTIES

Comparing each of n soil properties with every other produces $n(n\text{-}1)/2$ *correlation coefficients,* or for our collection 406 r's. If classified in intervals of 0.200 units, the frequency distribution in Table 7 results. Very low associations of pro-

TABLE 7 — *Frequency distributions of* 406 *correlation coefficients* $|r|$ *among* 29 *soil properties.*

Ranges of r	Number of r values	Examples (¹) of correlating properties with emphasis on N, C, C/N, aci, pac
0.999-0.800	13	N*aci, sba*Ca, pac*pH, C*N
0.799-0.600	28	Ca*Mg, sa*clay, hal*ME, C/N*pH
0.599-0.400	76	C*pH, N*iro, mi*ver, C*mi
0.399-0.200	113	mon*Na, si*aci, C*cry, clay*pac
<0.199	176	C/N*kao, N*K, Ca*aci, C*sba

(¹) The star denotes that the properties chosen are correlated.

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perties dominate, but it is the 40 high ones that are important. As judged from the arbitrarily selected examples, the organic constituents occur in all correlation ranges.

In the large overall correlation matrix (not shown) the 84 r-values which involve N, C, N/C appear erratic and puzzling. Why should N be highly covariant with aci ($r=0.852$) but barely so with K ($r=0.006$)? Or, to consider clays, why should C be positively correlated with halloysite and negatively with montmorillonite? Such questions are basic to pedogenesis and they figure prominently in discussions on soil classification. Answers are usually sought in terms of physical, chemical and biological soil processes, but these are still too poorly understood to offer much help. The entire problem of correlations of soil properties is formidable and largely unsolved.

Light is shed on the multitude of r-configurations of N, C, C/N by examining the correlation coefficients of the soil properties with their climatic state factors. It becomes at once apparent that C and N have positive r values with all those soil properties that are positively correlated with precipitation and negative r values with those that are negatively correlated with P. For carbon the design is displayed in Fig. 3. On the horizontal axis are plotted the $\pm r$'s for $s=f(P)$, on the vertical the $\pm r$'s for $C=f(s)$, where s indicates any soil property. As seen in the first quadrant, aci is well correlated with $P(r=0.675)$ and, in turn, C is strongly collinear with aci ($r=0.945$). In the third quadrant r for $pH=f(P)$ is markedly negative ($r=-0.772$) and so is $C=f(pH)$, with $r=-0.574$.

Clearly, it is the impact of precipitation on all soil properties that regulates their correlations with carbon. This observation strongly suggests that interpreting mutual associations of soil properties is facilitated by invoking their bondage with the state factors.

High correlation coefficients, such as $r=0.945$ for C*aci, are indicative of the existence of stable dyads, triads and

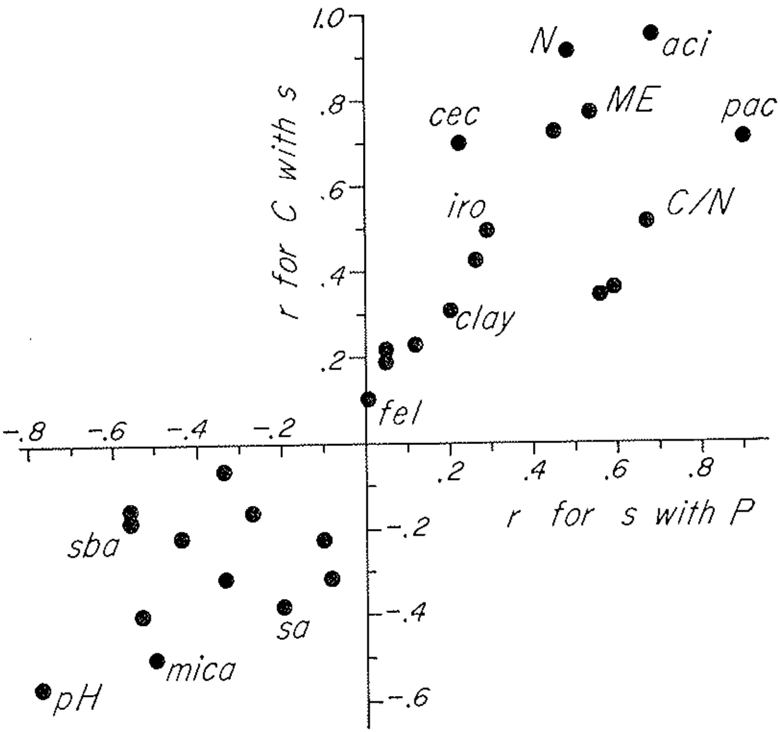

FIG. 3 — A correlation between correlation coefficients: r for $C=f(s)$ against r for $s=f(P)$, showing that carbon correlates highly with those soil properties that are highly correlated with precipitation (P).

clusters of properties. For the dyad C*N with r equal to 0.908, any covariance of C with another property s is mirrored in the r value of N with that same s. Thus, for $C=f(\text{cec})$, r is 0.701 and for $N=f$ (cec) r is 0.765. N*C*aci and sba*Ca*Mg are triads. A 6-variable cluster is given by N*C*aci*cec*ov*ME, but it has not been studied.

As said earlier partnership of variables may be coded as principal components, especially if the first component (1PC) has a high eigenvalue λ_1. Thus λ_1 of N*C*aci accounts for 93.5% of the combined variances of the three. Its 1PC was regressed with state factors in Table 5. Correlating the component individuals (scores) of N*C, sa*si, paci*pH, N*C*aci, and of the ten clay minerals with those of P and C produces *r*'s that fit into the scatter diagram of Fig. 3.

Recent advances in cluster research, Factor Analysis — used in soil fertility studies long ago by FERRARI et al. [5] — and numerical taxonomy may stimulate attempts at ordinating soil properties. Fig. 3 provides a convincing argument that state factors deserve to be included in the ordination. In fact, there is no compelling reason, philosophical or otherwise, why they should not.

The question how much *time* it takes nature to create a high correlation among soil properties is answered by the mud flows of Mt. Shasta (P = 123 cm, T = 9.6°C) in California. The sequence of flows, originally established by DICKSON and CROCKER [3], is sketched schematically in Fig. 4. The senior writer reexamined the field stratigraphy and confirmed the essential overlays, especially that of D on E, but could not be sure whether or not B different from C. Moreover, C-14 dating set the age of B as 300 years, not 60, as the authors had assumed. At a slightly higher elevation an older flow F was found but its exact stratigraphy has not yet been worked out. It is not shown in the flow sketch in Fig. 4.

In these flows 12 random samples (0-20 cm) were collected and analysed for aci and C. The regressions together with the *r* values are shown in Fig. 4. Surprisingly high coefficients are reached in a few decades and centuries even though neither C nor aci appear to have individually achieved steady state conditions. The age of the older flows has not yet been established but, as judged by inorganic and textural profile features, it cannot exceed a few thousand years.

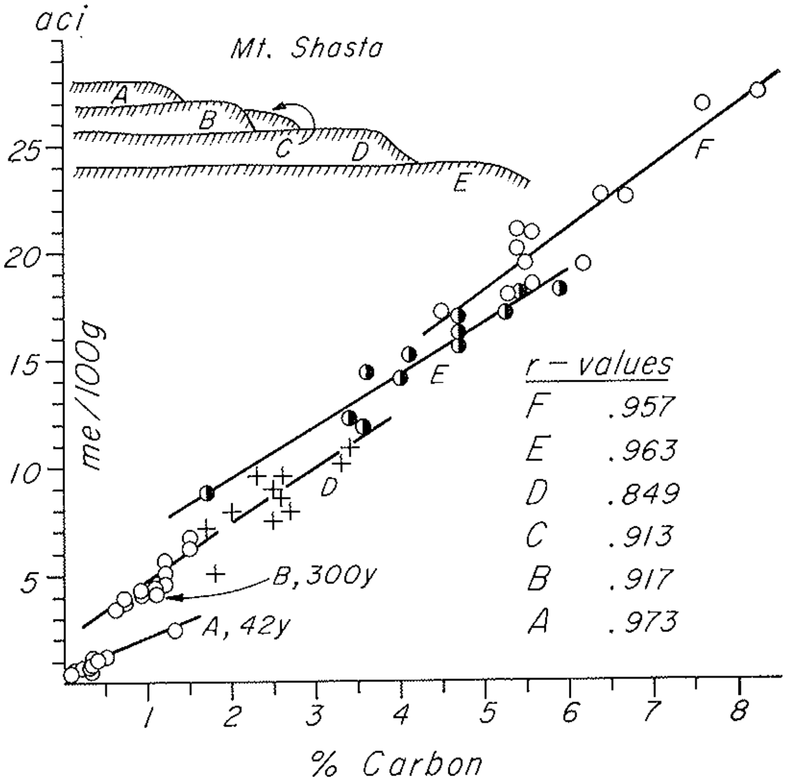

FIG. 4 — Effect of age of soil on the correlation coefficient of aci versus C. Mud flows of Mt. Shasta, dated as 42 years (A), 300 years (B), and a few thousand years for D, E and F.

The average number of me. of acidity per gram of carbon is close to 3.5, or 42 me acid per mol of carbon. For the corresponding Bi-soils (pines) the mean value is 5.0 me/gram C. The difference of 1.5 me of acidity may be attributed to the clay fraction which is high in Bi-soils but practically nil in the Shasta mud flows.

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MINERALIZATION OF SOIL NITROGEN

For a fertility test [9] on the Berkeley campus quantities of the 97 soils were placed in pots, four times replicated. The 2000 pots, all randomized, were processed simultaneously. Barley was used as an indicator plant. The « full treatment » consisted of an application of ammonium nitrate, monocalcium phosphate and sodium sulfate, designated as NPS. Potash was not included because previous experience suggested absence of K deficiencies. One of the partial treatments, indexed as PS, had nitrogen omitted. The *relative yield* RY in per cent was calculated as

$$RY = \frac{\text{mean yield of PS}}{\text{mean yield of NPS}} \cdot 100 \,.$$

It measures the soil's supplying power of nitrogen to the barley plants under the conditions of the experiment. The mean of all RY's was 19.6% with extremes of 6.0% and 72.0%. The variance of the RY population was large, $123.0(\%)^2$. As the RY yield is essentially an expression of the rate of mineralization of organic soil nitrogen, the wide yield variations testify to highly variegated soil microbiological activities. These will be assessed by way of state factors and soil properties.

will be assessed by way of state factors and soil properties.

Yields assigned to state factors. If soil properties are functions of state factors and if barley yields are controlled by soil properties, then the yields observed at Berkeley should exhibit a linkage to the state factors at soil origin, in accordance with eq. (1).

For all soils taken together the correlation coefficient of RY with mean annual precipitation (P) is 0.595. If, in addition, T, Pm, Sl, Fl and Lat are placed in multiple regression, R becomes as large as 0.714. Limiting regression analysis to Ai soils exclusively, the PCV method rises R to 0.80.

Even more striking is the behaviour of the yields FY of the full treatment pots NPS. Plant growth was expected to be uniformly good, but it was not. The yields of the Bi-soils at Berkeley declined systematically in proportion to the mean annual precipitation at the site of soil origin, with r equal -0.704. The impairment could be documented as phosphate fixation caused, presumably, by the demonstrable enrichment of gibbsite clays and iron oxides with rising rainfall. Multiple regression of FY with P, T, Sl, Fl and Pm (as texture) gives $R = 0.816$, and, if the clay minerals are included, R becomes 0.864.

There is good evidence, then, that soil fertility measured as RY or FY at Berkeley still bears the imprint of the factors of soil genesis, even though the soils had been moved, disturbed and manipulated.

Yet, a R^2 of 67% is still one third below the maximum figure of 100%. The source of the discrepancy most likely resides in the factor parent material which is poorly identified. No appraisal was made of chemical constitution, including the plant-important microelements, or of the mineralogical design. Since many of the rock components are transfered to the soil and as soil properties diversify microbial activity and plant growth, yield correlations should be higher for soil properties than for the state factors. But how much higher?

Genetic soil properties as yield determinants. If one were to sample soils haphazardly in a « random-landscape » — a hypothetical construct in which all state factors are geographically randomized — the probability of observing a close accord of yield and soil would be small because the soil properties are likely to be uncorrelated. The soil collection would be highly heterogeneous.

Contrarily, if an assemblage of soils is highly stratified according to continuous pedogenic sequences it is monotonely homogeneous. Yield functions should be promising, for all properties are arranged in orderly sequence and are intimately interrelated, viz. collinear.

The present collection which comprises calcareous, neutral and acid soils, sands and clays, humus-rich and humus-poor soils, gray desert, non-calcic brown and lateritic soils would suggest extreme heterogeneity were it not for the fact that the sites were chosen to yield gradual transitions, safe for the discontinuities of Ai- and Bi-rocks and of grass and pine flora. Accordingly, a certain degree of yield prediction is to be expected, especially when the samples are limited to within the discontinuous factor sets.

Correlation of yields with organic constituents are consistently high (Table 8). Either N or C alone, or in combination, or as principal components account for 63-64% of the yield variance. A completely randomized soil collection would not generate such high R^2 values.

TABLE 8 — *Correlation coefficients* r, *R*, *of relative yields with organic soil constituents and their principal components (PC). All soils.*

Soil variables	r or R	Soil variables		r or R
N	0.791	1PC(N*C) and C/N		0.802
C	0.800	1PC	of N*C*C/N	0.780
N, C	0.789	1, 2PC		0.787
N, C, C/N	0.802	1, 2, 3PC (1)		0.791

(1) Linear regression of RY with first, second and third principal components of the cluster N*C*C/N.

The pertinent contract between RY and total N is plotted in Fig. 5. The regression lines have the following forms:

all soils: $RY = 3.22 + 175.98\ N\ (r = 0.791)$

Ai-soils: $RY = 5.13 + 166.86\ N\ (r - 0.693)$

Bi-soils: $RY = 0.91 + 197.58\ N\ (r = 0.833)$

The scatter of the points, which is more erratic for Ai than Bi, is to be attributed in large part to those soil properties that govern the rate of nitrification and mineral uptake by plants. What are these properties? Soil fertility specialists would analyse for nitrates, including an incubation test, available K and phosphates, micronutrients, maybe nitrites and soluble aluminum, all of them properties that are not contained in our set of 29. Yet, *if collinearity among soil properties is high, the choice of variables should not be crucial,* and even the genetic characteristics should function as predictors of yields.

The R^2 values in Table 9, obtained by stepwise regression analysis tell a revealing story. For all soils (Ai + Bi) together, nitrogen alone explains 63% of the yield variability. Four additional soil properties, selected by the computer, augment R^2 to 71%. Ten statistically chosen properties raise R^2 to 73%. Regression with the PCV variables gave R^2 of 89%, a high value. Its standardized slope coefficients were positive, viz. yield enhancing, for N, C, hal, kao, clay, gib, ver, in that order, and negative, viz. yield retarding, for aci, pac, Mg, pH, iro, again in that order.

Confining the inquiry to one kind of parent material, either Ai or Bi, is equivalent to resolving the sample collection into two subsets which may or may not have different population parameters. Compared to the whole collection, multivariate regression with ten soil properties augments R^2 within the two rock subsets, from 73% to 81-82%. With further sample

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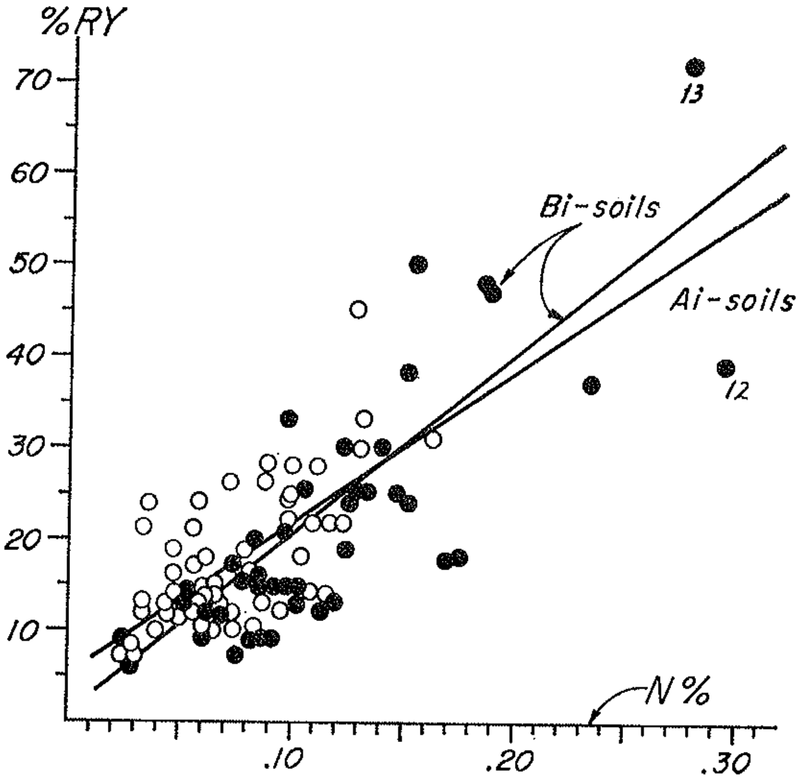

FIG. 5 — Relative yield RY plotted against total nitrogen content of soil. RY is an index of rate of mineralization of organic N.

modulation (pine soils only) R^2 rises still higher (87-89%), even though mean annual precipitation ranged widely, between 16 and 77 in. (40-196 cm). The unexplained variance is of the order of experimental error in pot test technique. Modulating the state factors evidently improves the correlation between yields and soil properties.

The scatter of the points in Fig. 5 is meaningfully explained. Thus for the Bi-pine soils No. 12 and 13, the former has an

TABLE 9 — *Explaining yield (RY) variance as R^2(%) by modulating state factors according to parent material and flora.*

State factor modulation \ Number of soil properties including N	% R^2		
	$N=1$	$N+4=5$	$N+9=10$
Ai -and Bi-soils together . .	63	71	73
Ai-soils only	48	72	81
Bi-soils only	69	75	82
Ai-soils, pines only	47	80	87
Bi-soils, pines only	66	84	89
Bi-soils, pines only, mult. regr. coeff. R	0.81	0.92	0.95

observed yield of 39%, the latter of 72%. The calculated yields are 38% and 73% respectively. Soil 13 is more fertile than soil 12 because it has much less acidity (aci) and much more Ca.

The middle column headed $N+4=5$ deals with regressions with those 5 soil properties that are at the top of the list of the 29, as far as their contributions to R^2 is concerned. For all state factor subsets (rows) the five invariably include N and aci; N/C and clay occur 3 times each and C, pH and pac twice each. Neither their order nor signs are consistent from one subset to another, nor should consistency be expected between discontinuous fields.

It is indeed astonishing that 5 properties should explain over 80% of the yield variation when the plant itself needs over a dozen different elements, not to mention suitable micro-soil structure for microbial activities. The explanation is to be sought in the high collinearity of many soil properties brought about by the systematic sampling procedure according to state factors.

SUMMARY

Theoretically, crop yields, soil properties and factors of soil genesis (state factors) are interrelated as a multivariate system.

To test this broad concept, 97 soils were collected in California along a moisture transect reaching from the desert to the perhumid region. Parent rock, exposure, slope and natural vegetation (pines, grasslands) were rigidly controlled. The mathematical model was based on linear regression analysis involving observational variables as well as principal components with and without varimax rotation.

The variability of soil properties, especially those related to organic matter, could be accounted for in high degree by the present-day soil forming factors, especially climate and natural vegetation. The old idea that N and C are linked by common microbial genesis could not be confirmed as the two elements behaved differentially. Nitrogen was but moderately related to climate and barely so to flora, but strongly to parent material and clay mineralogy. Carbon, on the other hand, responded strongly to precipitation and temperature and markedly to plant species, which was especially expressive in the behavior of C/N.

Clay mineralogy correlated with climate and parent material, and, at a given climate, also with floristic differentiation.

Correlation coefficients (*r*) among the soil properties ranged between near-zero and near the maximum of 1.00. The coefficients of carbon with the other soil properties were governed by their dependencies on precipitation. It takes but a few

decades or centuries to establish high r values between such pairs as carbon and acidity.

Soil fertility was ascertained in a large-scale standardized pot test experiment. The yields variations still reflected the state factors of soil origin. Degree of correlation of yields with multiple soil properties tended to depend on the genetic ordination of soil samples; the more heterogeneous the soil group as to dichotomous factors such as rocks and flora, the less was the multiple coefficient of correlation.

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DISCUSSION

Chairman: S. A. WAKSMAN

WAKSMAN

We have, according to our programme, fifteen minutes for discussion of this most interesting paper of Dr. JENNY. I would like to take advantage of the fact that I am the Chairman in order to suggest that there is one other, very important factor that might be considered. Dr. JENNY mentioned the kinetics of the soil, which is extremely important. The microbiological population of the soil is not necessarily the number of organisms or the kinds of organisms but the total activity of the population, as measured either as nitrogen liberation or carbon dioxide liberation, or by some other measurement. I think this might add to the factors which HILLGARD took into consideration. What do you think?

JENNY

This touches upon an important question, namely, the relationship and nature of the variables. In what aspect are the microbes in this area an independent variable? The idea is that every soil of the whole area during thousands of years received through wind and blowing and other ways all the microbes of the area, and then the activity of the microbes, which eventually brings about the steady state of the soil, is a dependent variable and is really controlled by these same state factors. Microbial activity is a process, and processes are not part of the state factor approach.

DHAR

What was the calcium phosphate status of your soil? Did you take up that question? Calcium phosphate status of a soil is of vital importance to fertility.

JENNY

In some of the fertility experiments we added phosphorus to bring about a modification of fertility and that is the way we learned that phosphate fixation was a function of the climate of these soils. And likewise, the calcium content was altered. But we have not introduced the natural phosphate level into the calculations of the factors' correlations. It would have been better if we had done this, but we didn't.

SWABY

Dr. JENNY, I notice that on most of your survey you have been speaking about virgin soils where man had meddled very little, and I am afraid that many of us are concerned with predicting the fertility of soils that have been very much man-altered. For instance, in many of the areas which are very arid you find man putting water on them, as irrigation water. He will also apply fertilisers. In no instance did I notice that man was one of the factors in your considerations and I think this is very important. Would you tell me what are your thoughts on this matter?

JENNY

We have selected these areas specifically from the viewpoint that as far as we know man had had no effect on it, at least white man. Now, I grant you if we bring in white man and modify the whole system, the situation becomes more complicated, but I thought it was good enough to try to see how the integration of the variables behaves in as simple a system as possible. Accordingly, I must admit that I cannot answer your question at this time.

FLAIG

Dr. JENNY, I followed your paper with great interest because we also tried to find out with statistical methods according to SNEATH the similarities of different humic fractions which are isolated from different soils, and to find out how near are the chemical and physical properties of the same type of different humic substances of different origin. I would like to ask you, did you only determine nitrogen and carbon content of soil organic matter, or have you also investigated parts of your soil organic matter with other methods?

JENNY

This is an embarrassing question and I must say we have not, and not because we underestimate the value of additional studies but simply for the physical impossibility of doing all the detailed field work and the laboratory work and the mathematical work and all that. It is just too big a project for us to bring in at this time your humus science too.

BROADBENT

I noted with interest that you find a much better correlation of nitrogen content with clay minerals than of carbon. In this connection, have you determined the quantity of ammonium fixed in the clay minerals of these soils?

JENNY

Naturally, when the results emerged, we were wondering what was the role of the clay minerals in the nitrogen correlations. All I can say is that we followed STEVENSON's technique to get all the nitrogen by prolonged Kjeldahl analysis. We have not explored this problem further.

ALEXANDER

If you look at a region in which the plant community has developed in isolation, for example, an island ecosystem, and contrast this with an ecosystem which has a comparable temperature, precipitation, altitude etc., what effects does this isolated plant community have on the levels of soil organic matter or nitrogen? You show no floristic effect, but there is a good chance of introduction of plants in the California region. This does not occur in some isolated ecosystems.

JENNY

Depending on the flora I would expect a vegetation effect, particularly on the carbon/nitrogen ratio and on certain aspects of acidity. Now, you are asking me to compare the isolated island with what?

ALEXANDER

If one examines two plant communities each developing in different conditions, for example an island, or consider an Australian

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locality, a South-East Asian region, or a Western hemisphere environment, does one have the same general results when temperature and precipitation are constant and the variable is the flora?

JENNY

I would, from the studies we have made here, expect a significant differentiation in many soil properties especially in organic matter.

HENIN

Le Docteur JENNY dans son très bel exposé nous a dit, si j'ai bien compris, que pratiquement toute la pédogenèse se trouvait gouvernée par les facteurs climatiques actuels et il a dit qu'il pensait que le problème des sols fossiles représentait peu d'importance étant donnée la vitesse avec laquelle les équilibres pouvaient s'établir. Vous êtes parti d'une région où, si j'ai bien compris, vous aviez comme matériel originel des roches éruptives. Si vous partez d'autres matériaux, par exemple ayant une certaine teneur en argile à l'origine, le fait même que vous trouviez une correlation très étroite entre la teneur en argile et la composition de votre matière organique, devrait amener une évolution différente pour le même facteur climatique. D'autre part, l'évolution que vous pouvez observer pour l'argile est possible parce que vous avez certaines réserves d'élements minéraux, par exemple de silice, pour former un minéral de type vermiculite ou montmorillonite mais si vous partez d'une roche plus pauvre en silice, par exemple une formation sédimentaire avec de la kaolinite, est ce que dans les conditions vous n'auriez pas d'autres formes d'évolution; autrement dit, est ce qu'on peut vraiment généraliser pour tous les types pédologiques ou est ce qu'il ne faut pas prendre, pour chaque type de materiel originel une séquence propre où le facteur climatique trouverait une expression plus spécifique. Est-ce que c'est clair?

JENNY

Oui, Monsieur.

JENNY

I should like to try to summarise the question in English. You think, Prof. HENIN, that I over-emphasized the climatic variable in clay formation as compared to the composition of the rock? I think I gave a wrong impression. We have always used two parent materials. In both of them the clay mineralogy is a function of climate, but also, as I tried to show, each parent material has its own sequence of clay minerals. For example, there is more montmorillonite in soils from basic igneous rocks and more iron oxide and gibbsite. I think the analysis has shown the importance of the clay mineralogy and the climate for explaining the variability of nitrogen, and the former includes the variation in the parent rocks. I fully concur that soil-climate relations will be different for different types of parent materials.

CHARACTERISTICS OF THE ORGANIC MATTER IN THE MAJOR SOILS OF THE WORLD AND ITS IMPORTANCE TO SOIL FERTILITY

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Organic matter is one of the most important factors in soil fertility. It is indispensable to plant life in its natural environment. This is why the result of the alteration of the lithosphere (crust of weathering) is not considered a soil by pedologists unless it is accompanied by a process involving living organisms.

ACTION OF THE ORGANIC MATTER

The action of the organic matter, or rather, of the humus which results from its decomposition and from new synthesis, can be either direct or indirect. The humus seems to act directly in increasing crop yields, either by acceleration of respiratory processes, by increasing cell permeability, by hormone growth action, or by combinations of all these processes. It supplies the plants, through biological decomposition, with nitrogen, sulphur and phosphorus in available form. Indirectly, it improves the physical properties of the soil such as aggregation, aeration, permeability and water-holding capacity.

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RELATION OF ORGANIC MATTER TO SOIL FERTILITY

Because of its complex role, it is difficult to evaluate the importance of organic matter to soil productivity. Most experiments, particularly field experiments, can only estimate roughly the part played by humus and that by the mineral elements in the humus. The macro and microelements supplied by manure can, of course, be replaced by fertilisers. In fact, in nature, organic matter does not supply the mineral plant nutrients. It concentrates and stores them in the surface of the soil. Its capacity to retain and exchange elements such as calcium, magnesium and potassium, prevents over-leaching of soils poor in clay. Given equal weights, the exchange capacity of organic matter is between two and twenty times that of the clay. Even if fertilisers alone could satisfy plant needs, organic matter would still be needed for erosion control and to reduce losses of such costly inputs through leaching. Perhaps one day there will be a synthetic resin capable of replacing organic matter in its exchange function at a price economically feasible.

Organic matter also is difficult to replace in its role in the improvement of the physical properties of the soil. Clay needs good aggregation because of the possibility of dispersion. Aggregation can be obtained by iron oxides, for instance, but then the exchange capacity is low, and although permeability is increased, water retention diminishes. Krilium and other similar compounds raised great hopes at one particular stage but the general application of such conditioners is still uneconomic.

Finally, its role as a catalyser of plant growth does not yet seem to be fully understood. However, chemistry is powerful and it is likely that chemicals will be found to replace organic matter in this particular property, since the amounts required are likely to be small.

If organic matter and humus are still indispensable to us, what should be the quality of the organic matter and in what proportions is it needed? It is difficult to answer the first question without answering the second since the relationship between organic matter content and yield often seems to depend both on the composition of the soil and the quality of the humus.

The significance of humus quality is a particularly complex question and much research is still needed to understand it fully. To date, it has been assessed by a few simple criteria such as physical aspect, pH, percentage base saturation, Humic acid/Fulvic acid ratio, carbon/nitrogen ratio, etc. Generally, the most effective humus has neutral pH, high base saturation, a H/F ratio larger than 1, and a C/N ratio around 10. It is important to understand for each crop the influence of the C/N ratio for equal applications of organic matter. A study of this kind was undertaken by YOSHIHISA MASHIMO [5] as shown in diagram 1. On the other hand, D.S. BULGEHEV [1] obtained the following relation between the content of organic matter/yield of a mixed fodder (vetch, oats, peas) for organic matter with nearly constant C/N ratio:

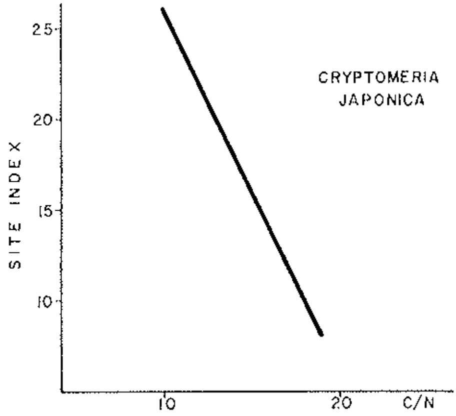
$y = 50.6\ x - 8.68$ in which x is the percentage or organic matter ranging between 0 and 3%.

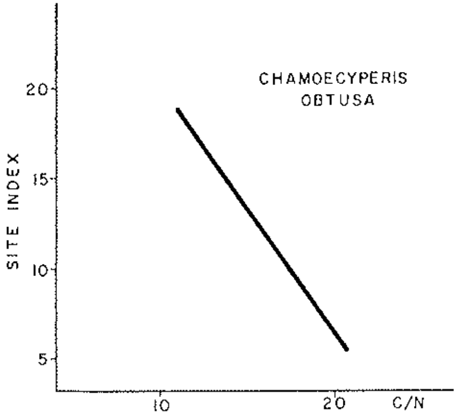
Diagram 2 represents the ratio of organic matter content to the production of wheat and maize.

The kind of crop should be specified since they do not all respond in the same manner. Although the C/N ratio generally indicates the availability of nitrogen in the organic matter, each plant has its specific requirements of this plant nutrient. Trees in general and certain saprophites, such as vanilla, grow well with C/N ratios up to 35. Above this, nitrogen deficiencies may occur.

Most plants seem to respond very well to an increase from 0 to 7% of organic matter of suitable C/N ratio; after which

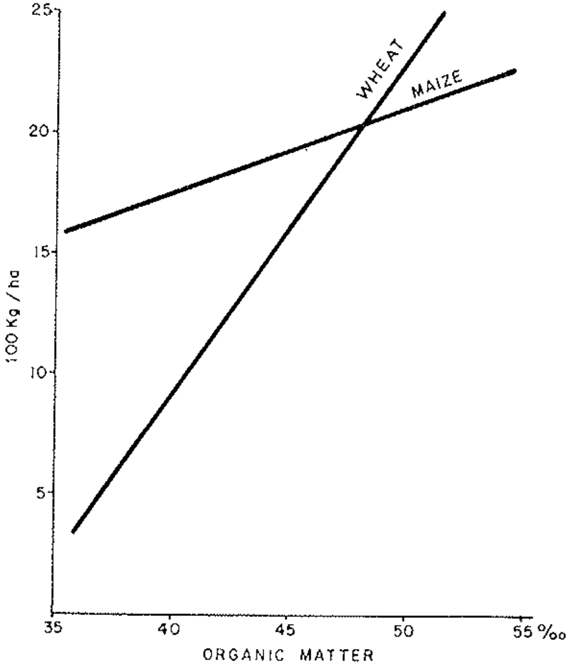
DIAGRAMI





[2] *Bramao* - pag. 4

DIAGRAM 2



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growth increases more slowly following a curve of the Mitcherlich type. J. VELLY and others describe changes in an exposed, compact B horizon of a Ferralsol from Madagascar, containing 1.35% carbon and 0.10% nitrogen. The control plot gave no yield of maize. With an application of 10 tons of bad quality manure, 231 kg/ha were obtained. With the addition of 200 kg of ammonium sulphate, 100 kg of urea, 300 kg of 18% superphosphate and 200 kg of 60% potassium chloride, the yield was increased to 2175 kg/ha. The manure alone and 300 kg of 18% superphosphate yielded only 269 kg/ha. Therefore, it seems that in this soil, manure alone was capable of supplying very little of the nitrogen requirements of the crop. It was the nitrogen fertiliser, plus the application of P and K, which significantly raised the productivity of this eroded soil.

The action of the organic matter on soil structure is difficult to measure as it varies with texture, kind of clay, etc. However, organic matter will reduce bulk density of the soil and improve its structure. There are, however, interactions with other factors. For example, DABIN [2] established that, with more than 2% of organic matter, a ratio Na/Ca 0.08 to 0.1 has a bad effect on soil structure. With less than 1% of organic matter a ratio Na/Ca from 0.03 to 0.05 is sufficient to have the same effect.

ORGANIC MATTER IN THE MAJOR SOILS OF THE WORLD

Each Great Soil Group under natural conditions has a characteristic range of quantity and quality of organic matter as a result of the natural equilibrium between accumulation of organic matter and its mineralisation. This equilibrium depends on the climate, organisms and parent material. It is upset by the interference of man with resultant modifications of the quality and content of organic matter.

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[2] *Bramao* - pag. 6

TABLE

Major soils (¹)		Organic matter content (²)	$\frac{C}{N}$ (²)	pH (²)	Base saturation (²)
Fluvisols		low	variable	variable	variable
Rhegosols		low	variable	variable	variable
Arenosols		low	medium	acid	low
Gleysols	ochric	low	medium to high	acid	variable
	humic	medium to high	medium to low	neutral	variable
	histic	very high	high	low	variable
Rendzinas		medium to high	medium	neutral to basic	high
Rankers		medium	medium	acid	low
Andosols		variable	medium to high	acid to neutral	—
Vertisols		low	medium	neutral	high
Ermosols		low	low	basic	high
Xerosols		low	low	basic	high
Halosols	ochric	low	medium	basic	high
	humic	medium to high	medium	basic	high
	solod	medium	medium	neutral to acid	medium
Planosols	ochric	low	medium	acid	low to medium
	humic	medium to high	medium	neutral	medium to high
Castanozems		medium	medium	neutral	high
Chernozems		medium to high	medium	neutral	medium to high
Phaeozems		medium to high	medium	slightly acid	medium
Cambisols	ochric	low	medium	slightly acid	low
	humic	medium	medium	acid	low
Luvisols		medium	medium	slightly acid to neutral	medium to high
Acrisols		low to medium	medium	acid	low
	humic	high	high	acid	low
Podzols		variable	high	acid	low
Ferralsols		low to medium	medium	acid	low to medium
	humic	high	high	acid	
Histosols		very high	high	variable	variable

(¹) Nomenclature and definitions internationally agreed and used in the preparation of the FAO/UNESCO Soil Map of the World (see WSRO note page 49).

This table refers only in a very approximate way to the average organic matter content in the major soils and related properties and conditions. It presupposes that the soils mentioned are uncultivated or under the so-called traditional agriculture.

Soils of regions where technological agriculture predominates may belong to the groups indicated, but may have also quite different qualities and properties of their organic matter due to soil management.

Whenever organic matter content in the soil and percentage of base saturation are medium to high soils are naturally fertile and productive. Agriculture can be established on this soil areas without much investment, provided, of course, that no other particular limiting factors are involved, such as presence of salinity or water-logging conditions. However, such limitations and others, such as shallowness or very coarse textures, are considered to be of local character when one looks at the extention of the soils on a global basis.

From the information which led to the preparation of the table, it can be estimated that while, under natural conditions, about 60% of the soil units of the world soil legend are well

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Report No 33 - Definitions of the Soil Units for the Soil Map of the World).

(2) Organic matter content:	below 2%	low
	2 to 6%	medium
	7 to 30%	high
	above 30%	very high
C/N ratio:	below 10	low
	10 to 14	medium
	15 to 30	high
	above 30	very high
pH:	below 5.2	acid
	5.3 to 7.5	slightly acid to neutral
	above 7.5	basic
Base saturation:	below 35%	low
	36 to 60%	medium
	above 60%	high

supplied with organic matter, the remainder are low or very low in organic matter.

Organic matter content is here referred to in terms of soil classification and not in terms of soil areas. It would have been desirable to present information on the organic matter content of the major soil areas, but the measurements and computation involved, being undertaken in FAO for the evaluation of world soil resources for agricultural production, are not yet sufficiently complete.

The table shows, always in approximate terms, the percentage of base saturation of the surface horizon of the major soils where organic matter is mostly concentrated. This is considered to be a very important criteria in relation to soil fertility and production. This is particularly important when considering the potentiality of project areas in the developing countries. In fact, soils with low saturation are often « problem soils » in agricultural development. Soils with high saturation are, in the absence of limiting factors, such as salinity and shallowness, usually the best soils of the tropical and subtropical regions.

DISCUSSION

Chairman: S. A. WAKSMAN

HERNANDO

I understood in your statement that you foretold that the organic matter does not produce good results when it is applied to the soil if the sodium and calcium ratio in the exchange capacity is high. Is this exact?

BRAMAO

What I meant was that for a high organic matter content a wide sodium calcium ratio is less harmful on the structure of the soil than for a low organic matter content.

HERNANDO

Because I heard also in relation with that last month in Arizona they got some problems when they tried to apply organic matter to soil citrus growing. They observe some deficiencies in the trees when they apply organic matter, and that is in some respect similar to what you were saying.

BRAMAO

I did not hear your question very well. When you say that in the case of citrus...

HERNANDO

In Arizona in the United States, in one experimental station in Tempe, they told me that they have some problems when they apply organic matter to the soil. Still the soil is not high in organic matter; it develops deficiencies in the trees, but this looks very surprising. Is it something similar to what you told us in your paper, and also I ask you if you have some explanatory information for that?

BRAMAO

I think that of course to answer your question one needs to know the kind of soils, the presence or absence of salinity, and also the kind of organic matter applied.

HERNANDO

Well, the soils also are in this case high in calcium and in your paper the soil is high in sodium, is it not? In this case it is the contrary. But the result is the same. Maybe there is not a clear explanation for that, hut I am interested to know if you or somebody else here can give some ideas about the possibilities of explaining this result.

BRAMAO

It seems that in soils high in calcium, citrus trees frequently develop iron deficiencies.

HERNANDO

Yes, they get the iron deficiencies but when organic matter is applied, not before. If no organic matter is applied, there should not be iron deficiency. Is that not surprising?

WAKSMAN

I would like to ask Prof. BRAMAO what he meant by bad manure.

BRAMAO

This is a very bad expression. I do realize it. I did not like to put it but that is how it was in the Author's paper.

SWABY

Prof. BRAMAO, I noticed that your aim is ultimately, I presume, to produce a world map showing the distribution of organic matter in the major soils of the world. The Russians have been doing this sort of work also. Whether there is any integration between your team and the Russians, I don't know, but some of this work is going to be discussed at Adelaide and I have had a preview of some of their papers and I would think that for a continent like my own, Australia, they must have done some very wild guessing as to contents of organic matter because we ourselves do not even know. That is because no really good analysis has been done, and I imagine that in your own classification you must have had some guessing to do also. How do you make these assessments? I would like to know something about the techniques you use.

BRAMAO

First I would like to answer your first question. We are not preparing the USSR part of the soil map of the world. Prof. KOVDA, who is not here today but was supposed to be, Academician Gerasimov and Prof. LOBOVA, make part of the Advisory Panel for the Soil Map of the World and are responsible for the Soviet contribution. There is an integration at the level of establishment of the common legend and agreement on the definition of soil units. This was difficult. It was, in 1966, in Moscow, during the 5th Advisory Panel meeting of the Soil Map of the World that an agreement was reached. Dr. HALLSWORTH and his group at Adelaide are preparing a 1/5,000,000 soil map of Australia integrated in the soil map of the world, using the international legend. The World Soil Resources Office of FAO, in cooperation with specialists from the countries concerned, is preparing the Soil Maps of South and Central America, Europe and Africa. The North America map (Canada, the United States and Mexico) is being put together in the U.S. Soil Conservation Service. The Canadian part was done under Dr. LEHEAY and ELRICH. After the completion of the map it will be possible to see the distribution of a soil on a world wide basis. The first thing one learns is that a soil can occur in different climates, as far as crop production is concerned. So we found that the Vertisols occur in several continents under some eight or nine major crop climatic conditions.

NORMAN

I think that perhaps in your last remark you went far in answering the question I was going to ask. It has always troubled me when we talk about making a Soil Map of the World, what we are really mapping. Are we trying to map the undeveloped soils of the world or are we trying to map soils of the world as we think they were before they were subjected to intensive agriculture? I realize that in some parts of the world there is no distinction between these two groups but when I think of the soils of Britain, for example, that have been cultivated for many hundreds of years, or the soils of Pennsylvania that surely are very different now from what they were as virgin soils, I wonder what we really are mapping.

BRAMAO

I think we are trying to show the soils as they are rather than as they were. I think that in large areas of the world, soils are not very much disturbed. But in other parts, in the highly developed areas, of course they have changed much with agriculture.

TURNOVER OF NITROGEN IN SOIL ORGANIC MATTER

F. E. BROADBENT

Department of Soils and Plant Nutrition - University of California
Davis, Calif. - U.S.A.

It has been known for many years that a condition of dynamic equilibrium exists between inorganic and organic nitrogen in soils. The availability of soil nitrogen to microorganisms and plant roots is largely controlled by the relative magnitude of the two opposing processes involved in this equilibrium, immobilization on the one hand and mineralization on the other. As used here, the term immobilization refers to any process which contributes to decreased availability of nitrogen, including fixation of ammonium ions within crystal lattice of certain types of clay minerals, assimilation by microorganisms and conversion to organic forms, the reaction between ammonia and organic matter which results in its being fixed in nonexchangeable form, and nitrosation reactions involving nitrites. Mineralization applies to the breakdown of organic forms of nitrogen and liberation of ammonia, largely through the activities of microorganisms. Although these two opposing processes are going on constantly in soils so long as conditions are favourable for biological activity, turnover rates are not necessarily high. JANSSON [6], for example, has postulated the existence of a large pool of passive organic nitrogen which contributes very little to the supply of inorganic nitrogen available to crops. Scarsbrook [14], who has recently reviewed the subject, states that the annual release of available nitrogen by soil organic matter is in the range of 2 to 4% per year. In view of Simonson's [15] reports on average age of organic matter of some surface soils in the midwestern United States ranging from 210-440 years, it is evident that the turnover in nitrogen may involve a matter of decades or centuries. In this paper, no attempt has been made to provide a comprehensive review of the subject of nitrogen turnover in soils. It is a discussion of recent experimental work involving use of the stable tracer N^{15} to provide information on: 1) factors affecting amount and rate of nitrogen immobilized, 2) the chemical nature of immobilized nitrogen, 3) assessments of availability to growing plants of previously immobilized nitrogen, and 4) the mathematical description of observed nitrogen mineralization as a possible predictive tool.

Effect of soil factors on nitrogen immobilization

Nonbiological mechanisms

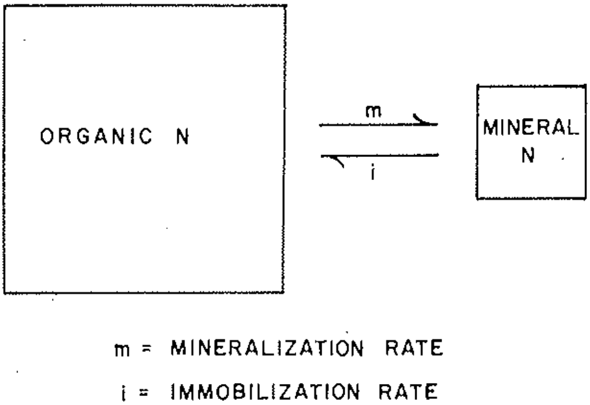

Fig. 1 — Model illustrating interchange between organic and inorganic N in soil.

Using Figure 1 as a basis of discussion, it may be noted that m or mineralization rate is a measure of the speed of the forward reaction whereby organic nitrogen is converted to ammonium and that i or immobilization rate measures the speed of the reverse reaction in which inorganic N is incorporated into the organic fraction. Fixation of ammonium by clay minerals in a sense may be considered as an irreversible component of the immobilization reaction and it does influence the equilibrium between organic and inorganic N. This irreversibility is illustrated in Figure 2 which shows the results of an experiment in which tagged ammonium sulfate was applied to a soil containing a small quantity of vermiculite. Exchangeable ammonium and clay fixed ammonium were determined

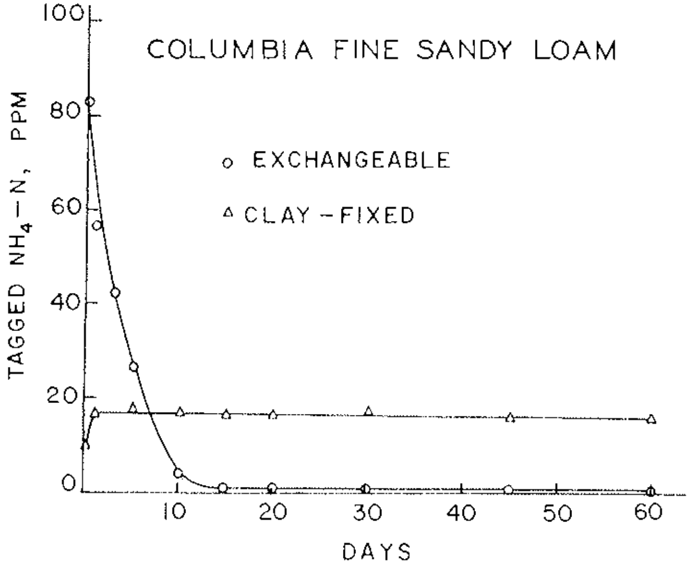

FIG. 2 — Exchangeable and clay-fixed ammonium derived from tagged $(NH_4)_2SO_4$ added to Columbia fine sandy loam.

at intervals over a period of two months. It will be observed that whereas the exchangeable ammonium dropped nearly to zero within about 15 days, the clay fixed ammonium reached a maximum within a few hours after application of ammonium sulfate and remained essentially unchanged thereafter. This indicates that clay-fixed ammonium is outside the biological realm for all practical purposes.

A second nonbiological mechanism of immobilization involves the reaction between ammonia and soil organic matter. This reaction has been known for many years and has been studied intensively by MATTSON and his associates [10, 11] and is the subject of a recent review by MORTLAND and WOLCOTT [12]. Table 1 shows the relative quantities of ammonia fixed by clay and organic fractions in four soils of widely varying properties after treatment with aqueous ammonia. In each case the organic fraction fixed a substantially larger quantity than did the clay. Very little is known about the rate of turnover of nitrogen immobilized in this fashion. Ammonium fixed by soil organic matter can be partially extracted from soils by a variety of extractants [4] but the plant availability appears to be very low, as shown by BURGE and BROADBENT [5].

TABLE 1 — *Ammonia fixation in four soils treated with* 1 *N* NH_4OH.

Kind of soil	Ammonia fixation, m.e./100g Clay fraction	 Organic fraction
Allophanic	0.0	5.65
Kaolinitic	0.11	10.6
Vermiculitic	1.37	2.19
Organic	0.21	28.0

BIOLOGICAL IMMOBILIZATION

Under conditions favoring biological immobilization, there is an initial period of very rapid decrease in the level of inorganic N which reaches a minimum within two weeks or less, followed by a period of net mineralization of nitrogen after the needs of the soil population are met. In terms of net change, complete turnover of immobilized nitrogen may occur within a few weeks. However, if one labels the added inorganic nitrogen and examines the organic fraction for its presence, it is found that although net turnover may occur, the actual nitrogen immobilized is quite stable. Moreover, the shape of the curve can be altered very drastically by a number of soil factors as will be shown below.

INFLUENCE OF TEMPERATURE ON IMMOBILIZATION RATE AND AMOUNT

The influence of temperature on total quantity of inorganic nitrogen immobilized and on the length of time elapsed before the turning point at which immobilization rate becomes smaller than mineralization rate are shown in Figure 3. This figure shows changes in total inorganic nitrogen and tagged inorganic nitrogen in Altamont clay loam amended with 1% straw after receiving an addition of 100 ppm N as tagged ammonium sulfate. Three observations are pertinent. 1) The total quantity of inorganic N eventually immobilized is not greatly affected by temperature, 2) the rate of immobilization is markedly temperature dependent, and 3) the mineralization of tagged inorganic N is much slower than that of total inorganic N indicating that the bulk of the mineralized N is derived from soil sources.

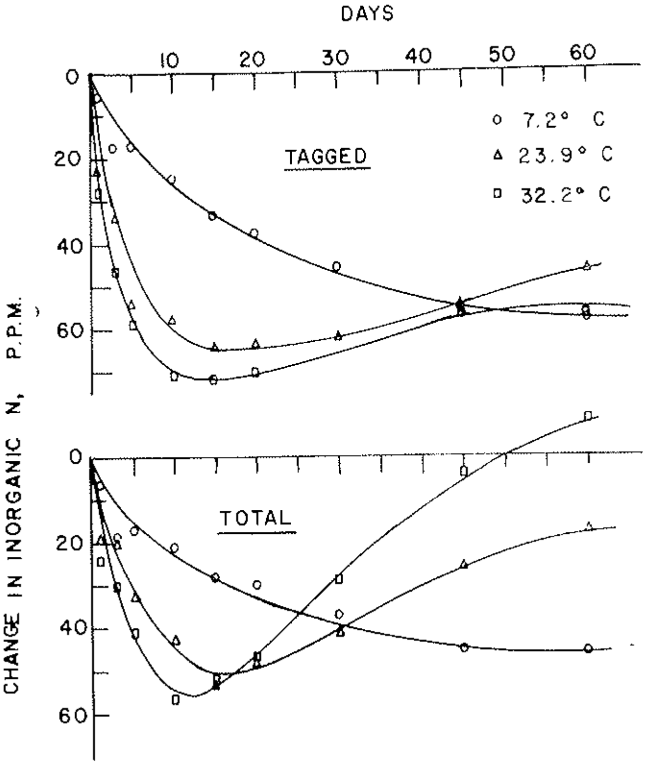

Fig. 3 — Influence of temperature on changes in total and tagged inorganic N in Altamont clay loam.

EFFECT OF SOURCE OF NITROGEN

Jansson et al. [7] has demonstrated the preference of microorganisms for ammonium nitrogen in the decomposition of plant residues. In soils the situation is complicated by the fact that an ammonium source cannot be compared independently with nitrate under normal conditions owing to rapid nitrification of ammonium-N. Moreover, disappearance of inorganic nitrogen cannot be used as a reliable estimate of immobilization in soils capable of fixing ammonium in significant quantities. However, immobilization can be measured by using tagged inorganic N and by analyzing the organic fraction for the tracer N. A comparison based on this technique is shown in Figure 4. Three soils were amended with 1% barley straw, after which 100 ppm N was applied either as ammonium sulfate or as calcium nitrate. Although the ammonium was rapidly nitrified, some exchangeable ammonium was present in all soils for at least 10 days. The data of the figure emphasize three points with respect to the differences between ammonium and nitrate sources of the N. First, ammonium sources are assimilated much more rapidly; the greater immobilization rate is evidenced by the steeper slope of the curve in the first few days of incubation. Second, the total quantity of nitrogen immobilized is substantially higher with an ammonium source. Third, there is some evidence that turnover of organic nitrogen, once immobilized, is greater with the ammonium source than with nitrate, since the ammonium curves taper off toward the end of the incubation period whereas those with nitrate do not.

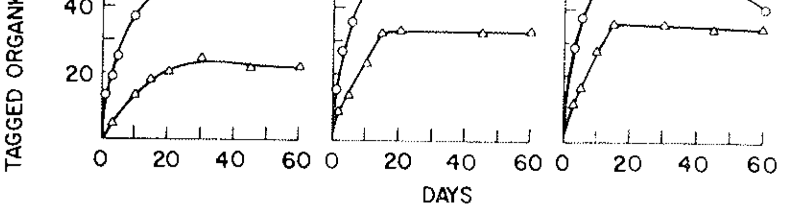

FIG. 4 — Immobilized nitrogen in three soils amended with 1% barley straw.

The influence of the nature of the inorganic source of nitrogen on immobilization is dependent on the pH of the soil, as illustrated in Figure 5. The data of this figure were obtained from samples of Montezuma clay adjusted to initial pH values ranging from 4.9 to 8.4. Nitrogen immobilized was measured by following the incorporation of tagged ammonium or nitrate nitrogen into the soil organic fraction. Some of the samples received a straw amendment and others did not. It is clear from the figure that ammonium nitrogen was utilized more extensively as the pH increased, whereas the reverse was true with nitrate. This behavior may probably be attributed to

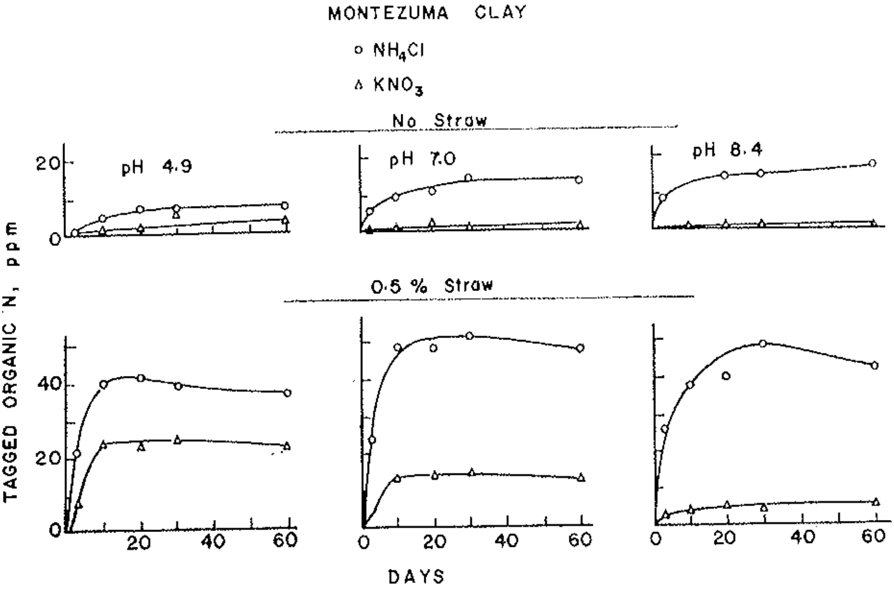

FIG. 5 — Nitrogen immobilized in Montezuma clay in relation to inorganic nitrogen source and initial pH.

the physiological acidity or alkalinity of these respective sources. Even in the absence of straw, the influence of pH was noticeable, particularly in the case of the ammonium source. It may be postulated that if the pH had been raised still higher, no nitrate may have been assimilated at all and that if the pH were sufficiently low ammonium and nitrate would be used in equivalent amounts.

MEASUREMENT OF MINERALIZATION AND IMMOBILIZATION RATES

Where two opposing processes are proceeding simultaneously as in the case of mineralization and immobilization of soil nitrogen, it is of interest to consider actual turnover rates as well as net changes of inorganic and organic nitrogen. The difference between actual immobilization and net immobilization is brought out in Table 2, employing data from experiments in which actual immobilization was measured by incorporation of tagged nitrogen into the soil organic fraction and net immobilization calculated from changes in level of inorganic N. Actual immobilization was in general substantially greater than net immobilization.

In tracer systems measurement of mineralization and immobilization rates can be made by using the equations of KIRKHAM and BARTHOLOMEW [9] provided the basic assumptions used in deriving their equations are valid for the system in question. Their equations are derived from the differential equations

$$\frac{dx}{dt} = m - i$$

$$\text{and } \frac{dy}{dt} = \left(\frac{b-y}{a-x}\right) m - \frac{y}{x} i$$

where x = total inorganic N
t = time
m = mineralization rate
i = immobilization rate
y = tagged inorganic N
a = total N in system
b = total tagged N.

By assuming that mineralization and immobilization rates are constant, they obtained particular solutions of these equations as follows:

$$m = \frac{x - x_0}{t} \cdot \frac{\log_e \left[\left(\frac{y}{b} - \frac{x}{a} \right) \Big/ \left(\frac{x y_0}{b x_0} - \frac{x}{a} \right) \right]}{\log_e \left(\frac{x_0}{x} \cdot \frac{a - x}{a - x_0} \right)}$$

$$i = m - \left(\frac{x - x_0}{t} \right).$$

A test of the validity of these assumptions is given by plotting x or total inorganic N as a function of time, which should give a straight line. A plot of this kind for Columbia fine sandy loam receiving barley straw in the presence of tagged calcium nitrate (Figure 6) shows that the curve may be divided into two straight line segments. Calculated values for mineralization and immobilization rates are shown on the chart. During the initial period of rapid decrease of nitrate nitrogen, immobilization rate is much greater than mineralization rate, whereas after about 10 days mineralization rate increases and immobilization rate becomes almost negligible. Similar data shown in Figure 7 in which Altamont clay loam was incubated at 7.2°C. Immobilization rate exceeded mineralization rate during the entire two month period.

TABLE 2 — *Comparison of net and total immobilization in 3 soils receiving 1% straw and 100 ppm tagged N as* $(NH_4)_2SO_4$.

Temp.	Net N immobilized, ppm	Tagged N immobilized, ppm
	Aiken clay loam	
7.5°	28	43
24.5°	35	47
32.2°	31	46
	Altamont	
7.5°	46	48
24.5°	53	54
32.2°	52	60
43.3°	25	58
	Columbia f.s.l.	
7.5°	39	62
24.5°	43	71
32.2°	48	64
43.3°	23	67

In order for a growing crop to receive a continual supply of nitrogen during its period of growth, it is necessary that the mineralization rate exceed the immobilization rate and this is the usual situation in nature. Even where soil conditions are made favorable for immobilization, as in several of the experiments cited, the period when $i>m$ is quite short. In the presence of plant roots which compete with soil microorganisms for available N, it is probably that the immobilization process is at least partially « short-circuited », with avail-

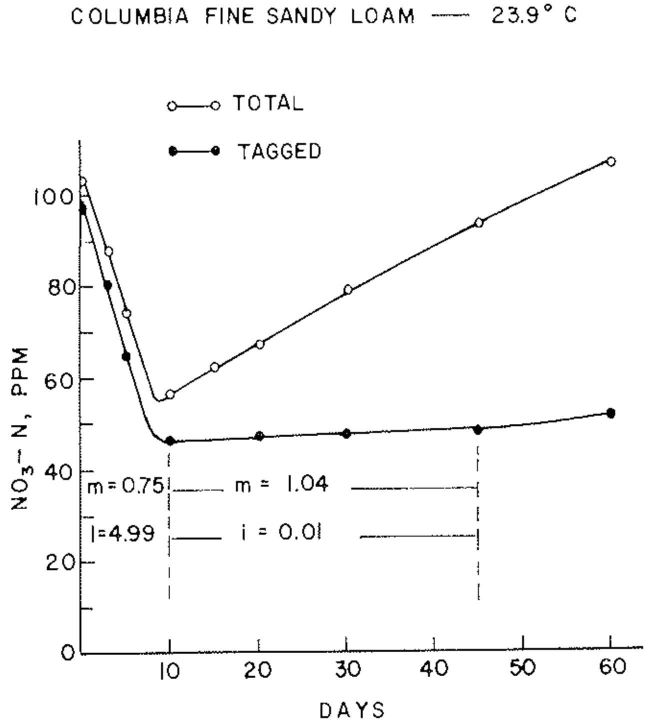

FIG. 6 — Nitrogen mineralization and immobilization rates in Columbia fine sandy loam at 23.9°C.

able nitrogen being assimilated as rapidly as it is produced. Actual measurement of immobilization and mineralization rates in the presence of growing plants has not yet been achieved.

CHEMICAL NATURE OF IMMOBILIZED NITROGEN

It is logical to assume that the incorporation of inorganic nitrogen into the soil organic fraction involves synthesis of amino acids by microorganisms and the subsequent conversion

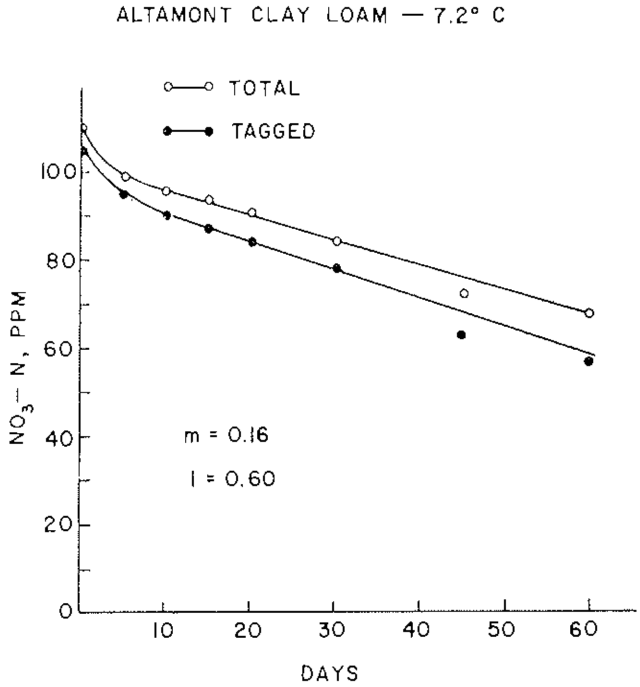

FIG. 7 — Nitrogen mineralization and immobilization rates in Altamont clay loam at 7.2°C.

of these to protein. Actual analysis of hydrolyzates of soil organic matter confirm the fact that a substantial part of immobilized nitrogen can indeed be found in the form of amino acids. STEWART et al. [16], for example, found that changes in the nondistillate acid soluble nitrogen fraction of soil hydrolyzates (largely amino acid N) was closely related to inverse changes in inorganic N of the soil and underwent fairly rapid turnover in their experiments.

TABLE 3 — *N in fractions of hydrolyzates of Columbia fine sandy loam amended with 2% straw an dfertilized with* 100 *ppm N as tagged calcium nitrate.*

	Total	Tagged	Total	Tagged
Days incubation	44	44	498	498
NH_4-N, %	30.7	16.8	30.0	17.9
Hexoseamine-N, % . . .	3.3	4.1	3.7	5.9
Amino acid-N, % . . .	42.0	52.9	38.5	49.8
Other hydrolyzable N, %	1.3	19.1	6.4	18.7
Non-hydrolyzable-N, % .	22.7	7.0	21.4	7.7

Table 3 shows the distribution of tagged organic nitrogen among four fractions in a soil which was cropped continuously following an initial application of tagged inorganic nitrogen fertilizer. In spite of 454 days difference in the time of biological activity, there was relatively little change in the distribution of tagged nitrogen among these fractions. The tracer N fractions, representing recently immobilized nitrogen, show less ammonia and non-hydrolyzable-N and more amino acid N than the bulk of the soil organic matter. In addition the soil hydrolyzates contain a significant amount of unidentified tagged N, whereas this fraction is a much smaller proportion of the total N. The data suggest that some amino acid N is gradually converted to other forms, possibly of greater resistance to biological attack.

Since immobilized nitrogen appears to become progressively less available as a function of time [3] the possibility exists that immobilized nitrogen is incorporated into organic substances of increasing molecular weight. Some evidence of this is provided in Figure 8 which shows fractions obtained by passing a humic acid preparation from a soil incubated three different

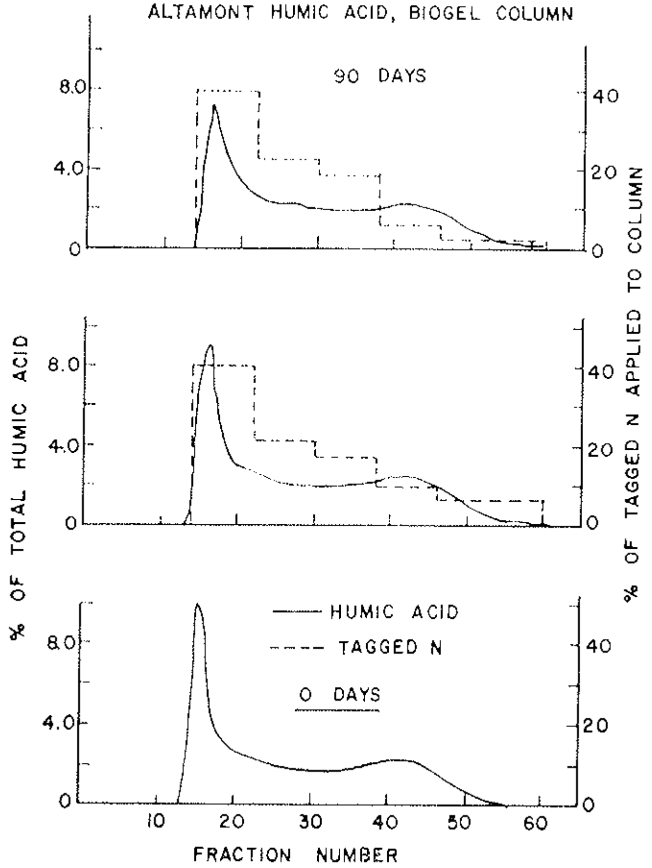

FIG. 8 — Elution curves of N-tagged humic acid passed through a biogel column.

time periods through a Biogel column. In gel filtration, since the high molecular weight compounds are excluded from the gel matrix, these will appear first in the effluent. Hence, the peak at the left hand side corresponds to the high molecular weight material. There is some suggestion in these data that the proportion of the tagged nitrogen in the higher molecular weight material is increasing as a function of time.

. . .

PLANT RECOVERY OF IMMOBILIZED NITROGEN

In relation to practical agriculture, two important questions are: 1) how long is immobilized nitrogen tied up before being mineralized? and 2) how efficiently is immobilized nitrogen recovered by crops? Although the bulk of soil nitrogen is commonly regarded as having low availability, one often reads statements to the effect that nitrogen immobilized in the decomposition of mature plant residues is tied up only temporarily and may subsequently be made available to crops. Actual tests of this view employing tagged fertilizer indicate that it is somewhat in error. For example, Figure 9 shows the uptake of previously immobilized nitrogen to a series of crops over a period of 594 days. In this experiment Montezuma clay was planted to sudan grass after treatments involving straw and tagged ammonium sulfate in various combinations and cropped until a total of 8 cuttings were harvested. After the first cutting, all treatments showed evidence of nitrogen deficiency, indicating that all crops after the first one were dependent entirely on mineralization of nitrogen from organic sources. It is apparent that very little of the tagged fertilizer N was utilized by the sudan grass after the second cutting, indicating that it was mineralized at a very slow rate.

Similar information is given in Table 4 which shows the residual value of nitrogen immobilized in Sacramento clay in rice culture. Tagged fertilizer N was applied before planting rice, and after the crop of rice was harvested more than half the initial tagged fertilizer was still present in the soil organic fraction. The following crop of sudan grass was able to utilize only a very small proportion of the immobilized nitrogen.

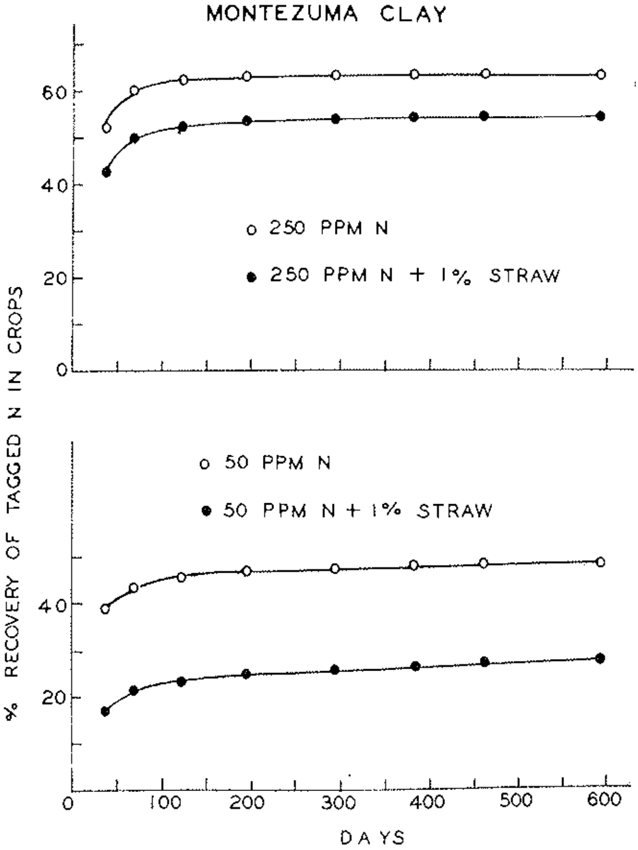

FIG. 9 — Plant uptake of immobilized nitrogen by 8 cuttings of sudan grass grown on Montezuma clay.

TABLE 4 — *Residual fertilizer N in soil after rice harvest and uptake of residual N by sudan grass following rice fertilized with* 120 *mg N as* $(NH_4)_2SO_4$.

Placement	Residual fert. N, %	Fert. N in sudan grass, %
Broadcast	57.7	0.8
Banded	52.6	1.2
Top-dressed	57.7	1.2
Sanded + top-dressed . . .	50.2	0.6
Top-dressed + top-dressed .	49.0	0.9

EQUATIONS FOR NITROGEN MINERALIZATION

In view of the very slow release of immobilized nitrogen in cropping experiments of fairly long duration, attempts were made to describe in mathematical terms the rate of release of this nitrogen as a possible means of predicting turnover rates. At first, it seemed reasonable to assume as did SALTER and GREEN [13] that the rate of nitrogen release was proportional to the quantity of immobilized nitrogen present in the soil at a particular time. That is, $\frac{dN}{dt} = -kN$ where N = organic N in soil at time t, and k is a constant. It was found, however, that the data of our cropping experiments did not fit this equation. Neither did JENNY's [8] modification of this equation to account for constant nitrogen input fit the data well.

Subsequent attempts, at curve fitting showed that the release of both tagged and untagged nitrogen from the soil organic fraction could be described reasonably well for periods up to two years by an expression of the form $N_c = At^m$, where N_c = crop uptake of N, t = time, and A and m are constants. Equations of this form had previously been found to describe carbon losses in organic matter decomposition in soils [2]. Figure 10 shows curves and corresponding equations for the release of previously immobilized nitrogen in two soils receiving an application of tagged fertilizer N but no organic amendment. Curves are obtained from the calculated equation

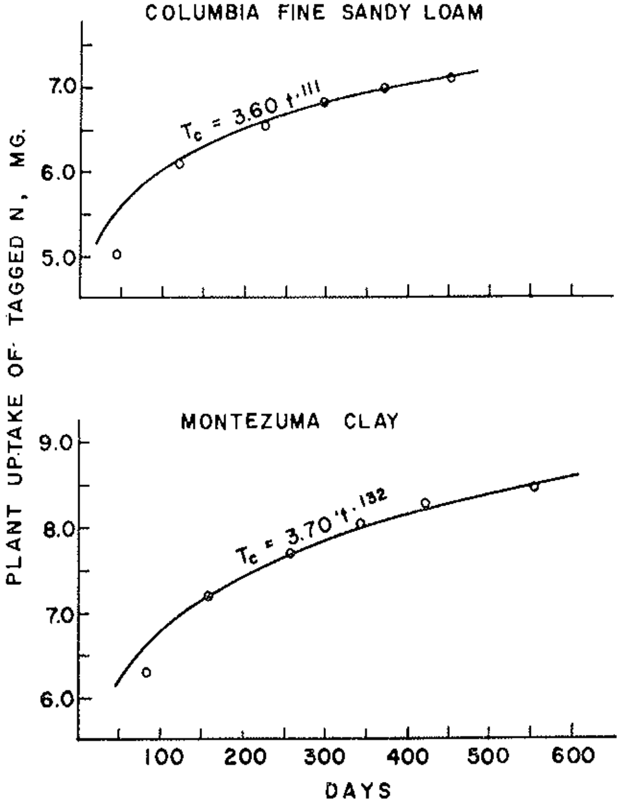

FIG. 10 — Mineralization curves for organic N in two soils receiving an application of N-tagged fertilizer.

and the points shown on the figures are actual experimental data. In the Columbia fine sandy loam 19.5% of the fertilizer N was mineralized in one year, and the corresponding value for Montezuma clay is 17.0%.

The influence of fertilizer nitrogen on the release of soil nitrogen is illustrated by Figure 11, which shows mineralization curves for Montezuma clay untreated and at two levels of fertilizer application. The enhanced rate of release induced by fertilizer application is only of temporary duration, however. It can be calculated that the rate of mineralization of soil N at the 75 mg. N fertilizer level would become equal to the check value in 139 days and in 231 days at the 275 mg. level. Total plant uptake of soil N in one year varied from 3.7 to 5.5% of the total present.

If it is assumed that the mineralization pattern of the first year is repeated in each succeeding year (which substantially overestimates mineralization rates for the second year in our experiments) then turnover times for fertilizer N can be calculated at more than 5-6 years, and soil N turnover times are at least 20-30 years. Extrapolation of the mathematical functions much beyond the experimental data is hazardous, but it is interesting to note that the same type of equation can be applied reasonably well to experiments of much longer duration. For example, the data for soil nitrogen in the 60-year continuous corn plots reported by WOODRUFF [17] fit the equation $N = 3400 - 716t^{.249}$ at least as well as does the equation $N = 3400e^{-.055t} + 1333\ (1 - e^{-.055t})$ based on the constants calculated from WOODRUFF's data by BARTHOLOMEW and KIRKHAM [1]. A comparison of calculated and observed values is given in Table 5.

The rate of turnover, $\frac{dN}{dt}$ at 60 years is 8.2 lbs/acre/yr by equation A and 4.2 by equation B. Regardless of which is the

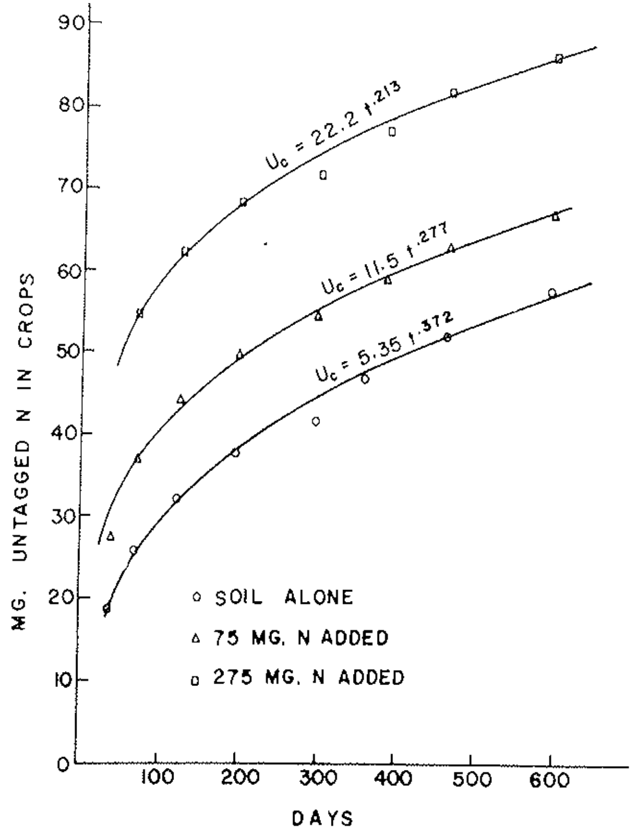

FIG. 11 — Curves describing mineralization of soil N in Montezuma clay as affected by fertilizer application.

more accurate estimate, the data serve to emphasize the fact that the nitrogen cycle in soil turns very slowly. Even recently immobilized N becomes stabilized within a short period of time.

TABLE 5 — *A comparison of soil nitrogen in continuous corn plots of* SANBORN *field with calculated value according to equations (A),* $N = 3400 - 716t^{249}$ *and (B),* $N = 3400e^{-.055t} + 1333\,(1\text{-}e^{-.055t})$.

years	measured N, lbs/acre	Calculated N, lbs/acre	
		A	B
0	3400	3400	3400
27	1800	1772	1802
40	1600	1607	1562
50	1500	1503	1466
60	1410	1417	1409

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[3] *Broadbent* - pag. 24

DISCUSSION

Chairman: S. A. WAKSMAN

WAKSMAN

I would like to ask the first question. What have you meant by the word humic acid? How did you measure it?

BROADBENT

The molecular weight sieving procedure involved a humic acid separate of organic matter. This technique is not applicable to insoluble organic matter and the humic acid to which Prof. WAKSMAN has referred was extracted by the customary alkali extraction, acid precipitation technique, in this case in a nitrogen atmosphere to prevent autoxidation.

WAKSMAN

You had such excellent data on amino acids which were easily understood. I became a little confused when you introduced the humic acid concept.

BROADBENT

I am sorry I did not clarify that point.

WAKSMAN

Any further questions?

DHAR

Please tell me whether in these nitrogen transformations there is loss of nitrogen; usually there is loss of nitrogen as gas in these experiments.

BROADBENT

In all of these tracer experiments we come up with a balance sheet for all of the tracer nitrogen as complete as we are able to obtain. We did not make direct determinations of gaseous losses of nitrogen from the soil but in almost every case there were deficits in the total nitrogen varying from 1 or 2% in the case of the long-term cropping experiments with straw added to perhaps as much as 30 to 35% in some other cases.

SWABY

Prof. BROADBENT I should first like to make a comment and then ask a question. It seems to me that the different behaviour of your tagged ammonia in aerobic soils and in anaerobic soils suggests that the ammonia is falling into a sink into which it disappears and becomes immobilised and the difference between the sink in the aerobic conditions and the anaerobic conditions suggest to me that you are getting oxygen containing free radicals formed under aerobic conditions, which do not occur in large amounts under anaerobic conditions. Now of course, most people will jump to the conclusion that these are due to the formation of semi-quinones and quinones from the phenolic constituents in the humus. I am not sure, however, if we have not over-emphasised this sort of free radicals, and I am wondering if you have thought about other free radicals that are known, such as for instance in the case of paraffinic chains you can get peroxides formed. Now I do not know whether they can cling on to ammonia so avidly as the humus does in your experiments. The other ones that come to mind though are derived from alcohols which can very easily be oxidised to aldehydes and ketones and these are known also to link on to ammonia, and indeed the Mailliard browning products of the food industry may be formed even under acidic conditions. These products are extremely resistant to attack and it is extremely hard to recover ammonia from them as it is from some of the humus polyphenols. Would you like to comment on this?

BROADBENT

In these experiments we have been talking about, we have not attempted the kind of fractionation that would answer the questions that Dr. SWABY has asked. I might comment that in other investigations we have looked at the aldehyde ammonia thing and came to the conclusion that this is of relatively little importance in soil organic matter. I would not state that as an established fact, this was our conclusion and I am very much interested in your suggestions of other possibilities but I am not in a position to really say whether they are of importance in these experiments.

CHAMINADE

Monsieur le Président, je voudrais poser la question suivante: dans l'intervention de l'argile dans la fixation de l'azote sous différentes formes, plusieurs mécanismes peuvent intervenir: il y a la fixation des ions ammonium sous forme échangeable et sous forme non échangeable, et il y a également des possibilités de fixation de produits intermédiaires entre l'azote organique originel et l'azote minéral: fixation possible en particulier des acides aminés. Dans quelle mesure cette fixation par l'argile de produits non encore minéralisés va-t-elle agir sur les possibilités d'évolution microbienne de ce produit?

BROADBENT

May I have a translation of this question?

I am not in a position to answer your question in detail. I will just say that the clay-fixed ammonium which was reported in our experiments was done by the procedure of DHARIVAL and STEVENSON and that it is recognised that in this procedure you may get trapped within the crystal lattice of the clays some organic components which may be involved in the fixation. We made no attempt at all to evaluate fixation by non-biological means. What we call immobilised nitrogen here is the total nitrogen in the soil corrected for the quantity of clay-fixed ammonium.

WAKSMAN

I should like to suggest that we postpone a further discussion of this paper because it is time to go to lunch. In the afternoon we will have more time.

The session is closed.

The session is resumed in the afternoon.

THE USE OF ISOTOPES IN SOIL ORGANIC MATTER STUDIES: A SURVEY

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More than twenty-five years have elapsed since the first attempts to use isotopes in following carbon and nitrogen transformations in soils. In many fields of biochemistry, radioisotopes used as tracers or markers have permitted great advances to be made in the elucidation of metabolic pathways, the recognition of intermediates, and the structural chemistry of products. In the biochemical studies of soil, however, these techniques have not proved as successful owing to the complexity of the microbiological events that occur when plant residues are incorporated, either naturally in the soil-forming process or directly by cultural operations. Yet knowledge of these events has been advanced by the judicious use of isotopes, though the obdurate problem of the structure of the soil humic compounds remains largely unsolved.

The early work at Ames, Iowa, in 1942 and during the late forties used the stable isotopes of carbon and nitrogen, C^{13} and N^{15}, of which only very limited quantities were available then. Studies involving these stable isotopes were dependent upon mass spectrometric determination of the relative abundance of ions differing in mass but identical in charge. Procedures were tedious, particularly for nitrogen. Moreover, the degree of enrichment over the natural abundance was not great, which imposed limitations on the protocols of experiments. Although N^{15} sources of high enrichment are now available, the sample must still be large enough to yield the necessary volume of gas for measurement. The reliability and precision of mass spectrometry have been greatly improved, but the preparation of samples for analysis remains burdensome.

When C^{14} sources became available, C^{13} was replaced in organic matter studies by C^{14}, for which, owing to its very half-life, no calculations had to be made for decay rate, and for which the sample size for determination could be much smaller than with C^{13}. The investigator now has available a great diversity of organic compounds, either randomly or specifically tagged with C^{14}, some of which have been profitably used in simplified systems for studying soil transformations. However, as will be mentioned later, the stable isotope C^{13} has certain compensating advantages that may have been overlooked. There are no useful radioisotopes of nitrogen; all have an extremely short half-life.

Soil organic matter transformations involve elements other than C and N, such as sulphur and phosphorus, whose chemical changes can be followed by use of the radioisotopes P^{32} and S^{35}. Investigators using these isotopes have mostly been concerned with the uptake of inorganic forms from soils and have not seriously addressed themselves to the cycling of these elements in relation to the C and N status of the soil.

A limited amount of work has been done with tritium, H^3. Putative precursors of humic compounds have been labeled by exposure to gaseous tritium in the Wilzbach technique, but complications arising from side reactions and the necessity for subsequent purification have discouraged investigators from using this approach. Moreover, there is concern that tritiated compounds may exchange with hydrogen atoms on unlabeled compounds. The radioactivity of tritiated compounds can readily be measured by liquid scintillation count procedures at low levels.

Plant materials can be readily labeled with deuterium by supplying the growing plant with deuterated water. Since deuterium is a stable isotope, its determination requires mass spectrometry or infrared absorption or densitometric methods.

Basic to the use of isotopes in following soil organic matter transformations is the question of whether isotopic fractionation takes place either in the biological or physical systems involved. In the case of the carbon and nitrogen isotopes, the evidence is somewhat equivocal, but the fractionation that occurs, though in all probability real, is so small as to be of no significance in most situations. N^{15}, a normal coustituent of the atmosphere, is present in the nitrogenous compounds of biological origin at a level close to the atmospheric atom percentage (0.365% N^{15}). The deviations from this figure in natural nitrogen-containing materials, including soil samples from a variety of sources, and samples taken within the profile at different depths, are in the direction of an apparent enrichment of the N^{15} abundance to an extent of not more than two percent. Similarly, although there is some evidence of carbon fractionation in certain systems, it is not believed that in the great carbon cycle of nature this is detectable. The radiocarbon dating procedures are based on this assumption. However, changes in recent years in the specific activity of atmospheric carbon dioxide will complicate studies involving C^{14} distribution in undisturbed profiles receiving annual increments of plant residues.

In general, then, a prerequisite of carbon and nitrogen transformation experiments is that the amount of the tracer isotope added should be such that at all sampling periods, and in all fractions studied, the expected enrichment will be substantially above the normal, or the radioactivity substantially above background. This can usually be accomplished in laboratory or greenhouse experiments, because highly enriched sources of the stable C and N isotopes are available. It can also easily be accomplished if C^{14} is involved, though certain limitations relating to the evolution of $C^{14}O_2$ may arise. It cannot so easily be accomplished in field experiments in which N^{15}-enriched nitrogen fertilizers are applied, particularly if the rate of application of the fertilizer nitrogen is relatively low in relation to the total soil nitrogen, as may be the case in soils well supplied with organic matter.

Because the carbon and nitrogen cycles in soils are geared together by the biological processes involved in decomposition and synthesis, dual or multiple-tagging may provide data reinforcement in certain types of experiments. C^{14} and N^{15} combinations have been used, but there is an opportunity here for the use of C^{13} also, particularly if the experiments include growing plants on an isotopically tagged substrate.

Of the various options mentioned above, the majority of investigators using isotopes in the study of soil organic matter transformations have chosen to add N^{15}-enriched ammonium or nitrate to soils containing native organic matter or to soils in which plant materials or other energy sources have been incorporated. They have then snbsequently determined the redistribution of the N^{15} in the inorganic and organic nitrogen fractions. Such studies dominate the literature.

In studies in which the decomposition of plant residues is to be followed, with particular attention to the mineralization of the nitrogen of the protein and other nitrogenous constituents, or to the immobiliation of a supplementary source of inorganic nitrogen, it may be necessary to start with isotopically tagged plant tissues or plant constituents. The satisfactory preparation of this material may in fact be more demanding in time and effort than the experiment in which it is subsequently used. There are obvious limitations to what can be prepared practicably. One might wish to have pine needles or oak leaves to use in leaf litter decomposition studies, but their preparation in anything but small quantities is not feasible. One turns then to relatively rapid-growing annual plants. If the experiment requires only that the nitrogenous constituents be N^{15}-enriched, the plants may be grown on some inert medium to which nutrients are added. N^{15}-enriched nitrate can then be supplied, preferably throughout the whole growth period, so that the N^{15} will be randomly distributed throughout the nitrogenous constituents in all parts of the plants. If soil is used as the substrate, the N^{15} abundance will be less because of dilution by the soil nitrogen.

Variations of this procedure have been introduced by supplying the N^{15} source only for a certain period, or as the plants approach maturity. Although nitrogen so applied may initially move into the rapidly growing parts of the plant, it will in time become reasonably well distributed, because nitrogen is a dynamic constituent with continuous turnover. Although absolutely random isotope distribution is probably not essential in most decomposition or mineralization experiments, it can be assured by supplying the isotope continuously.

To obtain plant materials labeled with C^{14} or C^{13}, elaborate growth chambers in which the plants are exposed throughout their whole period of growth to an atmosphere containing some $C^{14}O_2$ or $C^{13}O_2$ are required. Several sophisticated installations of this type, which in effect provide full environment control, have been built. It is not necessary that the partial pressure of CO_2 remain constant, only its isotope enrichment. Because of species-specific radioactivity levels that cannot be exceeded without plant injury, it is impossible to obtain highly labeled mature tissues. With C^{13}, this difficulty of course does not arise, nor do safety precautions have to be taken to detect any leaks into the external atmosphere. Species having small seeds are to be preferred for these investigations, so that the seed carbon constitutes no significant fraction of the total carbon.

Earlier investigators did not regard random labeling as essential, and for some purposes perhaps it is not, but investigators now recognize that if exposure to the isotopically enriched CO_2 is limited to a brief period or only to the later stages of development, the structural constituents such as cellulose and lignin of the older parts of the plant will be of lower relative specific activity. The plant, therefore, will not be randomly labeled. It is, of course, easy to carry out simultaneous incorporation of N^{15} into plants grown in growth chambers, by supplying enriched ammonium or nitrate in the nutrient solution or root medium.

Some experiments may require the plant materials to be uniformly mixed with soil or sand. Grinding in a small mill may be necessary. If the tissues are radioactive, this operation is hazardous unless performed in a vented glove box. Alternatively, for some purposes, the plant material may be subjected to chemical fractionation procedures in order to separate some of the major constituents, such as readily soluble components, the hemicelluloses, cellulose, and lignin.

ORGANIC MATTER TRANSFORMATIONS IN SOILS

Carbon and nitrogen transformations in soils are highly complex. The chemistry of the 'native' humus of soils is not known with assurance. This humus is a heterogenous product which appears to arise from plant and animal residues extensively decomposed by microorganisms. Characteristically, it also contains synthetic components arising from the microbial tissues. Concurrently, there may be condensation reactions or polymerizations that result in the production of larger molecular weight compounds containing nitrogen. Both the carbon and nitrogen are relatively stable, though not wholly resistant to further microbial attack, as is indicated by slow liberation of CO_2 and inorganic nitrogen; the rate can be influenced only within narrow limits. The nitrogen of soil humus is stable and becomes mineralized only slowly; it has been spoken of as a « frugal custodian » of nitrogen.

If plant residues are introduced into soil, an enormous surge in microbial activity ensues. Inorganic nitrogen may be immobilized in the newly formed microbial cells or released as ammonia if the plant residues contain more than sufficient nitrogen to supply the needs of the population. A whole new set of processes, therefore, is superimposed on the formerly quiescent level. Juvenile humic material is added to the old. The stable nitrogen reserve in the humic residues is increased, and the rate of mineralization may be increased also.

By employing isotopes of C and N, it was hoped that it would be possible to identify the path of carbon or nitrogen from known carbon or nitrogen sources and so to separate certain of the processes which may proceed simultaneously. Although the nitrogen cycle, as usually depicted, seems simple, there are some entrances, exits, and loops that present perplexing complications and have made the interpretation of isotope data uncertain. If the addition of carbon or nitrogen sources to soil resulted only in the superimposition of new transformations and processes, it should be possible to follow these easily by selective tagging with isotopes. However, if the newly inaugurated reactions are in effect coupled to the old, with each having effects upon the other, then the interpretation of data becomes less sure. Thus far, the extent of coupling of these two levels of microbiological and chemical transformations has not been clearly established. A helpful analogy is provided by a large smoldering firebed to which additions of combustible material are made. If the combustible material is well distributed on and through the firebed, as would be the case if an inflammable liquid were applied, there would in effect be only a single reaction, one of great intensification of the combustion. If, however, the combustible material was a solid and was added at one or a few locations, there would be local conflagration of the new material with some intensification of the combustion of the immediately adjacent firebed. The degree of coupling of events in this case would depend on the relative masses and areas of contact.

In soils, the humic residues do not possess the structure of the tissues from which they were derived, but instead are distributed extensively but nonuniformly on and between the surfaces of the mineral particles. Microbial activity is dependent on the presence of a waterfilm, the spatial domain of soil organisms fluctuates with the moisture content. As these fluctuations occur, soluble products may be dispersed locally. Natural additions of plant residues in the form of roots and rootlets and the mixing or incorporation of surface residues by insect or animal activity result in grossly random, nonuniform, and discontinuous sites of microbiological activity, unquestionably involving also the contiguous humus residues and any soluble constituents, inorganic or organic, in the immediately surrounding waterfilm, but not influencing or necessarily being in phase with activities a little further removed from the available substrate. The discontinuity of the soil micro-habitats in other than swampy or waterlogged soils has been insufficiently recognized. The events that can be followed by measurement of the evolution of CO_2 or the appearance or disappearance of ammonium or nitrate ions are the sums of the activities in innumerable microdomains. One is brought to the conclusion that in an intensely nonuniform system, the analogy of the smouldering firebed to which combustible material is added at a few locations may best suggest the nature of this activity. This leads to the conclusion that insofar as the activities affecting carbon transformations are concerned, the degree of coupling of the events relating to the humus residues with the events induced by the addition of plant residues may not be great. However, insofar as the activities affecting nitrogen transformations are concerned, the coupling may be closer because mineralized nitrogen has mobility and nitrogen is a metabolic component of all organisms.

These postulations have been limited to the simplified case encountered in many laboratory experiments. The situation provided by greenhouse or field studies is much more complicated, in that mineralized nitrogen and other nutrients are withdrawn by the plant and residues in the form of roots and rootlets are added. These additional processes make it likely that a still closer coupling of events might take place, particularly in the cycling of nitrogen.

Several classes of experiments involving carbon and nitrogen transformations in soils are listed below:

A. One can start with the simple situation in which a soluble energy source, e.g., sugar, is added to a humus-free soil, together with enriched ammonium or nitrate. In this experiment, rapid immobilization of nitrogen occurs initially as microbial tissues is synthesized, but mineralization later sets in as the microbial residues are decomposed. The experiment will yield information on the turnover rate of the microbially immobilized nitrogen and the decomposition rate of the assimilated carbon. Such experiments can be of long duration or involve repeated additions of an available carbon source.

B. Alternatively, if the addition of sugar and ammonium or nitrate, both isotopically tagged, are made to a humus-rich soil, preincubated so that its microbiological activities are at a steady state, the extent of coupling of the activities will be apparent from the ratios of N^{15} to N^{14} and C^{13} or C^{14} to C^{12} in the mineralized nitrogen and evolved CO_2.

C. The experiments described above can be varied by adding soluble organic compounds believed to be precursors of humus, or insoluble but homogeneous carbon sources, such as hemicellulose, cellulose, or lignin, or known combinations of these sources, and by fractionating subsequently residues in the soil by procedures likely to be specific for certain compounds.

Studies of the A, B, and C types are not numerous in the literature. Perhaps they are regarded by investigators as being overly simplified. Nevertheless, experiments of the A and B types, showing differences between the C and N distribution, can, if they are conducted long enough, provide information on the longevity of the juvenile residues originating from microbial tissues and the similarity or dissimilarity of its behaviour to that of the stable native humus.

D. A large class of experiments involve the incorporation of unlabeled plant residues such as straw into soil, either low or high in native humus, to which N^{15}-enriched ammonium or nitrate is also added. The primary transformations followed in such situations are the immobilization of nitrogen, the loss of carbon, and the subsequent mineralization of the immobilized nitrogen, the latter sometimes being determined by cropping and recovery of N^{15} in the plant tissues.

E. This class of investigation involves the incorporation of plant residues isotopically tagged with N^{15} and C^{13} or C^{14}, particularly when the residues are high enough in nitrogen that mineralization occurs promptly. Alternatively, a supplementary source of unlabeled ammonium or nitrate may be provided. A variant of this experiment involves determining the effects of adding different amounts of plant residues or of nitrogen supplements on the release of carbon from the stable native humus. This variant has been conducted by a number of investigators to test the hypothesis that « priming » occurs, that is, an acceleration of the rate of decomposition of the native humus, when readily available plant material is added. From these experiments have come a diversity of conclusions that seem to depend on the amount of organic residues added and the sampling times selected.

F. The question of the recovery of fertilizer nitrogen in the crop can be approached by employing N^{15}-enriched fertilizer. This permits the determination of the respective contributions made by the soil nitrogen reserves and the added fertilizer, and indeed, the pursuit of this question through subsequent crops. The extent of field plot experimentation has not been great, partly because of the expense of the N^{15} source at a sufficiently high isotope excess, and partly because of the large variation found between replicate plots and samples. Pot experimentation can be well controlled but certain nitrogen losses may be experienced both in pots and field plots that can render the findings indefinite. Variants of the type F experiment arise in nutritional studies in which the issue is the relative value of a particular form of nitrogen as the nitrogen source for a particular crop plant. Commonly, these experiments have compared ammonium and nitrate sources with determination of the relative efficiency in yield enhancement per unit of fertilizer nitrogen.

Although somewhat outside the scope of this discussion, N^{15} can be used effectively to follow such other segments of the nitrogen cycle as the nitrification process, denitrification, ammonia fixation by inorganic soil colloids, microbial nitrogen fixation, and symbiotic nitrogen fixation in higher plants. However, it must be noted that with the exception of the last-named phenomenon, all the other processes named could occur in the experiments discussed above and could constitute perturbations or complications in interpretation. The construction of a strict materials balance in C and N studies in soils is not easily achieved.

AN ASSESSMENT

A review of the literature leads to the conclusion that the use of isotopes in the study of carbon and nitrogen transformations in soils have not resulted in any giant strides. The high expectations of earlier workers that isotope distribution data would permit clarification of the complex biochemical processes common to all soils in which plant residues are incorporated have not been realized. Even the most central problem of the chemical structure of soil humus remains obdurate. That is not to say, however, that no progress has been made. Much more is known of the turnover of nitrogen in the two processes of biological immobilization and mineralization, which indeed proceed simultaneously with the net balance to the organic or inorganic side depending upon the condition and supply of the carbonaceous energy source. It is further recognized that a portion, at least, of the biologically immobilized nitrogen becomes stabilized or rendered less available to mineralization that might reasonably be expected if the assumption is made that microbial nitrogen is primarily protein nitrogen. There is a high probability that the phosphorus transformations follow a similar pattern. Parallel isotopic N and P studies on the same samples might be informative, but do not seem to have been attempted.

Investigations in which a carbon isotope has been used are far less numerous than those involving N^{15}. The pattern of current studies in this general field can be deduced from an analysis of original papers published in the past five years. Of 50 papers I reviewed, 70% fell into that class described above as type F, namely, those directed towards problems of ammonium or nitrate utilization. The remainder were about equally divided between types B, C and types D, E. It does not appear, therefore, that the use of isotopic carbon in such work is presently receiving much attention.

Only a few experiments using both a carbon isotope and N^{15} have been conducted, yet it is probably in this class of experiment that the greatest potential lies, because the rate of evolution of CO_2 provides information about the level of microbial activity, and the sources of the carbon can be distinguished from the isotope ratio. This may ultimately become blurred, but some further clarification may be possible by making a second addition of plant residues tagged with a different carbon isotope or possibly even labeled with a hydrogen isotope, though OH groups in biological systems may be too mobile.

Probably most C and N isotope studies have not been carried on for long enough periods. Much information about N immobilization and the rapid decomposition of readily available plant constituents can be obtained in the first few weeks, but the experiments must be prolonged if the subsequent release rate of the immobilized nitrogen is to be followed and a materials balance constructed.

To be fully realistic, such experiments should perhaps be carried out in sizeable containers analogous to lysimeters, though protected from rainfall that would cause leaching losses. Other experiments might make use of plants to remove the mineralized nitrogen. The plants, however, complicate the experiment because the roots contribute to the organic material in the soil. One worker has ingeniously attempted to measure this contribution by carrying out the experiment in a growth chamber in which the chamber CO_2 was isotope-enriched.

There is no question but that the difficulty of preparing plant materials labeled uniformly with C^{13} or N^{14} is a deterrent to investigators. Moreover, the determination of the stable isotopes is more demanding and time consuming that measurements of radioactivity. Even so, in carefully designed experiments, planned with attention to the information that has been acquired in the past twenty-five years, there is surely potential for advancing our knowledge of the complex biological events involved in the carbon and nitrogen transformations in soils, and of the nature of those humic substances that so greatly influence soil fertility.

DISCUSSION

Chairman: H. Jenny

Waksman

This is a field with which I am very little familiar. Has it been established definitely that, let us say isotopic ammonia for the sake of argument, is oxidised by corresponding bacteria in exactly the same way as normal form of ammonia? Do the isotopes affect the activities of the micro-organisms in any way whatsoever?

Norman

I do not think I can answer that with absolute assurance. If there is a biological separation, that is, if the isotopic reactions proceed at a different rate, the difference is very small. The chief evidence that there may be some fractionation of nitrogen really lies in experiments that Prof. Bremner has done and I think we should invite him to comment on this. Certainly the nitrogen effect is very small. With carbon there is a small amount of evidence of fractionation, I believe with yeast and a low molecular weight organic compound, such as formic acid, but this is not to be expected with compounds of high molecular weight.

Bremner

Bacterial fractionation of the stable isotopes of hydrogen, carbon, and sulphur has been reported, so the possibility that biological processes in soils may lead to fractionation of ^{14}N and ^{15}N clearly cannot be ignored. But I share Prof. NORMAN's view that the use of ^{15}N for studies of nitrogen transformations in soils is not likely to be complicated significantly by microbial or chemical fractionation of nitrogen isotopes. There is variation in the abundance of ^{15}N in soils and in different forms of soil nitrogen, but the variation is small.

ALEXANDER

In the area of discrete monomers rather than indiscrete polymers, significant progress has been made. In the realm of the transformations of pesticides, in a number of instances the fate of the molecule has been traced or the data are very clear that we don't understand the fate of the molecule, e.g. where a certain amount of the parent compound is added, not all of the carbon is recovered as CO_2. Hence, we have either a clear picture of what happens or a clear picture where we don't know what happens. In this case, the use of ^{14}C labelled materials, particularly together with gas chromatography, has been very helpful.

NORMAN

I think I did less than justice to that field, but I was really addressing myself to the organic matter residue aspect of the question rather than utilization of added organic compounds.

HERNANDO

I heard that you were talking about the problem of two different reactions at the same time when you apply organic matter to the soil, but I think also there is a problem with the possibility of the exchange of the carbon or nitrogen with the other carbons or nitrogens in the same molecule, and maybe with that we have also difficulties to get a clear interpretation of the reactions in the soil.

NORMAN

Well, if this takes place to any extent, it certainly would make the results questionable — if there was trans-methylation, for example, from a synthesised compound to a pre-existing compound, this could confuse the issue, but we don't know very much about that kind of reaction in soil; we don't have much reason to believe that that kind of reaction is important, but it certainly is not ruled out.

SWABY

I am very interested in this idea that one of the things holding up work is the absence of double labelled plant materials. In fact we have through Dr. ROVIVA a biosynthesis chamber for doing just this, which costs Rockefeller quite a few thousand dollars. Unfortunately, we can still only produce gramme quantities of these materials and it would seem to me that you want a giant chamber such as Prof. ZELLER has in Vienna to do this really well. We have made a suggestion — because we cannot handle it in Australia — that IBP look into this matter, particularly concerning work in the decomposer cycle, and we have not had a response yet because usually if you cannot do it yourself you find it very difficult to get someone else to do it for you. But it does seem to me that it is a very well worth while point you have raised here, which is holding up a lot of our work.

NORMAN

There was some discussion along these lines at the meeting at Brunswick some two or three years ago in hope that through the International Atomic Energy Agency there would be a way fonnd to produce these materials, but I do not know what — if anything — came of that.

THE ROLE OF ORGANIC MATTER IN SOIL MANAGEMENT AND THE MAINTENANCE OF SOIL FERTILITY

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Soil organic matter affects most of the physical, chemical and biological processes in soils. These, in turn, influence the crops growing on these soils. This paper is concerned primarily with these effects.

The nature and magnitude of these influences varies widely with changes in each of the major factors in the environmental complex. We shall consider some of the more important of these relationships as they occur in the two broad climatic zones of greatest importance to agriculture - the temperate zones and the tropical zones.

Most of our experience and most of the scientific information we have accumulated in the past has been collected in the temperate zones. Let us start our discussion with organic matter relationships in the temperate zones.

One of the best criteria of the level of development of agriculture is the degree of understanding and control which the farmer is able to maintain over the environment in which his crops and animals grow. When examined historically, the

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role of organic matter in agriculture varies widely with the level of its development.

For our present purposes we need to recognize 6 stages in the development of agriculture:

1. The preparatory stage which is really pre-agriculture, even a pre-man stage in which primitive plants established themselves at the more favorable spots on the earth surface. They lived and died, leaving the spot in which they lived a little richer than it was before. This continued for many thousands of years. As a result, the original sterile mineral fragments became mixed and coated with these organic remains. This mixture was richer in carbon, nitrogen, and water than the original rock powder. It was a primitive soil. As this soil increased in depth and in organic matter content, plant growth increased like an autocatalytic reaction and in time the surface of the earth was covered with a carpet of green. So it must have been before man arrived.

2. The next stage starts with man. At first he was a food gatherer, consuming what best pleased his palate from Nature's offerings. At this stage, he exerted but little influence upon the natural cycles established long before he appeared on the scene.

3. As he became better acquainted with Nature's offerings he discovered some plants which he preferred above others. As the numbers of people with similar tastes increased the supply of the favorite food plants available to each person within a convenient walking distance probably decreased and someone must have been motivated to try to do something about it.

The solution arrived at was a very simple but very basic one. Someone may have noticed that his favorite food plant grew best when there was less competition from other plants.

Perhaps if he could reduce the influence of competing plants, he could grow more of his favorite food in a small area and not have to hunt over such a wide area. Thus the struggle with weeds was started and agriculture was born. Gradually, the system of shifting cultivation evolved. It seems to have evolved independently in tropical areas in many parts of the world, and what is even more remarkable, assumed much the same form in each. Forests were cleared, allowed to dry during the early part of the dry season, then burned. The ash accumulated by the wide and deep foraging root systems was returned to the top soil. The nitrogen and sulfur was largely volatilized and even some of that in the leaf litter was lost. The trunks of many of the larger trees were too « green » to burn readily so their charred remains, often distributed at random, were left behind as grim reminders of the once noble forest! As a reward for his strenuous labor of clearing the forest with crude hand tools the farmer harvested fair crops for a year or two. Then yields started to decline, weeds gained a foothold; and after 3 to 5 years the plot was usually abandoned, the second growth forest allowed to take over. It gradually crowded out the weeds and in 15-25 years, often depending upon the density of the population, it was cut down for the next cropping cycle.

Shifting cultivation was best suited to tropical regions. The rate of regrowth of the forest was probably too slow for it to persist for long in more northern climates. In these areas, the bare fallow enabled the farmer to exploit the declining stores of fertility to a lower and an apparently limiting value, probably approached asymptotically. I have often been impressed by the fact that the lower limit of yields of the food cereals commonly reported (except paddy rice) are very similar: 8-12 bushels per acre or 500-750 kg per hectare. Nature seems to provide enough nitrogen by some process to grow a crop of this size almost indefinitely.

4. The beneficial effects of legumes on the yield of cereal crops which followed them in rotation was observed by farmers before the beginning of the Christian era. Such rotations were not systematically followed and combined with the production of livestock until much later. The famous Norfolk rotation, which combined the use of legume forage crops with root crops and cereals provided more winter feed for livestock. This enabled farmers to increase the numbers of livestock carried over winter and to increase correspondingly the amount of manure available for application to the cropped land. This system is commonly credited for the remarkable increases in the yield of wheat in England of from 10 to 20 bushels per acre during the latter part of the 18th century. This is one of the few examples I have found of crop yields being doubled by improved farming practices in the period before the introduction of chemical fertilizers. When crop yields approach the limiting value mentioned above, the limiting factor is usually the amount of nitrogen available to the crop. The Norfolk rotation by the systematic use of legumes and animal manures must have doubled the amount of nitrogen available to the wheat crop. This is one of the best examples in the history of agriculture of the important role which organic matter can play when systematically used in generous amounts. As we see it now, there were two reasons for the beneficial effects obtained: 1) the leguminous forage crop — usually clover — added to the meagre store of nitrogen left in the soil by long periods of exploitive cropping and 2) by feeding a high proportion of the larger crops which resulted from the use of legumes to livestock, 60-80% of the nitrogen removed in the crops was returned to the land in the form of manure.

5. The next important advance was the introduction of chemical fertilizers about the middle of the 19th century. Many naturally occurring products, like guano were used much earlier. Perhaps the two most significant steps were the inven-

tion of super-phosphate by Sir John Lawes about 1840 and the development of the process for synthesizing ammonia from the inexhaustible, free supply of the air by FRITZ HABER early in the present century. These were epoch making advances and both had a very great influence on the role of organic matter in maintaining the fertility of the soil. The nations which have learned to use commercial fertilizers adequately and wisely to supplement organic matter are today the countries with the most productive agriculture.

6. Crop yields in many countries have increased more in the last 50 years than in all the centuries before that time. These increases have not come from any one factor but by the synthesis of systems of management which incorporated all the separate ingredients. Most of the early research on the various single factors involved was done by scientists who were, as in most cases they have to be, specialists, interested in a rather narrow field and often working in isolation from scientists working in distinctly different fields. To the soil scientist interested in studying fertility problems, corn was corn. He generally used in his experiments the variety which the farmers in the area were growing. The corn breeder likewise wanted to be practical. He tested the genetic potential of his lines on soils fertilized and managed as farmers in the community fertilized and managed their soils. It was not until the last half century that they started to work together. They soon discovered that some varieties of corn or different hybrids differed widely in their yield response to different fertility levels. In fact, it soon became apparent that the spread between the yields of the older and the newer strains often tended to widen as the fertility of the soil was raised. These differences were especially significant in the case of the small grains like wheat and rice, our principal food cereals. Old varieties selected for centuries on the basis of performance at very low fertility levels responded in a very complex and at

first in what seemed to be a very illogical and unpredictable way. Almost always, there was an increase in their vegetative growth. The color of the plants became a darker green, the plants became taller especially in seasons with heavy rainfall and much cloudy weather. As such plants approached maturity the heads became heavier, the supporting culms broke under the strain before the grain was fully formed. This phenomenon, commonly referred to as « lodging » nearly always reduced yields and increased the labor and hazards of harvesting. As a result farmers learned by experience to be very conservative in their use of fertilizers, especially nitrogenous fertilizers including heavy applications of animal manures. Once the basic nature of the problem was understood, plant breeders increased their efforts to develop small grain varieties which were shorter in stature, with stiffer straw and hence resistant to lodging. By searching the world for parents with some of these desired characteristics then combining them with local varieties which were well adapted to the local environment, they were able, in a relatively short time, to develop plants with the desired specifications. Plant breeders from many countries contributed to these advances. Some of the best pioneering on dwarf types was done in Japan. Combining short stature with disease resistance was an important feature in the development of the so-called Mexican wheats by BORLAUG of the Rockefeller Foundation and his staff in Mexico. Similar principles guided the rice breeders at the International Rice Research Institute in their development of IR8, the so-called « Miracle rice » which has had such a profound and widespread influence upon the imaginations of farmers and government officials as well as scientists in the Rice Belt of Asia. New hope pervades the area.

7. The above picture is not complete. We have seen that if we are to get maximum yields from fertilizers it is necessary for plant breeders to develop new types of plants which can

make full use of the more adequate fertility level. But of what use is it to develop these high yielding strains and to spend money on fertilizers if insects or rats or diseases are going to wipe out the crop before it can be harvested? To get maximum returns from our investment in seeds of superior varieties and from heavier fertilization all other factors which tend to reduce yields must be controlled or counteracted. This necessitates adding an entomologist, a plant pathologist, as well as a weed and rat control specialists to our research team.

We need also an agronomist — ecologist — plant physiologist to study the environment and to define the combination of environmental conditions, including water supply, which will enable the crop to give high yields at minimum costs. The development and application of this more complete and better integrated approach to problems of crop production have given us a new conception of the potentials for food production throughout the world.

In many countries it has already resulted in the production of huge surpluses of certain crops. These crops are often produced by fewer people. Less than 7% of the labor force of the United States is engaged in farming. In addition to being abundant, food is relatively cheaper than ever before if cost is measured in terms of the proportion of his wages which an average factory worker has to spend for enough food to feed his family. This percentage has been reduced to 17 and is still going down!

Let us now consider how all these changes in modern agriculture have affected our ideas about the role of organic matter in food production. One measure of the importance which scientists attach to a subject is the number of papers which they have written and are still writing about it. Rated by this criterion, there is no subject in soil science which has received more attention from a greater number or a wider range of types of soil scientists than has soil organic matter.

There are a few points which I think are rather well established that are especially pertinent to my subject.

1. While soil organic matter influences the fertility of the soil in many ways, one of the greatest significance, if measured by its influence on crop yields, is as a source of inorganic plant nutrients. The similarity of the level of crop yields obtained over a long period of years by chemically equivalent supplies of plant nutrients from organic and inorganic sources, indicates that the major effect of the organic manures is due to the plant nutrients which they supply. This point, well established by the classical experiments at Rothamsted, has since been confirmed many times, in many places and by many scientists.

2. To understand the role of organic matter in soil fertility maintenance, we must differentiate two different forms: 1) the relatively recent additions of fresh organic matter in various stages of decomposition; and 2) the more stable residue which we call humus. The first has a rather transient existence in the soil. As it decomposes, part of it is completely oxidized to CO_2 and water and part is converted to humus.

3. Of these two forms the fresher residues have, gram for gram, by far the greatest influence on crop yields. This is because this form releases its store of crop nutrients more rapidly. Humus as the more stable form in which organic matter accumulates in the soil is the most abundant form and the one which contributes most to the durability of the fertility of soils. When the soil is planted to intertilled crops in the temperate region, about 2% of the total store of humus is decomposed each year releasing about 2% of the nitrogen and organic phosphate stored in the soil. A fertile soil with 5000 pounds of nitrogen stored in an acre of the plowed layer would release about 100 pounds of nitrogen per acre or enough to produce a 50 bushel crop of corn (approximately 2.5 T/Ha).

4. If soils are planted to perennial crops, either grass-legume sods or forests, and if all the dry matter produced is allowed to remain and decay *in situ* their organic matter and nitrogen content will slowly increase, the rate increasing as the amount of residues produced increases. It does not seem to be economically feasible to build up the organic matter content of soils while they are being used to produce intertilled, annual crops, large fractions of which are harvested and taken off the land.

5. The above facts do not seem to preclude the maintenance of high yields of crops if the soils are fertilized at a satisfactory rate, and the crop residues (roots, stubble, fallen leaves, etc.) are returned to the soil.

6. While organic matter is not necessary to produce high yields of crops receiving adequate amounts of inorganic nutrients in proper balance, practical management problems are often simplified if the soil contains a liberal amount of readily decomposable organic matter. Commercial fertilizers are usually added in relatively large quantities once or twice during the growth of the crop. This often results in concentrations higher than necessary at the time of application. Since these fertilizers are largely water soluble, leaching losses may be high during long periods of heavy rain. Since nutrients stored in organic residues are not soluble in water until released by microbiological processes, such leaching losses are not as serious from this source. As a result, the available nitrogen content is stabilized at an intermediate level, thus reducing the hazards resulting from either too much or too little.

ORGANIC MATTER AND THE MANAGEMENT OF TROPICAL SOILS

Two widely differing systems of management of organic matter are found in tropical regions. I shall comment briefly on these extreme types. They can often be found close to each other. As I sit at my desk in the Philippines writing this paper I can see several columns of smoke rising from mountain slopes only a few miles away. We are now in the midst of the dry season. There has been but little rain since early December. The sun has been bright and drying conditions have been ideal. As a result the trees and shrubs cut down last fall by the « kaingeros », as the practitioners of shifting agriculture are known in the Philippines, are now dry enough to burn in preparation for the planting of crops when the rains come again in May. These clearings are on rather steep slopes of highly erodible volcanic ash soils. Nearby I can see another mountain whose slopes are bare. There is no longer enough soil left for the forest to reestablish itself. This is one of the tragedies of shifting cultivation. The other is that people work so hard for so little. This is a subsistence type of farming. Little, if any, surplus is left over to sell. The crops raised go largely to feed the family. There is no money to educate children and without education but little opportunity for more lucrative employment. Yet it is estimated that 200,000,000 people in Africa, Asia and Latin America are supporting themselves by shifting cultivation!

The closer view from my office window is a beautiful rice paddy which produces 3 crops of rice a year. These three crops, when the new improved varieties and the best cultural practices are used produce an aggregate yield of 20 tons of rough rice per hectare per year. The average per capita consumption in the Philippines is about 85 kilograms. At this rate, this hectare of land in front of my office will produce enough rice each year to feed 235 Filipinos for a year. Shifting cultivation can support on the average about 20 people per square mile or 0.08 of a person per hectare! There are large areas in the tropical rice belt which support a population of 1400 per square mile which is 70 times the 20 per square mile supported by shifting cultivation. How can we account for such large differences in the productivity of land in the same climatic zone?

The essential details of soil management under shifting agriculture were described above. Most of the characteristic features of the intensive rice culture developed in China and Japan were described by KING in his book « Farmers of Forty Centuries » written in the first decade of this century before commercial fertilizers were widely used. The cardinal principle was to return to the soil every bit of organic matter which they could lay their hands on. Mud washed down from the hills into the streams and irrigation canals was scooped up and scattered over the rice fields, all crop residues were returned to the land. Excreta from people as well as animals was carefully saved and applied to the land at the appropriate time. The cost of the system in human labor was large, but it did produce a lot of food. This system involved the most intensive use of organic matter ever used on such a large scale, it reached its highest development near the large cities. The large city markets received many products from distant sources. The residues from these found their way into the « night soil » cisterns. In this way the intensively farmed land near the large cities was enriched at the expense of more distant and more sparsely populated areas. Today commercial fertilizers supplement and in places replace much of the organics used even half a century ago.

There is a very wide range of attitudes toward the use of animal manures in different countries. In Taiwan, one of the reason farmers give for raising pigs is that they need the pig manure to make compost. In India cow manure is highly prized but as a fuel not as a fertilizer. In the United States, when large, specialized poultry farms started to replace the smaller but more numerous farm flocks, poultry manure was highly prized and could be sold at a fair price to neighboring farmers. As the price of farm labor increased, the neighboring farmers could not afford to buy the poultry manure so the poultryman gave it to them gratis it they would haul it away. Today the poultryman has difficulty in disposing of his poultry manure. It is produced in such large quantities on farms handling several hundred thousand birds that it can no longer be given away for the hauling but the poultryman is forced to hire people to haul it away! It has become a liability instead of an asset to the poultryman. Considerable research is under way to find economic solutions to this problem; for, agronomically, poultry manure is just as effective as it has ever been. If it could be transported on a magic carpet to the small patches of the shifting cultivator of Africa what a difference it would make! But I fear the practical solution will have to be found closer to his home.

I have often tried to imagine myself as a shifting cultivator in a tropical rain forest area. I have asked myself the question: How would I try to solve the problems of feeding my family, educating my children and raising the standard of living of the family. After four years of research experience with intensive cropping system in the rice belt, I am convinced that some such approach may be one possible solution to the problems of shifting cultivation which is worth exploring.

Since nature has covered these areas with forests and since farmers use a fallow of trees to restore the fertility of the soil on the small patches on which they grow their food crops, I am inclined to think that 90-95% of all the non-alluvial areas should be kept permanently in trees. These areas are wonderful for growing trees. They grow so rapidly and so luxuriantly. A tropical forest for example will produce 5 tons of litter per acre per year. A deciduous forest in the temperate zone will produce only about one ton in the same period. Tropical soils will produce much organic matter in a year if you keep them at it. Trees do just that with but little attention from man.

I would not however use a 15-20 year growth of trees to produce a few hundred pounds of ashes. There are so many trees capable of producing more valuable products to choose from. There are trees which produce beautiful wood for furniture, for the construction of buildings, for industrial purposes — paper making, synthetic fibers, etc. There are other trees which produce edible fruits and nuts which are highly prized all over the world; cashew and macadamia nuts, a wide range of useful palm fruits; coconuts, oil palms, etc. There are trees and shrubs which produce our favorite beverages; cacao, coffee, tea, maté, etc. I am sure you can think of many others to add to the list. I would select from this large list a few of the tree crops best suited to my farm and market.

But man is not a termite and cannot live on wood alone even were it supplemented with the nuts and fruits mentioned above. He usually requires or at least wants, in addition, a wide choice of annual crops; cereals, root crops, leafy vegetables, pulses, etc. He may wish to keep a few animals; chickens, goats, pigs or cattle. If so he will need feed for them. I would use the 10% or so of my land not allocated for trees for these crops.

I would select the best land on my farm for this purpose. It would be the levelest area with the deepest and most fertile soil and the best watered on the farm. I would build my house near this area as it will require daily attention from me and my family. I would develop the best water supply possible with the means at my disposal, water for household use and water for irrigating as high a proportion of my annual crop area as possible. If there were no better source of water, I would « harvest » much of the surplus runoff from the 90% of my farm that is in trees and divert and store it near the small area reserved for annual crops. With water available for supplemental irrigation during dry periods I can keep this smaller area almost as green as the tree covered area all through the year. I would draw upon the traditional wisdom accumulated by generations of farmers. I would combine this time tested lore with the well established principles of modern science. I would seek seeds of the best varieties of each of the annual crops. I would attempt to provide them with an environment in which each could make its optimum growth. This would include the use of adequate amounts of chemical fertilizers. I would control pests, diseases and weeds. In short, I would do all that we know to be essential for growing high yields of crops. To make full use of a tropical climate, the soil should be covered with a few layers of green leaves as high a proportion of the time as possible. By intercropping, a succeeding crop can be established while the other crop is maturing. Many crops can be grown very economically in small containers fashioned from paper, straw, peat, grass sod, etc. for 3-4 weeks. These can be packed very close together. But little water will be required to carry them through this period and but little spray materials will be required to protect them from insects and many diseases. When the plants reach the optimum size, they can be transplanted to the field at the wider spacing needed for the rest of their growing cycle. By such techniques many vegetable crops will be ready for use in 30-40 days from transplanting. This makes it possible to grow 6-8 crops of short season vegetables on the same land each year. With most crops only about half of the dry matter produced is suitable for use as human food. The other half can usually be fed to animals and the manure returned to the land or it can be returned directly. In either case the amount of organic matter returned to the soil each year will be larger than the net average added per year from a 15-20 year period of bush fallow. By concentrating the fertilizer, water, spray chemicals available on this small intensively managed area maximum returns per unit of input will be attained and the foundations laid for a permanent agriculture. If wisely planned and executed such a plan would not only supply the food needed by the family plus some surplus for sale, while the 90% of the land in trees would, in time, supply the cash income required for other needs. This plan attempts to make the most of the tropical zone's greatest agricultural resource — a 12-month growing season.

DISCUSSION

Chairman: H. JENNY

FRANZ

I would explain that I think that there is a very great difference between the problem of economy of organic matter in temperate regions and in the tropics. We are studying firstly the problems of the temperate regions. There are now very great difficulties because the technique of agriculture is changing completely. Two regions with temperate climates have during a long time a very intense economy of organic substance. One is Eastern Asia and the other is Central Europe. Now, in Central Europe we have no workers and many of the farms have no cattle. So we have the problem of how we can now find a source of organic matter. The most important source of organic matter seems to be the yield of roots. The yield of roots has a very great importance because decomposition of roots is going on in the soil with little oxygen and goes much slower and with a much higher percentage of humification than the decomposition of material which comes on the surface of the soil. I think this is one of the most important things, and also important for the tropical regions, but really not sufficient there. And the other thing is that we must come to rotations which contain not only plants which grow only one year on the field, but two or three years. The decomposition of humus is more rapid the more we rake the soil. We must try to take the soil raking on a slow level. I think that it is very important to make widely extended studies of these problems in different climatic conditions and different soil conditions, so that we can rapidly gain sufficient experience. It would be very important to come to an international collaboration on this subject.

BRADFIELD

Of course your problem is not as serious — I am not worried about your people at all. I am sure that you are competent to meet your problems. You have at your disposal an immense chemical industry, you have good transportation, you know how to use fertilizers effectively. In the areas that I am talking about, they have none of these things. There is only a minimum of fertilizer and therefore it must be used very economically. It must not be used where there is an inadequate supply of water. It must be used where one can get the highest returns from very small quantities. One must depend upon organic matter for a high percentage of the fertility needed. Labour in these areas is cheap. In your country it is high, so that the problems while similar in a technical sense, because of the difference in the stage of development, have to be approached, I think, in somewhat different ways.

ALEXANDER

I would like to supplement Dr. BRADFIELD's very eloquent plea. My plea is directed more to the absent people than to those present. Not only do we need the application of soil science to practical agriculture but we and our colleagues in universities need to be concerned with the education of individuals from the developing regions. It is essential to participate in, to encourage, and even to subsidize the education of individuals concerned with tropical soil science, individuals whose homes are in the tropics and who will be spending their entire professional careers facing practical and basic problems of soil science in the tropical and in other developing regions.

SWABY

I would like to make some challenging remarks with regard to this proposal of Prof. BRADFIELD, that some of the tropical countries might well leave their forests or plant them to nuts or fruit (which could be exported or perhaps eaten) and alternate these with a small area fit for cropping, because I think this would be a solution for the people who are vegetarians; but I do not think it would be very good for tropical Australia, tropical New Guinea, tropical Indonesia, where the people are omnivorous and require a diet containing animal products. I think the answer here is different. Why not replace your forest by legume shrubs, herbaceous legume and grass pastures, such as we are doing ourselves. In fact the Central American people are now coming to us to get the selections we have made of their own tropical shrubs and legumes. And this means of course that you would introduce tropical animals that are fit to graze on these pastures and we have found that some of the best are tropical brahmin cattle, buffalo and goats and I am thinking that perhaps many of the countries in the region where I live would sooner have a diet of meat than a diet of nuts and fruit and would also reap more benefit by exporting meat than by exporting nuts and fruit.

BRADFIELD

I would agree with Prof. SWABY if I were an Australian. I am not sure I made it clear that I was thinking primarily of the tropical rain forest area, especially that in Africa. This area is not well suited to livestock, at least until they eliminate the tsetsi-fly and solve other problems. I fully agree with him that a way should be found for developing some livestock industry not only by growing forage crops to feed them but to utilize the 50% of the crops which would be produced in an intensive system which cannot be handled by the human stomach but which can be handled by ruminants. I would put everything I produced in this intensive system that could possibly be fed to an animal, through the animal. I would of course use a limited amount of forage crops but it would have to be, in this particular area, a rather limited area. If you go into drier areas like Kenya, Uganda and some of the other areas I would agree completely with Prof. SWABY.

CHAMINADE

Le Professeur BRADFIELD a fait allusion à un problème qui me touche de près et qui m'intéresse tout particulièrement: celui de la fertilité des sols tropicaux. Il est certain que le système qu'il a proposé fait appel à la jachère forestière et n'est praticable que dans les conditions climatiques qui permettent le développement de la forêt. Il y a des parties importantes des régions tropicales dans lesquelles ce développement n'est pas possible. Je pense que le problème de la matière organique comme facteur de fertilité dans les sols tropicaux est un problème particulièrement difficile à résoudre. Je suis personnellement convaincu que la matière organique est un facteur important de la fertilité des sols et je pense que dans ce cas — surtout dans les régions de savane, les régions soudano-sahériennes à précipitations de 500 ou 600 millimètres mal reparties, sans végétation forestière — le problème de la matière organique est à résoudre indirectement. La seule source de matière organique des sols est la photosynthèse, et par conséquent il n'y aura pas de matière organique dans le sol s'il n'y a pas de végétation. Actuellement, la possibilité qu'on a dans ces sols pour lesquels il faut absolument — c'est impératif — augmenter la production agricole, c'est agir sur les facteurs limitants les plus accessibles —

[5] *Bradfield* - pag. 20

je pense en particulier à la pauvreté minérale de ces sols qui reste dans la majorité des cas le facteur limitant la végétation, et la cause des récoltes très faibles. En agissant sur cette pauvreté minérale des sols, c'est à dire en apportant des fertilisation minérales on amorcera l'enrichissement du sol en matière organique. Il est possible, en des régions d'Afrique sèche, de tripler le rendement par la fertilisation minérale. Dans bien des cas même, la marge d'augmentation de rendement est encore beaucoup plus importante. Le Docteur Bramâo ce matin citait des expériences faites à Madagascar montrant que la production, à la suite d'une fumure minérale est passé de zéro à 9 tonnes de maïs par hectare. Il y a donc une énorme marge d'augmentation du rendement. C'est par là que s'amorcera l'enrichissement des sols en matière organique étant donné que au fur et à mesure que les rendements augmenteront, les résidus végétaux augmenteront parallèlement et on aura ainsi amorcé cet enrichissement de la matière organique des sols. Je crois que d'une façon générale, lorsqu'on pose ce problème de l'intensification de l'agriculture tropicale, on peut affirmer de façon catégorique que cette intensification ne sera possible que si le capital de fertilité de ces sols augmente.

Je vous remercie, Monsieur le Président.

GENERAL DISCUSSION OF PAPERS PRESENTED ON 22 APRIL 1968

Chairman: H. JENNY

BRADFIELD

I fear, in my desire to stay within the time limits, I have passed over certain points without making them clear. I quite agree with Prof. CHAMINADE. The thing that I was pointing out, Prof. CHAMINADE, was that on these small areas we must use very heavy fertilization. The reason that I suggested a small area is, that farmers in these areas cultivate only 0.5 to 1.0%; when people have but little capital, every possible step should be taken to get maximum returns from fertilizer. This can be done only by having control of water. It is useless to put fertilizer on soils which are subject to drought because the returns will be small and uncertain. With most fertilizers yield responses are linear function of the amount of fertilizer added up to a certain level. I would add fertilizer to this small area to the limit of this linear response because in that way I would get the maximum returns from my investment in fertilizer.

DHAR

I happen to be the only representative of the tropical people and it is worth while for you to know one or two things. In Allahabad where I work, the average soil temperature is 26°C all the year round. I went to Uppsala (Sweden) to test my photochemical theories, I lived there for one year, and then repeatedly visited Uppsala; about two years ago I was there, and the average temperature is 5°C. In Rothamsted (U.K.) it is about 8-9°; in Versailles about 90°; Madrid 15°; Rome 15°. Now this has a very important bearing on available nitrogen. In our soils in India we have 1% humus, that is 0.05% total nitrogen, which comes to about 1100 lbs of total nitrogen per acre of which 110 lbs are available. More than 10% of the nitrogen is in the available condition — 10% of the total nitrogen — and that is why foreigners who come to us see no manure, no compost, no fertilizers, but still we get a fairly good crop. Well, if the rain does not fail, we can easily obtain 800-1200 kgs of grains without any fertilizer. The straw, the residue stubble, the roots that are left, gradually get oxidised and fix nitrogen of the air, which I am going to talk about tomorrow. We always get a crop without fail if the water is there. Last year I was in Uppsala and there I went into details and found that although the humus is about 3%, three times the amount of ours, but the available nitrogen is only ½%. Whilst in our soil it varies from 10 to 30%, in Rothamsted the available nitrogen of the average soils is about 1 to 2%. So the tropical soil, in spite of a small nitrogen content, can produce some crop. But last year in Uppsala I found the Minister of Agriculture saying that « we give up cultivation in the whole of Sweden and grow trees because labour is costly and will purchase our needs for the country from the open market ». So you see it is a very difficult proposition. The glowing picture which my friend Prof. BROADFIELD has given is certainly stimulating but perhaps it is not so easy. It is certainly a very difficult question.

JENNY

I think we have had a good birds' eye view of tropical problems and maybe we can go deeper later on.

Let me shift to another aspect. When I heard Prof. BROADBENT and Prof. NORMAN I had the impression that they were apologetic about the slow rate of mineralization of nitrogen in the humus. This is an anthropomorphic attitude. Nature evolved these processes, I think, before man showed up on earth, and from the viewpoint of nature this is really a good thing, otherwise it could not build up the nitrogen and humus storage in the soil. Thus, if we think that organic matter is important for physical structure, for eration and all these aspects we must pay a price and the price is the low rate of mineralization of nitrogen in a normal soil. Now, this should be challenging enough to start a discussion in a different area.

BROADBENT

I did not intend to be apologetic about nitrogen mineralization rates, but I think probably the reason that so much emphasis was put on the slowness, the relatively low rate of mineralization, is that we hear today a great many recommendations in practical agricultural management for fertilizing organic residues. The philosophy goes that you add the fertilizer to the residue, it is tied up by the residue in a form which is resistent to leaching during the winter, and then when the next crop is planted the nitrogen will be mineralized and made available to the succeeding crop. Our experiments do not support that idea. Fall fertilization has been poor practice, at least in regions where the climate is warm enough to permit leaching of the soil, to permit biological activity to go on during the fall, and so we have put a great deal of emphasis on the idea that you need to fertilize the crop and not to residue, and this is one reason for the great emphasis that was stressed in the paper I presented.

BRADFIELD

Prof. T. L. LYON at Cornell University conducted a long-term experiment in which equivalent amounts of nitrogen fertilizer were applied directly to the crop in one case, and in the other case to residues of straw. These experiments were continued over a period of about 20 years. The application of the straw in every case, from the beginning of the period until the end of the period, consistently reduced the yields. The only thing gained by the use of the straw over this long period was a slight increase in residual nitrogen at the end of the 20-year period.

ALEXANDER

I am disturbed by the high ratio between the rate of mineralization and the rate of immobilization. This runs counter to my understanding of my microbial physiology. Mineralization presumably is a growth-linked process and consequently one would expect a predictable amount of nitrogen being assimilated microbiologically during nitrogen mineralization. On the basis of our knowledge of microbial behaviour, such high ratios between the two rates are unexpected and possibly unlikely. Is it possible that both rates are being estimated incorrectly because the nitrogen which is being mineralized and then immobilized never appears free in the inorganic form in soil but rather is held within the cell and does not equilibrate with extracellular inorganic nitrogen.

BROADBENT

I might just comment briefly on it. The figures which I discussed privately with Prof. ALEXANDER this morning indicating ratios between mineralization and immobilization rates on the order of 100 were not in this particular experiment which was reported today. In one part of the data for which you saw slides, mineralization rate is 1.04 and immobilization rate is .01, and with a magnitude that size, I am not prepared to risk my reputation to say that it was not actually .05, something of this kind, which would make something of a difference. The ratio changes from 100 to about 20, which would certainly be more reasonable in view of the question that you have raised. There is of course a possibility that in determining inorganic nitrogen we are actually sampling part of the organic fraction. We do know that in distillating extracts of organic soils with magnesium oxide we get a substantially higher ammonium content than we do with a phosphate buffer at about pH 8, the implication here being that some hydrolysis of the organic fraction has occurred. Prof. BREMNER is much better qualified than I to comment on that specific point, but in most of our soil extracts we find that the magnesium oxide distillation does in fact recover fairly reliably inorganic ammonium, but there is the possibility of hydrolysis.

FLAIG

In order to know how nitrogen may be immobilized or mineralized we made some experiments. A part of the nitrogen is fixed in soil organic matter by special reactions, as has been mentioned this morning, also by condensation on different phenols. We investigated different phenolic degradation products of lignin which can be identified in soils by different methods; we used for our experiments also different phenols which are synthesized by microorganisms. The addition of amino acids by phenols occurs at pH value between 6.5 and 8. There are two reactions, one is the nucleophilic addition in 1,4-position, and the second reaction is the oxidative decarboxylation of the amino acids by formation of ammonia CO_2 and a corresponding ceto compound. The rate of these two reactions depends upon chemical constitution of the phenolic compounds. Some of the phenolic compounds cause a strong addition and a weak deamination others a strong deamination and only a weak addition. During the addition reactions polymerization occurs to products which can be precipitated by hydrochloric acid. The precipitates have nearly the same behaviour as the (so-called) humic acids. The addition reactions of amino acids do not only depend upon the chemical constitution of the phenols but also upon the chemical constitution of the amino acids. We investigated this problem with different labelled amino acids. These reactions occur in the pH range of 6.5 to 8 but at this pH hydroquinone or hydrooxyhydroquinone do not add amino acids and do not deaminate amino acids. The reactions with this type of quinones occur only at a pH range which is higher than 8.

To find out where the carbon skeleton of the amino acids remains, we worked with different specifically labelled amino acids. With these experiments it could be exactly demonstrated, how far addition reaction and oxydative deamination occur. It could also be shown that precipitates have a higher content of nitrogen than it corresponds for the addition of one amino acid. Some further reactions must occur. An example is discussed in one of the next slides.

The addition and deamination may be explained with a scheme which is comparable with TRAUTNER's et al. (1950). During these reactions also amino phenols are formed. This morning Dr. BROADBENT showed possible reactions for the formation of heterocyclic compound by reactions of aminophenols. The scheme shows that one phenol can deaminate several amino acids. That is important to understand the different other reactions and perhaps also the occurrence of ammonia from amino acids in the soil.

Furthermore, we investigated the distribution of the nitrogen after the reactions between amino acids and 1,2-diphenols, for instance between glycine and catechol. Partly the substances precipitable with acids have a higher nitrogen content than the addition product of one catechol and one amino acid. Therefore it is necessary to study now this nitrogen is bound. Some possibilities of heterocyclic bound nitrogen are discussed by formation of phenoxazines, phenoxazones, ring structures with nitrogen and sulphur as heteroatoms, pyridin derivatives.

Also in the case of resorcinol derivatives, brown polymers are formed in the presence of oxidizing agents.

During the condensation of phenols with amino acids, peptides or proteins, dark coloured products are formed. With labelled compounds it could be shown that all amino acids of peptides or proteins can be identified after hydrolysis with the exception of the N-terminal amino acid. This type of nitrogen fixation may also be important for the explanation of not determinable N in soil organic matter.

SWABY

I wonder if I might make a comment on Prof. FLAIG's explanation for the fixation of ammonia by phenols. While I agree that this does occur under mildly alkaline conditions in test tubes, and probably occurs in neutral and alkaline soils, I am afraid that I cannot believe this is a mechanism that is possible in acidic soils. I have a feeling that we have to look for some other free radicals to combine with the ammonia under acidic soil conditions, and this is why I raised the question this morning about the possibility of aldehydes and ketones doing this. I am not sure that even these are able to do it because in our experience, though they will do it under acidic conditions, it is extremely slow, but it is difficult to imagine small molecules like aldehydes persisting long in a soil where micro-organisms are mostly very hungry. We have to look for niches in the soil which can hold aldehydes until ammonia or amino acids approach them to effect linkage. The only niche that I could think of was inside autolysing cells of micro-organisms. I have written about this so I won't say any more about it. I would like to hear your opinion.

FLAIG

I spoke only about the fixation of nitrogenous compounds by phenols. According to our experience the fixation of nitrogen by aldehydes or ketones is also not very large. One reaction which may be possible is after the cleavage of the benzene ring, which I mentioned. This is also possible in biological environment.

Surely it would also be necessary to investigate the mechanism of fixation of ammonia by different aldehydes. Not all fixation of nitrogen in soil can be explained by reactions with phenols.

JENNY

Thank you very much, Prof. FLAIG. Any questions? I would like to give a chance to Dr. BAVER, if you don't mind.

BAVER

I would like to make a couple of comments, one with respect to Dr. BROADBENT's paper verifying what he had to say with respect to our experience in Hawaii on the immobilization of nitrogen by the organisms. In line with Dr. JENNY's comments this is a favourable situation because we are now growing sugar cane on these hydrol humic latosols where we have large amounts of rain. We find that the added ammonia nitrogen that we put on either as ammonia sulphate or in the form of urea is tied up rather rapidly by the micro-organisms. Even with large amounts of rainfall, using ^{15}N as tagged nitrogen, we find hardly any leaching under these conditions. The situation with respect to mineralization, however, seems to be the more favourable under the tropical conditions of Hawaii than Dr. BROADBENT has expressed because we apparently get a more rapid decomposition of the immobilized nitrogen under these conditions. One of our biggest problems has been to find out how much of this mineralizable nitrogen is in the soil in order to be able to suggest an intelligent nitrogen fertilization programme. We found in certain soil situations, for example, that we get up to 200 pounds of mineralizable nitrogen per acre resulting from an application of nitrogen two years previously. Consequently, we had to develop techniques for finding this out, otherwise we would get into difficulties with respect to the juice qualities of the sugar cane.

Regarding what Dr. BRADFIELD has said, and we found under the tropical conditions of Hawaii that sugar cane, other crops, including coffee, if provided the minerals and then the nitrogen, would give tremendous increases in yield as compared with the organic residues that were turned under. As a matter of fact, when I first went to Hawaii I thought that the only way to improve some of those poor soils was to turn under organic matter. We got some Mauritius beans and I was terrifically disappointed when I obtained the same yields of cane on the area on which I put mineral fertilizers. I must admit, however, that under our conditions we did have a lot of capital to put into this fertilization programme, but I would support Dr. BRADFIELD's idea that the use of the mineral fertilizers in the tropics would be somewhat similar to what we have found under a rather highly mechanized agriculture in Hawaii.

ALEXANDER

As a soil microbiologist, it is very pleasant to see soil chemists using microbiological information, but I would like to caution about the use of information derived from intracellular transformations to processes which occur outside the cell. For example, you show the condensation of hydroxymuconic semialdehyde with ammonia to form a nitrogen heterocycle. The muconic acid semialdehyde presumably appears only inside the cell and is metabolized immediately and probably never appears outside the microbial cell.

FLAIG

May I answer?

JENNY

Yes, briefly if possible, as we would like to postpone discussions on cellular and biochemical reactions to another day.

FLAIG

I will only say briefly that all mentioned reactions occur outside the cell with exception of muconic acid aldehydes.

HENIN

Je pense que quand on parle d'une décomposition de l'ordre de 1% par an de la réserve dans le sol, on parle d'une valeur moyenne, parce qu'un certain nombre de travaux qui sont actuellement faits en France montrent que pendant la période chaude, il arrive que l'on trouve dans le sol des quantités d'azote minéral nitrique et ammoniacal qui représentent 4 à 5 fois, peut-être plus encore, la quantité moyenne qui paraît disparaître chaque année. Cela supposerait que nous avons en superposition un processus à court terme avec des minéralisations et des re-organisations rapides de l'azote. Ce fait explique que certaines années on puisse obtenir sans fertilisation azotée des récoltes importantes, en particulier de céréales.

Mais il y a certainement un mystère, parce que les quantitées d'azote minéral qui sont mises en évidence correspondent souvent à beaucoup plus qu'une fertilisation azotée importante: il s'agit de savoir pourquoi les végétaux ne l'utilisent pas complètement. Comme on opère sur un mètre d'épaisseur, peut-être les racines ne peuvent pas l'absorber et il se trouve re-organisé avant d'avoir pu être absorbé par le végétal. Ces réflexions me conduisent à la remarque suivante: la transposition d'une expérience précise faite sur un volume de terrain restreint à ce qui se passe dans un profile, doit être faite, je crois, avec beaucoup de prudence.

JENNY

Are you addressing this to anyone special, or does anyone wish to comment?

HENIN

Non, je souhaite seulement que l'un de nos conférenciers me dise si ces phénomènes peuvent être expliqués par leurs expériences.

BROADBENT

I might just comment, Prof. HENIN, that in some of our experiments the percentage of nitrogen reserves which is mineralized in the growing season or perhaps 120 days may reach 12 to 15% in a temperate region, but this is the extreme situation; I must say I am quite astonished by the magnitude of the values which you have discussed. This is very high indeed and the total soil nitrogen will surely be depleted in a very short time if this continues annually.

HENIN

Is this nitrogen coming back in organic form in a short time, or not?

BROADBENT

We think not.

Bramao

Dr. Bradfield explained that OM is necessary for high yields. How much organic matter is really necessary in soils for satisfactory crop growth? How much organic matter is needed for the biochemical reactions that take place in soils? Farmers in Brazil found the Terra Roa soils to be the best soils for production of coffee. The production of coffee was a very extractive type of agriculture, and in a few years some soils yielded low productions and were put to pastures — and finally abandoned with their decline of productivity. The research carried out in Campinas permitted the reclamation of these soils with use of fertilizer and sprinkling irrigation. The soils come back to high levels of coffee production. These soils under virgin conditions have a large amount of organic matter — about 6%. This helped the growth of coffee, particularly during the dry season by conserving the moisture. With the application of fertilizers and sprinkling irrigation, high yields were restored, perhaps higher than the initial yields. Dr. Bradfield referred also to the old Rothamsted Experiments. The wheat plots have been for such a long time in continuous production of wheat. Their organic matter content dropped very much to a low content and remained there in a new equilibrium. My question therefore is: recognizing the difficulty of building up organic matter in soils, how much organic matter is really needed in soils? We all have seen how much application of mineral fertilizers have contributed to the productions of sugar cane and pineapples in Hawaii, in Brazil and in other countries in the tropics, in farms with modern management in which soil management is well developed as in developed countries.

Jenny

I think we should consider this question during one of our sessions, but now it is closing time, as the bus is waiting.

II

MATIERE ORGANIQUE ET PROCESSUS CHIMIQUES

THE NITROGENOUS CONSTITUENTS OF SOIL ORGANIC MATTER AND THEIR ROLE IN SOIL FERTILITY (*)

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The primary purpose of this Study Week, as I see it, is to evaluate present knowledge concerning the nature and properties of the organic constituents of soils and to define and discuss the main problems in research on the structure of soil organic matter and the role of organic matter in soil fertility. In this paper I will attempt to summarize current knowledge concerning the composition and properties of the nitrogenous constituents of soil organic matter and to focus attention on some of the problems and needs in research on the role of soil organic matter in nitrogen aspects of soil fertility.

FORMS OF NITROGEN IN SOILS

Until fairly recently, it was generally accepted that soil nitrogen occurred almost entirely in organic forms because

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(*) Project N° 1070 of the Iowa Agricultural and Home Economics Experiment Station, Ames, Iowa.

many investigations had indicated that inorganic forms of nitrogen rarely accounted for more than about 2% of the total nitrogen in soils. But work by RODRIGUES [1] in 1954 indicated that some soils contain substantial amounts of clay-fixed ammonium that is not recovered by methods commonly used to determine ammonium in soils, and numerous investigations since 1954 have indicated that more than 10% of the total nitrogen in some surface soils and as much as 60% of the nitrogen in some subsoils is in the form of fixed (nonexchangeable) ammonium (for reviews, see [2, 3]). These investigations leave very little doubt about the occurrence of fixed ammonium in soils, but serious doubt exists concerning the accuracy of the methods used to determine fixed ammonium since recent work [4] has shown that these methods give widely divergent results. This is illustrated by Table 1, which shows the averages of the fixed ammonium N values obtained by different methods witb six soils containing from 0.081 to 0.912% nitrogen. Studies to evaluate the methods listed in Table 1 have revealed defects in all methods studied except the KOBr-HF procedure proposed by SILVA and BREMNER [5], but several possible defects of methods of determining fixed ammonium are difficult to investigate, and the KOBr-HF procedure may have some of these defects. For example, it is possible that soils contain, within the lattices of clay minerals, labile organic nitrogen compounds (e.g., amides, amino sugars) that are not removed or decomposed by the KOBr pretreatment used in the KOBr-HF method to remove organic nitrogen compounds but are released and extensively decomposed to ammonium by the treatments used to liberate and estimate fixed ammonium after pretreatment with KOBr. We are currently investigating the use of infrared spectroscopy for estimation of fixed ammonium in soils because there is a possibility that this technique may allow estimation of fixed ammonium without application of chemical treatments that may cause interference by organic nitrogen compounds. But the results thus far obtained by using the NH_4^+ deformation band at about 1430 cm^{-1} for estimation of ammonium by infrared spectroscopy are not very promising in relation to development of a reliable method of estimating fixed ammonium in soils.

TABLE 1 — *Comparison of methods of determining fixed ammonium in soils* [4].

Method	Average fixed ammonium N value (ppm. of soil) (¹)
RODRIGUES (1954)	917
SCHACHTSCHABEL (1960)	316
SILVA and BREMNER (1966) . . .	204
BREMNER (1959)	181
DHARIWAL and STEVENSON (1958) .	166
MOGILEVKINA (1964)	52

(¹) Six soils.

Another finding in recent work that complicates research on soil nitrogen is that some soils contain nitrogen that is not determinable by KJELDAHL or DUMAS techniques [6]. But this analytical difficulty has been experienced with only a few subsoils containing high levels of fixed ammonium N, and there is currently no evidence to indicate that the total N contents of surface soils cannot be determined satisfactorily by DUMAS or KJELDAHL procedures.

Although the analytical problems mentioned indicate that existing data concerning the distribution of nitrogen in subsoils must be treated with some reserve, there seems no reason to question the conclusion from numerous investigations that more than 90% of the total N in most surface soils is organic nitrogen.

Current knowledge concerning the forms of organic nitrogen in soils is based largely on studies involving identification and estimation of the organic nitrogen compounds released by treatment of soils with hot acid (for reviews, see [7, 8]). These hydrolysis studies have shown that between 20 and 50% of the nitrogen in most surface soils occurs as bound amino acids, and that between 5 and 10% is in combined amino sugars (hexosamines). The amino acids and hexosamines in soil hydrolysates have been identified, but the soil complexes containing combined amino acids and hexosamines have not been characterized. Purine and pyrimidine components of nucleic acids and nucleotides have been detected, but present information indicates that not more than about 1% of the total nitrogen in surface soils is in the form of purine or pyrimidine derivatives. Other organic nitrogen compounds, including choline, ethanolamine, creatinine, and allantoin, have been detected in soils or soil products, but there is no evidence that they account for a significant amount of the organic nitrogen in soils, and the chemical nature of about half of this nitrogen remains obscure.

It is commonly assumed that the bound amino acids in soils are largely, if not entirely, in the form of proteins or peptides, but the failure of attempts to isolate what can be reliably described as protein or peptide material from soils or soil organic matter preparations has led several workers to question this assumption. Some support for the belief that a significant amount of the combined amino acid N in soils is in amino acids bound by peptide linkages has been provided by the finding [9] that 28-32% of the hydrolyzable amino acid N in organic matter extracted from soils by use of Dowex A-1 chelating resin is released as free amino acid N by a proteolytic enzyme isolated from *Streptomyces griseus* (¹). This proteinase is distinguished by its remarkably low specificity and exceptionally high proteolytic activity [10, 11], and LADD and BRISBANE [12] recently found that it released 28-39% of the hydrolyzable amino acid N in soil humic acid preparations as free amino acids. Further evidence for the occurrence of protein or peptide material in soil organic matter has been provided by the recent isolation of protein material from a soil humic acid preparation by SIMONART, BATISTIC, and MAYAUDON [13]. This is a significant achievement and it should stimulate further work to characterize the amino acid complexes in soils.

It seems likely that some of the combined amino acid N in soils is in mucopeptides (amino acid-amino sugar complexes) and teichoic acids (ribitolphosphate or glycerophosphate polymers containing ester-linked alanine), because recent work has shown that these polymers are important constituents of bacterial cell walls. The possibility that some of the organic phosphorus in soils occurs as teichoic acids seems to deserve attention, because a substantial amount of this phosphorus has not been identified, and it has been shown that teichoic acids account for as much as 50% of the material in some bacterial cell walls.

Recent work by SINGH and BHANDARI [14] has suggested that arid and semiarid soils may contain large amounts of amino sugars, but we have found that the amino sugar contents of surface soils from arid and semiarid regions are similar to those of surface soils from temperate areas.

The presence of amino sugars in higher plants has only recently been established, and the amino sugars in soils probably are largely, if not entirely, of microbial origin. Amino

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(¹) This enzyme is sold under the trade name of Pronase by Calbiochem, 3625 Medford Street, Los Angeles 63, California, U.S.A.

sugars occur in many substances synthesized by microorganisms (polysaccharides, antibiotics, mucopeptides, etc.), and recent work has shown that several of these substances contain amino sugars besides glucosamine and galactosamine. It seems very likely that at least one of these sugars, namely muramic acid, occurs in soils, because, like glucosamine, this hexosamine derivative has been detected in all bacterial cell walls analyzed for amino sugars. But no amino sugars besides glucosamine and galactosamine have thus far been detected in soils, and the hexosamine N liberated by hydrolysis of soils with 6*N* HCl appears to be largely, if not entirely, in the form of these two amino sugars. Some of the hexosamine N in soils probably is in the form of chitin (a polymer of N-acetylglucosamine), because this substance occurs in most fungi and in the exo-skeletons of soil-inhabiting insects.

Many theories have been advanced concerning the nature of the unidentified organic nitrogen in soils, and no attempt can be made to discuss these theories here (for reviews, see [7, 8]). Attention may be drawn, however, to the recent suggestion [7] that some of this unidentified nitrogen may be in heterocyclic compounds (pyridine derivatives) formed by microbial decomposition of plant lignins and other phenolic substances in soils as outlined in Fig. 1. This suggestion seems to deserve serious consideration, because it is now well established that soil fungi can convert methoxyl groups to hydroxyl groups (reaction A), that soil pseudomonads synthesize enzymes which effect reaction B, and that reaction C (nonenzymatic) occurs when catechol (1:2-dihydroxybenzene) and protocatechuic acid (3,4-dihydroxybenzoic acid) are oxidized by these enzymes in the presence of ammonium. Support for the suggestion that microbial decomposition of plant lignins in soils may involve the reactions outlined in Fig. 1 has been provided by studies of NORMAN, BROADBENT, FLAIG and others indicating that decomposition of plant lignins by soil microorganisms leads to loss of methoxyl and phenolic hydroxyl

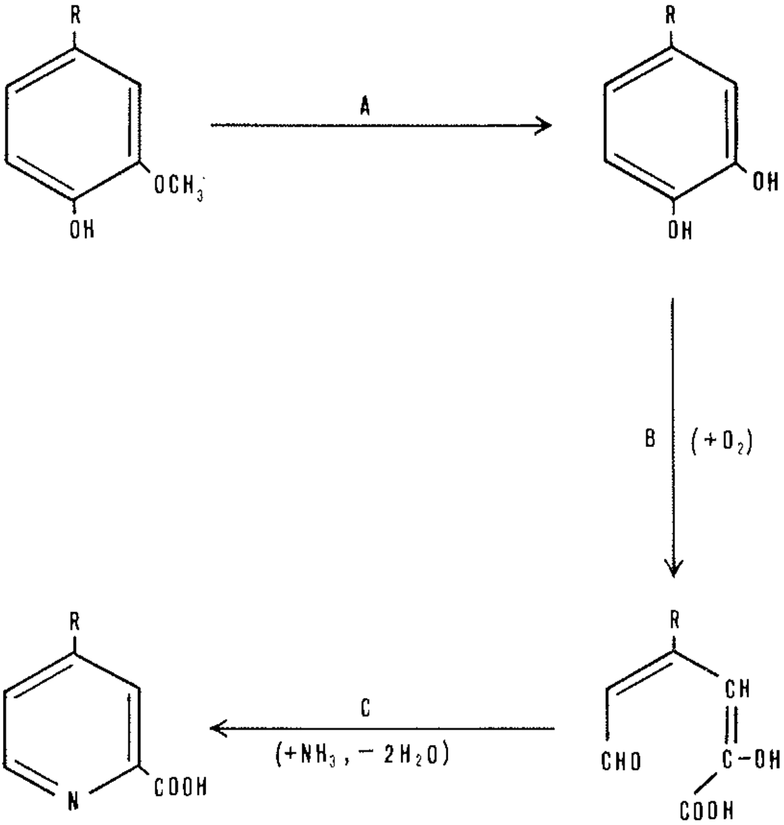


FIG. 1 — Possible mode of formation of pyridine derivatives from lignins and other phenolic substances in soils. A, demethylation (enzymatic); B, oxidative ring fission (enzymatic); C, ring closure (nonenzymatic).

groups and to introduction of carboxyl and nitrogenous groups. The formation of heterocyclic nitrogen compounds in soils as outlined in Fig. 1 would help to account for the occurrence of substantial amounts of nonhydrolyzable nitrogen in soils and for the ability of soil organic matter to chelate metals (α-picolinic acid derivatives have chelating properties).

CHARACTERIZATION OF ORGANIC NITROGEN COMPLEXES

Attempts to characterize the organic nitrogen complexes in soils have been greatly hindered by the lack of satisfactory methods of separating organic and inorganic soil constituents. The classical method of separation involving extraction of the organic constituents with strong alkali (usually 0.5*N* NaOH) dissolves a substantial amount of organic matter, but has the disadvantage that the material so dissolved is partly hydrolyzed and otherwise modified during extraction. Many attempts have been made to develop milder methods of extracting soil organic matter (for reviews, see [7, 8]), and methods involving use of reagents having the ability to complex or chelate polyvalent metals have gained some popularity in recent years. But these mild methods of extraction are usually considerably less effective than the classical procedure, and recent work has shown that organic matter isolated by mild methods from soils having appreciable amounts of clay always contains a substantial quantity of mineral material that is difficult to remove by mild techniques. For example, we have found that, although a substantial amount of organic matter can be separated under mild conditions by shaking aqueous suspensions of clay soils with sodium-saturated cation-exchange resins [7, 8], the organic matter thus separated has a high ash content and cannot be rendered ash-free by repeated treatment with dilute HCl or HF or by other reasonably mild methods of removing inorganic material. Also, we have found that humic acid preparations isolated by mild procedures from soils containing 15-60% clay have much higher ash contents than preparations isolated by the customary 0.5*N* NaOH technique (cf. LEVESQUE and SCHNITZER [15]) and that their ash contents can be reduced substantially by treatment with 0.5*N* NaOH. These and other observations in recent work suggest that sodium pyrophosphate and other reagents used for extraction of soil organic matter under mild conditions disperse clay-organic matter complexes, and that these complexes are not decomposed by neutral or mildly alkaline reagents but are degraded by strong alkali. It is relevant in this connection that there does not appear to be any report in the literature of isolation of humic acid preparations with low ash contents from clay soils without use of strong alkali or hydrofluoric acid.

It is important that methods of removing mineral material associated with soil organic matter preparations be devised because this material interferes with various methods of characterizing organic substances. For example, we have found that the mineral material present in soil humic acid preparations isolated by mild procedures vitiates use of infrared spectroscopy and complicates use of enzymatic and pyrolysis-gas chromatography techniques for investigation of the organic material in these preparations (cf. SCHARPENSEEL [16]).

Many methods of fractionating soil organic matter have been described, but few have shown promise of being useful for characterization of the organic nitrogen complexes in soils. It is obvious that any material as complex as soil organic matter can be fractionated by a wide range of variety of techniques. The problem in research to characterize the nitrogenous constituents of soil organic matter is to devise fractionation techniques that serve a useful purpose (e.g., techniques that permit isolation of organic material having a much higher nitrogen content than soil organic matter as a whole or that separate amino acid or amino sugar complexes from other fractions of soil organic matter). The phenol-paper chromatography technique recently used by SIMONART et al. [13] to fractionate soil humic acid preparations has obvious value, because it effected separation of proteinaceous material containing 14.8% nitrogen. The continuous particle electrophoresis technique recently developed by Beckman Instruments Inc., Fullerton, California also seems to hold considerable promise for fractionation of soil organic matter.

CLAY-ORGANIC MATTER COMPLEXES IN SOILS

The difficulties encountered in attempts to isolated substantial amounts of ash-free organic matter from soils containing appreciable amounts of clay are not difficult to explain, because there is good reason to believe that much of the organic matter in such soils is in the form of clay-organic matter complexes [17, 18].

According to JACKS [19], « the union of mineral and organic matter to form the organo-mineral complex [in soils] is a synthesis as vital to the continuance of life as is photosynthesis. » This conclusion can be questioned on the grounds that it is very difficult, if not impossible, to make valid judgments concerning the relative importance of various natural processes, but there is no doubt that the interaction between clay and organic soil constituents has a profound effect on the physical, chemical, and biological properties of soils and greatly affects soil fertility.

The importance of research to determine the nature and properties of the clay-organic matter complexes in soils has long been evident, but such research has been hindered and discouraged by the lack of methods of isolating these complexes without serious modification of their properties. Recent work [20], however, has led to development of a sonic vibration method of dispersing soil particles that permits isolation of clay-organic matter complexes without use of chemical treatments and under conditions that seem unlikely to cause serious modification of inorganic or organic material. This vibration method of dispersing soil colloids allows more realistic and meaningful investigations of the mechanisms of dispersion and aggregation of soil particles than have hitherto been possible, and recent work at Iowa State University [21, 22] involving application of this technique to soils containing appreciable amounts (10-67%) of clay has led to development of dispersion-aggregation concepts that can be summarized briefly as follows:

1. The difficultly dispersible compound particles in soils of high base status are fine sand- and silt-size microaggregates (mostly $<250\ \mu$ in diameter) consisting largely of clay mineral and organic colloids linked by polyvalent metals. These microaggregates may be represented as $[(\text{C-P-OM})_x]_y$, where C = clay mineral particle, P = polyvalent metal (Ca, Mg, Fe, Al, etc.), OM = organo-metallic complex (humified organic matter complexed with polyvalent metals), $(\text{C-P-OM})_x$ and C-P-OM represent compound particles of clay size ($<2\ \mu$), and x and y are finite whole numbers with limits dictated by the size of the primary clay particles.

2. The bonds linking the C-P-OM particles into the larger $(\text{C-P-OM})_x$ and $[(\text{C-P-OM})_x]_y$ units are readily ruptured by sonic vibration and can be disrupted by mild shaking treatments if the interparticle bonds are weakened in some manner (e.g., by the substitution of sodium for some of the polyvalent metals in these units).

3. The stable microaggregates postulated are formed by a mechanism that is essentially a reversal of what occurs when soil particles are dispersed by vibration or water shaking. The reversible process involved can be represented as follows (D = dispersion; A = aggregation):

$$[(\text{C-P-OM})_x]_y \underset{\text{A}}{\overset{\text{D}}{\rightleftarrows}} y(\text{C-P-OM})_x \underset{\text{A}}{\overset{\text{D}}{\rightleftarrows}} xy(\text{C-P-OM})$$

4. The process of microaggregate formation in soils renders organic material inside microaggregates physically inaccessible to soil microorganisms.

These concepts are of course oversimplified, and we do not mean to imply, for example, that C-P-C and OM-P-OM linkages do not contribute to aggregation or that other types of linkages do not occur (e.g., bonding through aluminum or iron oxides, or hydrogen bonding). In our view, the absolute and relative amounts and the nature of the clay minerals and humified organic matter present in a particular soil or horizon will determine how much of the clay material occurs as microaggregates, and these factors also will determine the size, shape, and stability of the microaggregates formed.

The microaggregate theory outlined helps to account for many findings in studies of the aggregation and dispersion of soil particles and of the abilities of various reagents to extract organic matter and to disperse soil colloids. For example, it helps to explain the fact that the sodium salt solutions most effective for extraction of soil organic matter are also very effective for dispersion of soil particles and are solutions that have the ability to complex or precipitate polyvalent metals (Na pyrophosphate, Na fluoride, Na oxalate, Na citrate, etc.). This theory also provides an explanation of the difficulties experienced in attempts to isolate humic acid preparations having low ash contents from soils containing appreciable amounts of clay. And it helps to explain the apparent high resistance of the organic nitrogen complexes in soils to microbial decomposition and the finding that there is a close relationship between the organic matter and clay contents of soils developed under comparable conditions.

CONTRIBUTION OF SOIL ORGANIC MATTER TO THE NITROGEN NUTRITION OF CROPS

Nitrogen plays a key role in world food production, and one of the most important contributions of soil organic matter to soil fertility is that it provides a substantial amount of nitrogen for crop growth and acts as a natural storehouse for this important plant nutrient. But the striking increases in crop yields resulting from increased use of nitrogen fertilizers have made it obvious that the amount of nitrogen made available for crop growth by mineralization of soil organic matter during the growing season is rarely sufficient to meet the demand for this nutrient in current cropping practices. This has emphasized the need for a laboratory test that will provide an index of the availability of soil nitrogen and aid prediction of the amount of fertilizer nitrogen required to produce a desired crop yield.

Many chemical and biological methods of obtaining an index of soil nitrogen availability have been proposed (for review, see [23]), but most appear to have limited value, and none has gained widespread acceptance. The most commonly used methods are those involving estimation of the mineral N produced when soil is incubated under conditions that promote mineralization of soil N. These methods have a rational basis, because the agents responsible for release of mineral N during incubation of soils are those which make organic soil N available for crop growth during the growing season. Many incubation methods have been proposed, but some have rather obvious defects, and most do not meet several apparent requirements [23]. A simple aerobic incubation method which meets these requirements has recently been developed [24], and greenhouse tests indicate that this method provides a good index of soil nitrogen availability [25]. An even simpler incubation method was recently developed from the finding [26] that there is a close relationship between the amount of ammonium N produced by incubation of soil under waterlogged conditions and the amount of (ammonium + nitrate + nitrite)-N produced by incubation under aerobic conditions, and this method has given good results in greenhouse trials [25]. However, unpublished work in our laboratory indicates that this waterlogged incubation technique does not give satisfactory results with some types of soils, and there is evidence [25] that the results obtained by waterlogged and aerobic incubation methods of assessing soil N availability are markedly affected by sample pretreatments (air-drying, air-dry storage, etc.).

It seems appropriate to comment here on the use of plastic films to effect aeration in incubation work, because there is evidence that these films do not have properties generally ascribed to them. For example, it is commonly assumed that polyethylene films are more permeable to carbon dioxide and oxygen than to water vapor and that, when used to seal the mouths of incubation vessels, they permit rapid diffusion of oxygen and carbon dioxide but do not allow significant escape of water vapor. But the literature indicates that polyethylene is four to five times more permeable to water vapor than to carbon dioxide [27], and we have found that polyethylene films commenly used for aeration in incubation experiments do not permit rapid diffusion of oxygen or carbon dioxide.

TABLE 2 — *Average percentage losses of different forms of nitrogen on cultivation and incubation of soil* [28, 30].

Form of nitrogen	Average percentage loss (10 soils)	
	Cultivation	Incubation
Total N	36.2	16.5
Nonhydrolyzable N	39.4	15.2
Hydrolyzable N		
Total	35.2	17.0
Ammonium	28.6	9.4
Hexosamine	27.6	19.8
Amino acid	43.0	18.7
Hydroxyamino acid	—	21.1
Unidentified	34.5	21.1
Fixed ammonium N	0.2	—0.7

A chemical approach to the problem of obtaining a laboratory index of soil N availability is attractive, because chemical methods of analysis are usually more convenient than biological methods when large numbers of samples must be analyzed on a routine basis as in soil testing laboratories. But use of chemical techniques is open to the criticism that no chemical reagent is likely to simulate the activities of soil microorganisms, and the chemical methods thus far proposed are completely empirical and make no allowance for the fact that the nitrogen mineralization-immobilization cycle in soils is controlled by the supply of energy material for microbial processes. Development of rational chemical methods has been hindered by lack of knowledge concerning the relationships between the composition of the organic matter and the availability of the nitrogen in different soils and by lack of information concerning the organic forms of nitrogen in soils that are most readily mineralized and made available for plant growth by soil microorganisms. Attempts have recently been made to characterize the mineralizable nitrogen in soils by studying the changes in nitrogen distribution that occur when soils are subjected to cultivation or incubation treatments that promote mineralization of organic N [28, 30]. These studies have shown that, although prolonged cultivation or incubation leads to marked decreases in the amounts of various organic forms of N, it generally has little effect on the percentage distribution of these forms of nitrogen and does not lead to loss of fixed ammonium N (see Tables 2 and 3). The last finding leaves very little doubt that the native fixed ammonium in soils is essentially unavailable to plants and microorganisms. The results of these studies are rather discouraging in relation to development of chemical tests for potentially available N in soils, because they indicate that it will be difficult to obtain the type of information needed for development of rational tests.

TABLE 3 — *Effects of cultivation and incubation on the nitrogen distribution of soils* [28, 30].

Form on nitrogen	Average nitrogen distribution (10 soils)			
	Before cultivation	After cultivation	Before incubation	After incubation
	% of total soil N			
Nonhydrolyzable N	25.4	24.0	26.0	26.4
Hydrolyzable N				
Total	74.6	76.9	74.0	73.6
Ammonium	22.2	24.7	19.9	21.6
Hexosamine	4.9	5.4	6.9	6.6
Amino acid	26.5	23.4	27.3	26.5
Hydroxyamino acid	—	—	5.4	5.1
Unidentified	21.0	22.5	19.9	18.8

A recent evaluation of chemical and biological methods of obtaining an index of soil N availability showed that a chemical method involving estimation of the nitrogen extracted from soil by boiling water and potassium sulfate solution [31] gave better results than other chemical methods tested and compared favorably with incubation methods [25]. This chemical method seems to deserve further evaluation because, besides being more rapid and precise than incubation procedures, it has the important advantage that its results are not significantly affected by air-drying or by air-dry storage of soil samples before analysis. A chemical method recently proposed by JENKINSON [32] also shows enough promise to merit further evaluation.

TABLE 4 — *Effects of soil mesh-size and moistening-drying treatment on amount of nitrogen mineralized by incubation of soils under waterlogged conditions at 30°C for two weeks* [21].

Soil	Mesh-size	Treatment before incubation (¹)	Nitrogen mineralized by incubation (ppm. of soil)
Webster	< 10	None	94
	< 10	MDS	93
	< 300 (²)	None	220
	< 300 (²)	MDS	54
Regina	< 10	None	55
	< 10	MDS	55
	< 300 (²)	None	158
	< 300 (²)	MDS	64

(¹) MDS, air-dry soil was moistened (1.2 ml. water/gm. of soil), air-dried (25°C; relative humidity, 45%), and sieved (<10-mesh).

(²) Prepared by grinding <10-mesh soil.

Recent literature on laboratory methods of obtaining an index of soil N availability reflects a considerable lack of appreciation of the limitations of these methods and of the difficulties in evaluation and interpretation of their results. Laboratory tests performed on surface soils cannot be expected to integrate the numerous interrelated soil-plant-environment factors that affect the release and uptake of nitrogen and regulate plant growth during the growing season, and this must be taken into account when results of these tests are being interpreted. It is clear that rainfall data should be considered when laboratory tests are used to predict nitrogen fertilizer requirements, because short periods of heavy rain during the growing season can lead to extensive loss of nitrate through leaching or denitrification. It is also evident that account should be taken of ammonium and nitrate present in the soil profile at the time fertilizer is applied. Recent work has shown that considerable amounts of nitrate can accumulate in the surface and subsurface horizons of soils receiving substantial annual additions of fertilizer nitrogen and that analyses of such soils for nitrate provide a better basis for prediction of nitrogen fertilizer requirements than do laboratory tests designed to assess the potential availability of organic nitrogen in soils.

The difficulties in prediction of nitrogen fertilizer requirements have tended to encourage the practice of applying more fertilizer N than seems necessary from the results of laboratory tests. This practice can be profitable where the cost of fertilizer N is low and it is known that crop yield levels are determined largely by the amount of fertilizer N applied. It is now apparent, however, that continued application of excessive amounts of nitrogen fertilizer may create serious health hazards by leading to accumulation of toxic amounts of nitrate in feeds and ground waters. This means that research to develop better methods of predicting nitrogen fertilizer requirements is needed both to ensure efficient use of fertilizer N where nitrogen fertilizers are expensive and to guard against excessive use of fertilizer N where nitrogen fertilizers are cheap.

BIOLOGICAL STABILITY OF THE ORGANIC NITROGEN COMPLEXES IN SOILS

Numerous investigations have shown that, although a substantial amount of nitrogen is made available for crop growth through mineralization of the organic nitrogen complexes in soils by microorganisms, the amount of organic nitrogen mineralized during the growing season usually does not represent more than about 3% of the total amount present. It is difficult to account for this because the nitrogenous substances added to soils in the form of plant and animal residues are not particularly resistant to decomposition, and present knowledge indicates that more than 40% of the organic nitrogen in most surface soils is in forms that are normally mineralized rapidly by soil microorganisms.

The apparent high resistance of the organic nitrogen complexes in soils to microbial decomposition has considerable practical significance, and several theories have been advanced to account for the stability of these complexes. These theories cannot be discussed adequately here (for reviews, see [7, 8]), but attention can be drawn to recent work [21, 33] which suggests that some of the organic nitrogen in soils is resistant to mineralization because it is physically inaccessible to microorganisms. Support for this « physical inaccessibility » concept was provided by work showing that grinding of <10-mesh soils to <80-mesh leads to a marked increase in the amount of nitrogen mineralized when soils are incubated under aerobic or waterlogged conditions [33]. Table 4 shows data obtained when this work was extended to determine the effects of fine-grinding of air-dry soils (to <300 mesh) and of moistening and drying finely ground air-dry soils on the rate of mineralization of soil nitrogen by microorganisms [21]. It can be seen that grinding of <10-mesh soil to <300-mesh greatly increased the amount of nitrogen mineralized by incubation under waterlogged conditions. It is also evident that moistening and drying of <300-mesh soil to aggregate soil particles resulted in a large decrease in the amount of nitrogen mineralized by incubation, whereas this moistening-drying treatment had no effect on the amount of nitrogen mineralized by incubation of <10-mesh soil. These findings are consistent with the theory [21] that the structurally stable microaggregates in soils consist largely of clay-organic matter complexes and that the process of microaggregate formation renders organic matter within microaggregates physically inaccessible to microorganisms. This theory also helps to account for differences observed in the rates of accumulation and decomposition of organic matter in different types of soils. For example, it explains why fine-textured soils accumulate more organic matter than do coarse-textured soils under the same environmental conditions and why it is much easier to build up or maintain the nitrogen content of clay soils than to increase or stabilize the nitrogen content of sandy soils.

Several investigations (e.g., [34]) have indicated that tillage treatments promote mineralization of soil nitrogen, and ROVIRA and GREACEN [35] found that laboratory tillage (disruption of soil aggregates in a ring shear machine) increased the oxygen uptake of soils. The effect of tillage on nitrogen mineralization has been attributed to improved aeration, but ROVIRA and GREACEN suggested that the increased oxygen uptake they observed following laboratory tillage of soils could be due to « exposure of organic matter from inaccessible micropores » as well as to improved aeration. The effect of grinding on nitrogen mineralization clearly cannot be attributed to improved aeration, because grinding increases the amount of nitrogen mineralized by incubation of soils under waterlogged as well as aerohic conditions. And the conclusion that grinding increases the rate of mineralization of soil nitrogen by disrupting microaggregates and exposing nitrogenous organic material previously inaccessible to microorganisms is supported by the finding that treatments promoting formation of microaggregates reduce the rate of mineralization of soil nitrogen (Table 4).

The theory that some of the organic nitrogen in soils is physically inaccessible to microorganisms seems reasonable in view of evidence that some of this nitrogen is so protected by clay minerals that it is inaccessible to chemical reagents. For example, it has been found that treatment of mineral soils (particularly subsoils) with hydrofluoric acid to decompose clay minerals dissolves a substantial amount of organic nitrogen that is not extractable by acidic, neutral, or alkaline reagents before treatment with hydrofluoric acid [36, 37, 38]. And the ability of soil clay minerals to render nitrogen inaccessible to microorganisms is evident from the work reported in Table 2, which leaves very little doubt that the native clay-fixed ammonium in soils is essentially unavailable to plants or microorganisms.

ROLE OF SOIL ORGANIC MATTER IN CHEMO-DENITRIFICATION

Until a few years ago, it was generally accepted that gaseous loss of nitrogen from soils occurred largely, if not entirely, through volatilization of ammonium or denitrification of nitrate. Recent work, however, has provided strong presumptive evidence that substantial gaseous loss of fertilizer nitrogen can occur through chemical decomposition of nitrite formed by nitrification of ammonium or ammonium-yielding fertilizers in soils (for reviews, see [39, 42]). The processes whereby nitrite is decomposed chemically in soils resemble denitrification in that they lead to volatilization of nitrogen as N_2 and N_2O, and CLARK [43] has proposed that the term chemo-denitrification be used to designate gaseous loss of nitrogen from soils through chemical decomposition of nitrite formed by nitrification of ammonium.

During the past five years we have studied the chemical decomposition of nitrite in soils by N^{15}-tracer techniques and have conducted a variety of investigations designed to elucidate the mechanisms of chemo-denitrification [42, 44-47]. This work has shown that nitrite decomposition in soils is controlled largely by soil pH and organic matter content and is accompanied by fixation of nitrite N and by formation of

NO_2 as well as N_2 and N_2O. The effect of pH on nitrite decomposition in soils is illustrated by the data in Table 5. Our work thus far does not permit definite conclusions about the reactions responsible for formation of NO_2, but it leaves very little doubt that the fixation of nitrite N and the evolution of N_2 and N_2O observed on treatment of soils with nitrite are due to reaction of nitrite with soil organic matter. Some of the evidence for this conclusion is given in Table 6, which shows that the amounts of nitrite N fixed and the amounts converted to N_2 on treatment of soils with nitrite in pH 5 buffer increase with increase in soil organic matter content, and that clay minerals and soils pretreated to remove organic matter do not promote nitrite decomposition at pH 5 and do not fix nitrite N or convert nitrite to N_2 or N_2O.

TABLE 5 — *Effect of soil pH on nitrite decomposition in soils* [42].

Soils		Average recovery of nitrite N (%)			
pH range	Number of samples	As nitrite (¹)	As nitrate (¹)	As fixed N (¹)	As NO_2 (²)
4.8-6.0	5	7	4	9	55
6.1-6.5	9	48	1	5	41
6.6-7.0	11	65	2	4	28
7.1-7.8	5	92	2	1	7

(¹) Average recovery in experiments in which 3-gm. samples of sterilized soils were treated with 1 ml. of $NaNO_2$ solution containing 600 μg. of N^{15}-enriched nitrite N and incubated for 4 days at 25°C.

(²) Average recovery in experiments in which 10-gm. samples of sterilized soils were treated with 3 ml. of $NaNO_2$ solution containing 1 mg. of nitrite N and incubated for 2 days at 25°C.

TABLE 6 — *Recovery of nitrite N added to pH 5 buffer containing various materials* [42] (1).

Material (2)	Recovery of nitrite N after 24 hours (%)						
	As nitrite	As nitrate	As NO_2	As N_2	As N_2O	As fixed N	Total (3)
—	82	3	15	0	0	0	100
Soil, 8.9% C (20 gm.)	44	3	15	21	1	15	99
Soil, 4.3% C (20 gm.)	59	4	14	12	1	9	99
Soil, 2.3% C (20 gm.)	68	3	15	7	<1	6	99
Soil, 0.3% C (20 gm.)	78	3	15	1	<1	2	99
Ignited soil (20 gm.)	83	3	14	0	0	0	100
Oxidized soil (20 gm.)	82	3	15	0	0	0	100
Quartz sand (20 gm.)	83	3	14	0	0	0	100
Clay (20 gm.) . . .	82	3	15	0	0	0	100
Humic acid (1 gm.) .	49	6	16	19	1	9	100
Lignin (1 gm.) . . .	23	8	13	27	1	27	99

(1) Fourteen ml. of pH 5 Na acetate buffer ($4M$) containing material specified were treated with 6 ml. of $NaNO_2$ solution containing 8 mg. of N^{15}-enriched nitrite N. Treatments were performed at 25°C in sealed vessels (helium-oxygen atmosphere) containing vial of $KMnO_4$ solution. NO_2 evolved was determined by analysis of $KMnO_4$ solution; N_2 and N_2O were determined by gas chromatography.

(2) Ignited soil was obtained by heating soil containing 8.9% C at 700°C for 4 hours and contained no organic matter. Oxidized soil was obtained by heating soil containing 4.3% C with KOBr-KOH solution and contained less than 0.01% C. CLAY was mixture consisting of equal parts (by weight) of kaolinite, illite, montmorillonite, and vermiculite.

(3) Recovery as (nitrite + nitrate + NO_2 + N_2 + N_2O + fixed)-N.

Several workers have postulated that inorganic materials promote nitrite decomposition in soils but our work indicates that inorganic soil constituents have little, if any, effect on nitrite decomposition under aerobic conditions and are not involved in the reactions leading to fixation of nitrite N or formation of N_2 and N_2O.

To identify the organic soil constituents that promote chemical decomposition of nitrite, we recently studied the reaction of nitrite with a wide range of organic materials selected to include organic substances that have been isolated from soils or are believed to contribute substantially to soil organic matter [42]. The data thus obtained indicate that phenolic substances are largely, if not entirely, responsible for the fixation of nitrite N and the formation of N_2 and N_2O observed on treatment of soils with nitrite. Of numerous organic materials tested, only those containing phenolic hydroxyl groups had the ability to decompose nitrite rapidly at pH 5 and to both fix nitrite N and convert nitrite to N_2 and N_2O under mildly acidic conditions. Table 7 summarizes data obtained in studies of the abilities of more than 100 organic materials to decompose nitrite at pH 5.

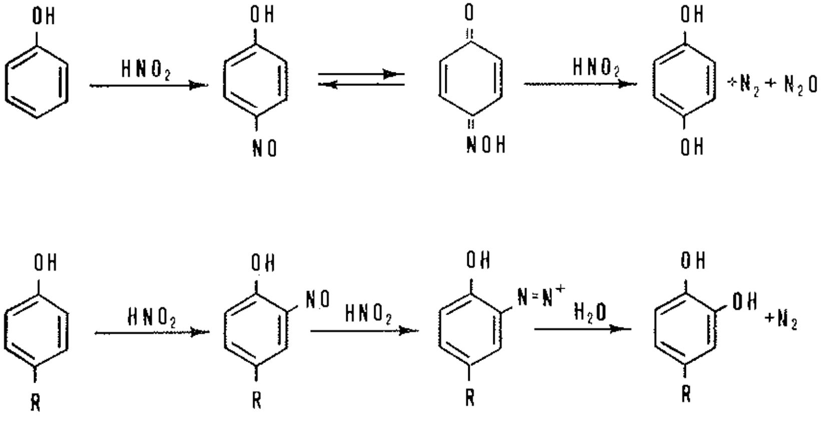


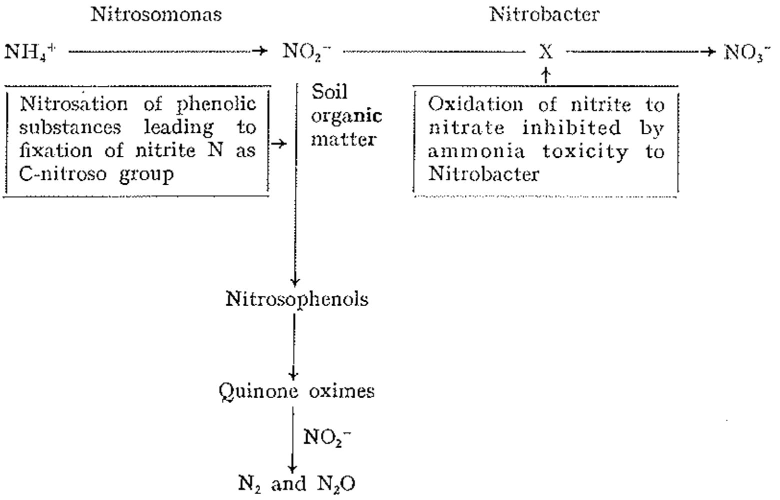
FIG. 2 — Postulated reactions of phenols with nitrous acid

TABLE 7 — *Abilities of various organic materials to decompose nitrite at pH* 5 [42] (¹).

Materials	Ability
High molecular weight:	
Polysaccharides	None or slight
Proteins	None
Nucleic acids	None or slight
Lipids	None or slight
Polyphenols (lignins, tannins, etc.)	Marked or very marked
Humic acids	Marked
Low molecular weight:	
Amino acids	None
Amino sugars	Slight
Amides	None
Purines and pyrimidines	None or slight
Carboxylic acids	None
Sugars and alcohols	None
Aromatic compounds (nonphenolic)	None
Phenols, monohydric	Marked or very marked
Phenols, dihydric	Very marked
Phenols, trihydric	Very marked

(¹) One mg. of nitrite N (as $NaNO_2$) was added to 20 ml. of pH 5 Na acetate buffer (0.5*M*) which contained 0.1 gm. of high molecular weight material or was 0.025*M* with respect to low molecular weight material and the mixture was shaken slowly for 24 hours at 25°C. Ability of material to decompose nitrite was determined by analysis for nitrite N after 24 hours. Where ability is described as slight, the recovery of nitrite was not much lower than the recovery obtained when no organic material was added (88-90%). Where ability is described as marked, the recovery of nitrite N did not exceed 45%; where ability is described as very marked, the recovery did not exceed 5% and was usually zero.

Several investigations have indicated that, under the acidic conditions used in the Van Slyke nitrous acid method of estimating free amino groups, phenolic compounds react with nitrous acid to form nitrosophenols which tautomerize to quinone oximes that are decomposed by nitrous acid with formation of N_2 and N_2O (see Fig. 2 for postulated reactions). We have obtained evidence that such reactions occur when phenolic substances are treated with nitrite under mildly acidic conditions and have concluded that the role of soil organic matter in chemo-denitrification can be represented by the following simplified diagram:



Gaseous loss of nitrogen from soils by chemo-denitrification is promoted by application of high rates of ammonium or ammonium-yielding fertilizers. This fertilizer practice is widespread in the United States and will become common in many countries during the next decade. It could lead to accumulation of fixed nitrite nitrogen in soils because there is evidence that this nitrogen is not readily mineralized by soil microorganisms [44, 48].

In view of the finding that soil organic matter can reduce nitrite to N_2 and N_2O under soil conditions, it is possible that the denitrification process in soils leading to gaseous loss of nitrate N as N_2 and N_2O may involve chemical decomposition of nitrite formed by microbial reduction of nitrate.

The accumulation of evidence that nonbiological decomposition of nitrite may be an important step in the nitrogen cycle is significant, because it is generally assumed that nonbiological reactions play little, if any, part in the transformations of organic matter and of the major nutrient elements in soils. Further evidence that this assumption deserves scrutiny has been provided by recent work showing that some pesticides are decomposed in soils by nonbiological reactions [49, 50].

It is clearly important that research on chemo-denitrification be encouraged because there is good reason to believe that this process has considerable practical significance under modern conditions of nitrogen fertilization and has been responsible for some of the gaseous losses of nitrogen previously attributed to « aerobic denitrification ». Recent tracer work in our laboratory has shown that substantial gaseous losses of fertilizer nitrogen occur when soils treated with urea and other ammonium-yielding fertilizers are incubated under aerobic conditions that do not lead to significant gaseous loss of nitrogen through volatilization of ammonium or denitrification of nitrate, and there seems little doubt that these losses occur through chemo-denitrification. Some of the results obtained in this work are reported in Table 8.

USE OF N^{15}-TRACER TECHNIQUES

Although it has long been evident that many aspects of the nitrogen cycle cannot be studied satisfactorily without use of N^{15}-tracer techniques, relatively few tracer investigations of nitrogen transformations in soils have been reported since the pioneer work of NORMAN and WERKMAN [51] in 1943. This is usually attributed to the high cost of the equipment and labeled nitrogen compounds required for work with N^{15}, but several problems besides cost have restricted use of N^{15}-tracer techniques, and these problems are not generally recognized. And since the U.S. National Committee for the International Biological Program has recently stressed the need for dissemination of information concerning use of N^{15} as a tracer in biological studies, it seems appropriate to discuss some of the problems limiting the application of N^{15}-tracer techniques in studies of nitrogen transformations in soils.

TABLE 8 — *Amounts of added N volatilized on incubation of soils treated with urea and potassium nitrate for 2 weeks* (¹).

Soil	Form of N added	% of added N volatilized	% of added N volatilized as NH_3
Primghar sicl	Urea	21.6	0.6
(pH 7.0)	KNO_3	0.1	0.0
Clarion sal	Urea	13.1	0.3
(pH 6.9)	KNO_3	0.3	0.0
Fayette sicl	Urea	16.6	0.1
(pH 6.5)	KNO_3	0.0	0.0

(¹) Soil samples were treated with 333 ppm. of N as N^{15}-enriched urea or KNO_3 and incubated at 30°C for 14 days at water level equivalent to 50% of water-holding capacity. A slow stream of water-saturated ammonia-free air was passed over the surface of each sample during incubation and the ammonia volatilized was trapped and determined.

Many of the difficulties experienced in use of N^{15} as a tracer in research on soil nitrogen transformations have been due to deficiencies in the methods available for N^{15} analysis. The standard procedure for N^{15} analysis is a three-stage technique involving conversion of the labeled nitrogen to ammonium, oxidation of the ammonium to N_2 by alkaline sodium hypobromite solution in the complete absence of air, and determination of the isotopic composition of the N_2 by mass spectrometer analysis. Besides requiring expensive equipment and special facilities, this procedure has the disadvantages that, when performed as usually recommended, it is complicated and time-consuming and requires a substantial amount (ca. 1 mg.) of nitrogen for satisfactory results. Moreover, there are many sources of error in this procedure (see Table 9), and considerable care is needed to obtain accurate results. The various sources of error will not be discussed here (for discussions, see [52-54]), but the importance of preventing cross-contamination of samples during distillation of ammonium for N^{15} analysis should be emphasized, because it is not generally appreciated that cross-contamination can lead to serious error. Simple methods of eliminating or greatly reducing cross-contamination of ammonium samples are now available [55, 56], but it is obvious from analyses of ammonium samples sent to us for mass spectrometer assay of N^{15} that some workers are reluctant to use these methods and are not convinced that cross-contamination can cause serious error in N^{15} analysis.

TABLE 9 — *Sources of error in N^{15} analysis.*

Stage of analysis	Source of error
1. Conversion of labeled N to ammonium	Incomplete conversion Contamination of ammonium by volatile amines Use of nonspecific method of conversion Cross-contamination during distillation of ammonium (incomplete distillation of previous sample) Loss of NH_3 during concentration of ammonium sample Contamination of ammonium sample by atmospheric NH_3
2. Conversion of ammonium to N_2 by oxidation with NaOBr	Incomplete removal of dissolved and gaseous N_2 before conversion Incomplete conversion Failure to recover dissolved N_2 after conversion Contamination of N_2 by N_2O and O_2 Air leakage during conversion
3. Mass spectrometer analysis of N_2	Contaminants in N_2 sample Air leakage during analysis Method of correction for air leakage

The most serious limitations of the procedure for N^{15} analysis have been the lack of satisfactory methods of converting different forms of labeled nitrogen to ammonium and the need for a substantial amount of nitrogen for mass spectrometer assay of N^{15}. But recent work [5, 24, 52, 55, 57-60] has provided methods of converting different forms of soil nitrogen to ammonium that permit both determination and isotope-ratio analysis of inorganic and organic forms of nitrogen in soils (total, exchangeable ammonium, fixed ammonium, nitrate, nitrite, hexosamine, amino acid, hydroxyamino acid, urea, etc.). These methods are simple and precise (the only special equipment required is the steam distillation apparatus shown in Fig. 3), and their development allows much more detailed tracer studies of nitrogen transformations in soils than have hitherto been possible. Moreover, recent work [52, 55] has shown that both the amount of ammonium and the time required for isotope-ratio analysis of ammonium can be greatly decreased by modification of the techniques normally used for this analysis, and it is now possible to obtain accurate and reproducible isotope-ratio values with as little as 40 μg. of ammonium N and to perform more than 40 N^{15} analysis of ammonium samples in a normal working day. These developments have eliminated many of the analytical problems encountered in use of N^{15} as a tracer in research on nitrogen transformations in soils.

The Dumas method would appear more suitable than the Kjeldahl procedure for isotope-ratio analysis of total soil N because it converts labeled nitrogen directly to N_2. Recent work in our laboratory [6] leaves little doubt that the Coleman Model 29A Nitrogen Analyzer (an automated Dumas instrument) could be adapted successfully for N^{15} analysis of soils by use of highly purified (completely nitrogen-free) CO_2 as carrier gas and by use of liquid N_2 to freeze out CO_2 in the N_2-CO_2 mixture obtained by Dumas combustion. But our experiences with the Dumas technique indicate that the customary procedure for N^{15} analysis of total soil N involving Kjeldahl digestion may prove more convenient and reliable than procedures based on use of Dumas combustion for conversion of total soil N to N_2.

The fundamental assumptions in use of N^{15} as a tracer are that the behavior of N^{15} in physical, chemical, and biological processes is identical to that of N^{14}, and that these processes do not therefore lead to isotopic fractionation or to variation

[6] *Bremner* - pag. 31

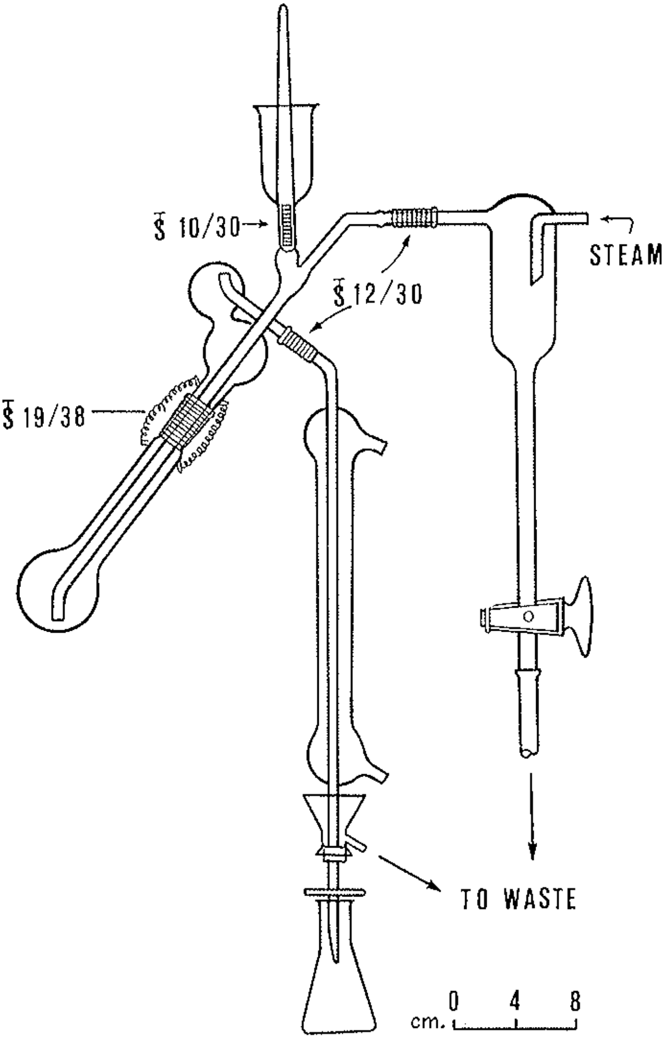


Fig. 3 — Steam distillation apparatus used for separation and estimation of ammonium in methods for determination and isotope-ratio analysis of different forms of nitrogen in soils (total, fixed ammonium, exchangeable ammonium, nitrate, nitrite, hydroxylamine, amino acid, hydroxyamino acid, hexosamine, urea, etc.).

in the relative abundance of the nitrogen isotopes in natural materials. There is evidence that these assumptions are not entirely valid. For example, the methods used commercially for concentration of N^{15} depend upon the fact that N^{15} and N^{14} in the form of ammonium ions or nitrogen oxides behave differently in exchange reactions, and evidence for nitrogen isotope fractionation in natural substances has been reported for peat, coal, rain, rocks, and minerals [61, 62]. Evidence for fractionation of nitrogen isotopes in soils has been provided by recent work showing that there is variation in the abundance of N^{15} in soils and in different forms of soil nitrogen [54, 63]. Some of the data obtained in this work are reported in Table 10. Data obtained in recent analyses [64, 65] of natural and synthetic amino acids and of manufactured inorganic nitrogen compounds are included because they provide additional evidence that the N^{15} content of natural materials can differ significantly from that of atmospheric N_2 (0.366 atom % N^{15}) and they emphasize the need for caution in use of manufactured nitrogen compounds as reference standards in isotopic analyses. The variation detected in the abundance of N^{15} in soils is small, but it must be considered in some types of tracer studies of nitrogen transformations in soils, and it indicates that the basic assumptions in such studies must be treated with some reserve.

TABLE 10 — *Excess of N^{15} found in various natural and synthetic materials.*

Material	N^{15} excess (atom %)
Soils (¹)	
Promise clay	0.0068
Grundy silt loam	0.0066
Sable silty clay loam	0.0057
Austin clay	0.0017
Cisne silt loam	0.0003
Fargo silty clay	− 0.0002
Webster clay loam	− 0.0008
Tama silt loam	− 0.0012
Amino acids (²)	
Glycine (natural)	0.0108
Alanine (synthetic)	0.0054
Arginine (natural)	0.0045
Threonine (synthetic)	− 0.0057
Glycine (synthetic)	− 0.0073
Serine (synthetic)	− 0.0376
Miscellaneous (³)	
Sodium nitrite	− 0.065
Sodium nitrite-sodium nitrate mixture	− 0.056

(¹) BREMNER et al. [54] and CHENG et al. [63].
(²) GAEBLER et al. [64].
(³) CLUSIUS and PIESBERGEN [65].

Since several laboratories are now contemplating purchase of mass spectrometers for N^{15}-tracer research, a *caveat emptor* may be timely here. The importance of selecting a mass spectrometer that can be used successfully for N^{15} analysis should be stressed because several workers who have acquired mass spectrometers in recent years have found it very difficult or impossible to use their instruments for nitrogen isotope-ratio analysis. It is easy to acquire a white elephant, because many types of mass spectrometers are now available commercially and it is difficult to obtain reliable advice about choice of an instrument for N^{15} analysis. For example, several manufacturers have recently recommended that mass spectrometers fitted with getter-ion pumps be purchased for nitrogen isotope-ratio analysis, but it is now evident that, although these pumps have valuable features, they introduce memory effects that vitiate mass spectrometer assay of N^{15}. Another problem in N^{15} analysis is that the inlet systems of mass spectrometers available commercially must be modified for isotope-ratio analysis of small amounts of nitrogen. This is not a serious problem with mass spectrometers fitted with glass inlet systems, but modern mass spectrometers have metallic inlet systems that are not readily modified.

In view of the problems encountered in selection and use of mass spectrometers for N^{15} analysis, it seems obvious that attempts should be made to persuade manufacturers to design instruments that can be used successfully and without modification for nitrogen isotope-ratio analysis. It would not be difficult for manufacturers to do this, because very few modifications of existing spectrometers are needed to make them suitable for N^{15} analysis.

The difficulties in use of mass spectrometry for N^{15} analysis have stimulated attempts to find alternative methods of N^{15} assay, and methods involving use of optical spectroscopy, nuclear magnetic resonance, infrared spectroscopy, microwave spectrography, and other physical techniques have been reported. The most promising of these techniques seems to be optical spectroscopy [66, 67]. The other techniques studied require instruments more costly than mass spectrometers or appear to have serious limitations when used for N^{15} analysis.

Enquiries we receive indicate that many people interested in using N^{15} as a tracer find it difficult to locate source of N^{15}-enriched compounds, and the discussions on the use of N^{15} in the recent report of the FAO-IAEA Technical Meeting at Braunschweig on « The Use of Isotopes in Soil Organic Matter Studies » may tend to confirm an apparently general impression that there are only two or three sources of N^{15} and that very few types of N^{15}-enriched compounds are available commercially. There are, in fact, at least seven commercial sources of N^{15} [52], and a wide variety of N^{15}-enriched compounds can be purchased. For example, Isocommerz GmbH (Lindenberger Weg 70, Berlin-Buch, D.D.R.) can supply more than 80 nitrogen compounds with low, medium, and high N^{15} enrichments, including amides, amino acids, amines, pyridine and quinoline derivatives, choline, ammonium salts, nitrates, nitrites, and hydroxylamine.

The high cost of N^{15}-enriched nitrogen compounds is usually mentioned when problems in the use of N^{15} are discussed, and this certainly restricts the use of N^{15} in field experiments. But compared with the instrumentation and labor costs in N^{15} work, the cost of the isotope is usually very small for laboratory experiments and reasonable even for pot experiments. The price of N^{15} in the United States currently exceeds $300 per gram, but it could be reduced to as little as $30-40 per gram by a substantial increase in the market for this isotope. The problem here is a paradox: the price of N^{15} is dictated by the demand for this isotope, and the demand is dictated by the price. The solution to this problem is for national or international organizations to make arrangements whereby manufacturers of N^{15}-enriched compounds are guaranteed the market they need to achieve a substantial reduction in the price of these compounds.

Since the cost of N^{15} is a serious hindrance to use of this isotope as a tracer in field experiments, the possibility that N^{15}-depleted nitrogen can be utilized for tracer research deserves attention. Large quantities of N^{15}-depleted nitrogen are obtained as a by-product of the ammonium exchange method used commercially for concentration of N^{15}. The nitrogen in this waste material contains about 0.03 atom % N^{15}, and it may prove useful as a tracer in some types of field experiments.

Although recent work has eliminated several serious analytical problems in tracer studies of nitrogen transformations in soils, it has not provided techniques urgently needed for tracer investigations of denitrification and other processes leading to gaseous loss of nitrogen. For detailed studies of these processes, it is necessary to use closed system techniques and to have methods that permit identification, estimation, and isotope-ratio analysis of the nitrogenous gases evolved from soils in closed systems.

The basic problem in use of closed systems is to maintain a closed atmosphere that is normal with respect to oxygen and carbon dioxide concentrations and to otherwise ensure that the process under investigation proceeds as in open systems. The difficulties in development of satisfactory closed system techniques cannot be discussed adequately here, but they can be illustrated by reference to recent experiences in our laboratory in work using closed systems. The purpose of this work was to estimate the amount of nitrogen volatilized as NO_2 through chemical decomposition of nitrite formed by nitrification of urea in soils. Preliminary experiments indicated that the failure of several investigators to detect NO_2 as a product of nitrite decomposition in soils had been due to their use of closed systems that promoted sorption of this gas by moist soils and conversion of NO_2 to nitrate. This conclusion was supported by our finding that, whereas very little nitrate is formed by treatment of soils with nitrite in open systems, large amounts are formed when the treatment with nitrite is performed in closed systems. This meant that, to detect and estimate formation of NO_2 by chemo-denitrification in closed systems, it is necessary to absorb this gas as soon as it is evolved, and we decided to use alkaline potassium permanganate solution for this purpose. We found, however, that when this reagent was used to study formation of NO_2 in closed systems, it practically eliminated gaseous loss of nitrogen through chemo-denitrification. This surprising result has been explained by our finding that, when soils treated with ammonium-yielding fertilizers are incubated in closed systems containing alkaline permanganate solutions, this solution sorbs CO_2 so effectively that it greatly retards oxidation of ammonium by the nitrifying organisms in soils.

Determination and isotope-ratio analysis of the nitrogenous gases evolved from soils present formidable analytical problems [53, 54, 68, 69], and it seems unlikely that these problems will be solved without extensive research. The recent development of helium-ionization detectors permits detection and estimation of very small amounts of N_2 and N_2O in gaseous mixtures by gas chromatographic techniques, but it is still very difficult to determine NO_2 by gas chromatography. Moreover, to utilize gas chromatography for estimation of N_2 in studies of processes leading to gaseous loss of nitrogen from soils, it is necessary to conduct these studies in closed systems having artificial atmospheres in which helium or another noble gas replaces N_2, and it is difficult to avoid leakage of air into such systems, which vitiates analyses for N_2. Also, there is evidence that gases of the helium group can cause physiological responses in biological systems [70]. Other difficulties encountered in development of satisfactory closed system techniques are evident from the valuable work of ROSS, MARTIN, and HENZELL [71].

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DISCUSSION

Chairman: FLAIG

FLAIG

Thank you very much, Dr. BREMNER, for your very interesting paper. I enjoyed very much your basic research work and your criticisms on the different methods. I think it is always useful that one develops new methods and compares them with other methods. This basic research work is always a progress in soil science.

WAKSMAN

I would like to make one comment and ask one question. I do not know whether you may have been too young during the First World War, but it has been a common practice in the United States to apply sodium chloride to the soil. The sodium chloride appeared to have a very important fertilizing effect, probably by liberating some ammonia fixed on the clay particles. It was a base exchange phenomenon. The question I would like to ask is, why have you introduced in such an excellent paper on the nitrogen distribution in the soil organic matter this archaic concept of humic acids?

BREMNER

I share your opinion about use of terms such as « humic acid ». But such terms are generally intelligibile and it is easier to talk about « humic acid preparations » than to define the method of preparation each time such preparations are mentioned.

WAKSMAN

I would prefer not to introduce so much confusion in this concept of soil organic matter. Why not say alkali extractable soil nitrogen?

BREMNER

I would say alkali extractable nitrogen if referring specifically to nitrogen extracted by alkali. But to describe humic acid nitrogen it would be necessary to say alkali-extractable, acid-precipitable nitrogen and perhaps add additional terms to indicate the method of isolation. What is needed is international agreement about the nomenclature of soil organic matter preparations.

REESE

You say in your paper that the nature of about half of this nitrogen remains obscure? Is it not likely that a good deal of this is of chitinous nature, i.e. the highly insoluble types of polymeric material in the soil which contain nitrogen? Are your extraction procedures such as to obtain these highly insoluble substances?

BREMNER

The procedure we use for hydrolysis of amino sugar complexes gives complete hydrolysis of chitin added to soils.

ALEXANDER

I would like to repeat a point made previously, namely, the potential danger of extrapolating from results which presumably apply only to intracellular products (such as the formation of hydroxymuconic semialdehyde) to extracellular processes which presumably take place in soil. Would you comment on the possible occurrence in soil of nitroso aromatics, nitro aromatics or oximes.

In regard to chitin and other aminopolysaccharides, if they are complexed with polyaromatics, would the polysaccharide become more resistant to acid hydrolysis, as it does in the case of enzymatic hydrolysis?

BREMNER

To my knowledge, there is no evidence for the occurrence of aromatic nitroso, aromatic nitro, or oxime nitrogen in soils. But our work indicates that soils receiving large applications of ammonium or ammonium-yielding fertilizers may in time contain significant amounts of nitroso nitrogen.

I cannot answer your question about hydrolysis of aminopolysaccharides complexed with polyaromatic compounds. We have not studied such complexes and I have not seen any report in the literature of their behaviour on acid hydrolysis.

ALEXANDER

In the last few years, many organic compounds containing oxidized nitrogen have been described. I do not know how one applies the information derived from pure cultures to soil.

SWABY

I wondered if you could enlarge a little on this idea of heterocyclic nitrogen. We have been looking for purines and pyrimidines in humic acid hydrolysates, and we get small quantities of these but so small that they cannot represent more than a tiny fraction of the heterocyclic nitrogen. Lately we have been looking for pyridine derivatives and having the greatest difficulty. We have done this for another reason, really; we have been studying decomposition of a weedicide, PICI-ORAM, which is a substituted pyridine, and we have the greatest difficulty in extracting this weedicide with many solvents and then analyzing it by U.V. spectrographic methods, because a great many of the aromatics that come out with these have similar absorptions. I wondered if you had thought about ways and means of actually identifying this hpothetical pyridine?

BREMNER

We have been trying to find reliable methods of identifying pyridine derivatives in soils for several years but have not thus far been successful.

WAKSMAN

I am very much interested in all the groups of micro-organisms of the soil; you mentioned only one and that happens to be one of my pet organisms. I want to call your attention to the fact that actonomycetes have been found capable of attacking resistant organic compounds.

BREMNER

Our work confirms previous evidence that the proteinase produced by *Streptomyces griseus* has very low specificity and exceptionally high proteolytic activity. It releases considerably less amino acid N from soil organic matter preparations than does hot 6N HCl, but is much more effective than other enzymes we have tested.

HERNANDO

I should like to ask some questions abont table 3. You show there the average nitrogen distribution before cultivation, after cultivation, before incubation and after incubation. I should like to know if you have a good agreement in the replication of these values because the differences are so close that the difference in replication may be higher than the value you put in the table.

BREMNER

The data reported represent the *average* values for 10 soils. There was good agreement among replicates.

HERNANDO

Thank you; that is what I wanted to know.

FRANZ

I would like to come back to the very interesting question of organic compounds with clay minerals. I remember that a few years ago we saw microscopic photographs in Prof. FLAIG's Institute where we saw that goethite was fixed on caolinite and that between goethite and the organic matter there was another fixation. Could it be possible in this theory you have explained that minerals like goethite can take the role of the iron you indicated here?

BREMNER

Yes, I believe so.

FLAIG

Electrodialized caolinite does not fix electrodialized humic acids, unless there are thin layers of iron hydroxides or aluminium hydroxides on the surface of the caolinite, as Dr. BREMNER told you. Also in the presence of calcium or magnesium ions, fixation occurs.

BRADFIELD

I would ask a question regarding the organic matter clay complex. Is there any evidence of a fairly definite limit to the amount of organic matter which can be fixed by clay as an organic clay complex, and what are the levels?

BREMNER

I have no answer to your question. We would like to know the answer.

BROADBENT

In connection with the proposed mechanism for the reaction of nitrites with components of organic matter, liberation of nitrogen gas and nitrous oxide, do you have any explanation or hypothesis for the occurrence of ammonia derived from the nitrite you reported?

BREMNER

I have no theory regarding the mechanism of ammonium release, but we have shown that nitrosophenols are decomposed by hot 6N HCl with formation of substantial amounts of ammonium and that nitrophenols yield only trace amounts of ammonium under the same conditions.

OBSERVATIONS ON THE SOIL ORGANIC MATTER FRACTION DECARBOXYLATED BY ACIDS (*)

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It is characteristic of soil organic matter that upon boiling in strong acids carbon dioxide is released. The methods used for determining this are modifications of the LEFEVRE and TOLLENS [27] procedure developed for the quantitative determination of uronic acids and involve boiling the soil for 4½ to 5 hours in 12% HCl. Using this method soils have been found to liberate from less than 1% to over 5% and, in a few soils, over 6% of their total organic carbon as CO_2. Since the CO_2 released represents only a portion of the molecule from which it is derived the original compound may form a large fraction of the soil organic matter. Present evidence indicates that the CO_2 liberated is derived mainly from carboxyl groups. Since not all of these groups are decarboxylated it is apparent that the particular chemical structure involved with the carboxyl groups or the presence of other groups must also be involved. It is also possible that a portion of the CO_2 arises from groups other than carboxyl. Knowledge of the specific nature of structures

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releasing CO_2 would aid in understanding the chemical nature of soil organic matter and of its origin and reactions.

The actual quantities of carbon dioxide liberated have been determined for a wide variety of soils by a considerable number of workers. Usually, the values obtained have been expressed in terms of uronic acid or polyuronide content of the soil organic matter. In view of the doubt as to whether uronic compounds are the actual source of the CO_2 released, values reported in the literature reviewed here have been recalculated where necessary and the carbon in the CO_2 expressed as percent of the total carbon present in the soil.

SHOREY and MARTIN [40] who first reported the liberation of CO_2 from soils by the LEFEVRE and TOLLENS procedure made determinations on surface samples of 11 soils varying in total organic carbon from 1 to over 53%. The amount of carbon liberated from these soils varied from 0.86 to 4.7% of the total carbon. Most of the values, however, fell in the range of 2.1 to 2.7% of the total carbon. WAKSMAN and REUSZER [49] using a small number of soils found losses of 1.0 to 2.6% of the carbon in peat and the highly organic layers of forest soils while the loss in the B_1 layer of a podzol soil was 5.4%. Cultivated mineral soils lost from 1.0 to 1.8% of their carbon. In an extensive study NORMAN and BARTHOLOMEW [34] determined the decarboxylation of the profile horizons of 20 soils representing 4 soil groups. The carbon dioxide liberated varied from 0.3 to 6.5% of the organic soil carbon with most of the values falling between 2.0 and 4.0%. In later work by FULLER [19] with 14 soils the amount of carbon liberated fell within the range of 2.0 to 3.0% for most of the soils. Subsequent determinations by workers in widely separate regions, but usually with only a few soils, have given similar values [7, 11, 24, 36, 37, 41, 42, 46, 47].

The proportion of the soil carbon capable of being liberated by boiling 12% HCl is usually lowest in the A horizon, high in the B horizon and somewhat variable in the C horizon but often even higher than in the B horizon. In the soils studied by NORMAN and BARTHOLOMEW [34] the carbon lost from surface samples by decarboxylation seldom reached 3%, values equalling or exceeding this usually occurred only in the lower portions of deep A horizons. In the B horizons the CO_2 released usually represented over 4% of the soil carbon. Comparatively few C horizons were studied and the decarboxylable content was somewhat variable. The B horizons of podzol soils are particularly rich in decarboxyable material. Presumably this is related to the high carboxyl content [38, 39] of these horizons. The proportion of the total carbon in decarboxyable form in a given soil, however, was found to increase with decrease in carbon content [20, 49]. The proportion of decarboxyable carbon in composts also was usually found to increase with advancing stages of decomposition [11, 42, 49] although exceptions to this are reported [19]. It appears from these findings that either the easily decarboxyable substances are more resistant to decomposition than the remainder of the soil organic matter or that with advancing biological decomposition they are synthesized by microbial action. Cropping and fertilization practices were found to effect the decarboxyable content of a soil as they affected the total carbon content [20]. Effects on the proportion of the carbon released by decarboxylation were small. However, cropping systems exhaustive of soil organic matter such as continuous maize led also to higher proportions of the carbon being lost in the decarboxylation procedure.

Early workers using the LEFEVRE and TOLLENS procedure on soil as a specific determination for uronic compounds ascribed the liberated CO_2 to the carboxyl groups of uronic acids. The quantities of carbon dioxide liberated indicated very large proportions of uronic compounds in the organic matter of many soils. Thus a CO_2 release equivalent to 4% of the total soil carbon would indicate that approximately one-fourth of the soil carbon was in uronic acid combination. With 5% of the soil carbon being liberated uronic carbon would represent 30%

of the soil carbon and in a few isolated instances this value was indicated as being as high as 45% of the total soil carbon.

Some caution with respect to acceptance of the liberated CO_2 representing only uronic acids was expressed early. Use of such terms as « apparent uronic acid » apparently also denoted some question as to the actual source of CO_2. These views were reinforced by the finding [40, 49] that the furfural yield in the decarboxylation procedure was insufficient to account for the uronic acid content of the soil organic matter indicated by the CO_2 yield. Searches for compounds other than uronides liberating CO_2 in the decarboxylation procedures, however, were generally unsuccessful. Thus NORMAN and MARTIN [35] found that of 8 common organic acids only pyruvic acid decarboxylated to an appreciable extent and this only to the exent of 5.4% of the total weight of the compound. Later FULLER, BARTHOLOMEW and NORMAN [21] found that 2-hydroxy, 4-hydroxy, and 3,4,5-trihydroxybenzoic acids, ellagic acid and phenolic acids from redwood bark did not decarboxylate appreciably. TRACEY [45] in 1948 summarized such studies by various workers on 43 compounds none of which released appreciable CO_2 except for pyruvic acid as already noted. TRACEY [45] added determinations on 45 additional compounds not previously studied. Of these only 6 liberated appreciable amounts of CO_2. These compounds, with the percentage of their total carbon lost in CO_2, were the following: Allantoin, 4.6-23%, dependent upon the quantity of sample used; alloxan, 7.4; 4-aminobenzoic acid, 1.8; ascorbic acid, 12.3; hypoxanthine, 6.3; urea, 36. In addition, it was found that the rate of decarboxylation determined as outlined by NORMAN [33] as a diagnostic method for detecting the presence of uronic acids, was quite similar for soil uronides [19]. These results gave no reason to doubt that uronides were the principal source of CO_2 lost in the decarboxylation procedure on soils and this view as to the origin of the CO_2

became widely accepted. Later work definitely established the presence of glucuronic acid [18] and galacturonic acid [43] in soil organic matter.

Other findings also cast doubt on the probability of uronides being the sole or even the principal source of the CO_2 lost in decarboxylation. MATTSON and KOUTLER-ANDERSON [30], however, were the first to seriously question the view that uronides were the principal source of the CO_2 liberated from soil organic matter. Their finding that humus contained little acidity resulting from hydrolysis led them to doubt the existence of large amounts of uronic acids in soil organic matter. They further found that allowing humus samples to stand under alkaline conditions in the presence of air led to increased amounts of decarboxyable substances. The greatest increase was found for an acid lignin prepared from beech leaves where there was no possibility of uronic acids being formed upon autooxidation. Increased knowledge regarding composition of the soil polysaccharide fraction cast further doubt upon the validity of the conclusion that CO_2 liberated in decarboxylation arises primarily from uronic acids. FORSYTH [18] isolated from a number of soils a polysaccharide material apparently common to all the soils. It contained 16% uronic anhydride or one molecule of uronic acid for each 6 molecules of hexose and pentose sugars. Others [14, 31, 50] in similar studies have reported uronic acid contents ranging from 10 to 20% of the soil polysaccharide fraction. As BREMNER [3] has pointed out, if decarboxylation values, are accepted as representing uronic acid, then on the basis of the sugar: uronic acid ratios occurring in soil polysaccharides absurdly high values result for polysaccharide content of the organic matter in many soils. Frequently a polysaccharide content exceeding the total soil organic matter would be indicated. Findings emphasizing these views, are reported by a number of workers [15, 41].

Values for uronic acid determined by a colorimetric method specific for these compounds [29] were much lower than those found by the decarboxylation procedure and were in reasonably good agreement with furfural values [12]. The differences between the two methods were particularly marked in the organic matter of podzol B horizons where the colorimetric method indicated very low values. The results of these determinations found corroboration in the difficulty of detecting uronic acids in these horizons even by procedure so sensitive as chromatographic tests [8, 8-*a*]. Neither was it possible to isolate appreciable amounts of polysaccharide from the organic matter of podzol B horizons [37]. It appears, therefore, that much of the CO_2 liberated from these horizons must rise from sources other than uronic acids. A number of other findings indicate the same conclusion for soil organic matter from other soil horizons also. While there is considerable similarity between the liberation rate of CO_2 from uronic acids and soil by 12% HCl a number of dissimilarities also occur. Thus soils were found to decarboxylate substantially at temperatures as low as 50 to 75°, at low acid concentrations such as 1% HCl, and with some soils even in boiling water [5, 7]. Under none of these conditions did uronic acids give appreciable decarboxylation. As a result of these findings it has been concluded that much of the CO_2 liberated from soil organic matter by acid decarboxylation is derived from sources other than uronic acids [11, 15, 41]. A more extensive review of this problem has recently been presented by DEUEL and MEHTA [9].

The foregoing conclusion has led to further search for compounds other than uronic acids undergoing decarboxylation in the LEFEVRE and TOLLENS procedure. MATTSON and KOUTLER-ANDERSSON suggested hydroxy acids as a possible source of CO_2. They were apparently led to this by a statement by GORTNER [23] that hydroxy acids in solution (malic being used as an example) undergo decarboxylation in light. There is, however, little evidence in the literature to support the suggestion that such acids liberate CO_2 in the decarboxylation procedure. GORTER [22] as early as 1908 observed that by heating chlorogenic acid in H_2SO_4 or HCl (5%) CO_2 was released. The CO_2 was found to come from the caffeic acid (3,4-dihydroxycinnamic acid) component. It was also noted that hydrocaffeic acid did not decarboxylate. DUBACH [11] stated that beta-keto acids, 2,4 and 2,6-dihydroxybenzoic acids, and N- and O- heterocyclic acids may be decarboxylated. Apparently, however, no data with these compounds have been reported. DAHN and HAUTH [6] reported the decarboxylation of polycarbonyl compounds as did TRACEY [45] in finding alloxan and allantoin to decarboxylate.

In the present work the susceptibility to decarboxylation of a number of additional compounds has been determined. The quantitative release of CO_2 was measured and for those compounds undergoing considerable decarboxylation the rate of release was determined both with HCl and H_2SO_4. The results are then compared with similar determinations made on a number of soils.

The decarboxylations were carried out in apparatus similar to that described by DICKSON, OTTERSON and LINK [10]. The decarboxylation vessel was a 500 ml. round bottom flask with 3 necks. A reflux condenser was fitted to one neck, one served for introduction of CO_2 free air for aeration and the other for introducing a thermometer with its bulb immersed in the reaction mixture. An aeration rate of 10 liters per hour as recommended by WHISTLER, MARTIN and HARRIS [51] was used in all determinations. A Y-tube was placed in the effluent line which permitted passage of the gas through either of two Meyer sulfur absorption bulbs containing N/12 NaOH. The aeration stream could thus be passed through one absorption bulb for a chosen period of time and then diverted through the other bulb. Determination of the CO_2 liberated in short periods and calculation of the rate of liberation per unit of time made it possible to detect changes in rate of decarboxylation with time and to determine any differences in the pattern of liberation of CO_2 from various soils and compounds. CO_2 liberated was determined at 10 minute intervals during the first hour, at 15 minute intervals during the second hour, at 30 minute intervals during the third hour, at the end of the fourth hour and at the end of the 4½ hour heating period. The beginning time was taken as the time at which the bath temperature reached 135°C. Boiling of the reaction mixture started within 5 or 6 minutes after this time. Temperature of the boiling 12% HCl reaction mixture was about 105°C and for 12% H_2SO_4 about 103°C. Raising the temperature of the wax bath did not affect the temperature within the flask but led to more vigorous boiling and increased somewhat the liberation of CO_2.

The amount of carbon released as CO_2 during each collection period was calculated as mg per hour per gm of substance in the case of known compounds and per gm of carbon in the case of soils. The resulting values were plotted at the midpoint of the time represented by any collection period.

For the known compounds one gm samples were used for the decarboxylation unless otherwise indicated. For the soils 30 gm samples were used. In all cases 150 ml of 12% (w/v) acid was used. With all soils the sample and acid were placed in the boiling flask late in the afternoon and then aerated overnight at room temperature to remove any inorganic carbonate or absorbed CO_2 present [21]. The next morning the wax bath in which the boiling flask was immersed was heated to 135°C. at which time collection of CO_2 for the determination was begun. Approximately 30 minutes were required to reach this temperature and very little CO_2 was liberated during this time. The bath was heated by an immersion heater the temperature of which was controlled by a variable transformer. It was found necessary to use a stirrer to maintain a uniform temperature in the bath. In this manner it was possible to maintain a precise constant temperature of the bath.

A description of the soils used in this work is given in table 1. With the exception of the A_1 horizons of the podzols and the prairie soil the samples were all quite low in organic matter. Determinations were made in soils primarily to obtain data on the characteristics of CO_2 liberation from soil organic matter which could be used for comparison with similar data obtained from known compounds.

The chemical compounds used were chosen either on the basis of similarity to chemical structures postulated as being present in soil organic matter, or of having been suggested as undergoing decarboxylation with no actual data reported, or of possibly aiding in understanding the nature of the decarboxylation process. Not all desired chemicals were available for study. The compounds used were all of a high degree of purity, many of them being of reagent grade.

The amount of carbon liberated in the decarboxylation of the various soils is shown in table 2. The values fell within the limits previously reported by other workers. The organic matter of the B horizons was found in general to have a higher decarboxylable content than the A horizons, the differences, however, were less marked than usually found by others. A more detailed consideration will be given later in a discussion of data on the rate at which CO_2 was liberated.

Among the known compounds there were 71 which liberated little or no CO_2 in the decarboxylation procedure (table 3). Twenty-five liberated no CO_2 while none of the remainder liberated more than 1.7 gm of carbon from one gram of compound. No compound liberated appreciable CO_2 unless the carboxyl group was present.

The presence of certain groups of compounds in this list may be noted. Aliphatic acids, except for a limited number to be discussed later, did not release CO_2 to any appreciable extent. These included acids of varying chain length and degree of bond saturation. Seven hydroxy acids were in this group — citric, 2-hydroxyisobutyric, lactic, malic, 2-hydroxybutyric, mucic and tartaric. A number of these have been

TABLE I — *Soils used and certain of their characteristics.*

Name	Soil group	Horizon	Depth inches	pH	Percent organic carbon
Carrington loam					
C2918	Gray-brown podzolic			4.8	1.19
C2919			22-43	4.6	0.32
Chalmers silt loam	Humic-Gley	Ap	0-6	6.3	1.79
		B	16-24	7.7	0.63
Hagerstown silt loam					
S22914	Red-yellow podzolic	A_1	0.7	6.2	1.14
S22917		B_2	19.30	5.4	0.48
Kalkaska sand	Podzol	A_1	0-5	4.4	8.60
		B_{21}	18-22	4.3	1.79
		B_{22}	22-37	4.0	1.08
Marshall silt loam	Brunizem	A_1	0-11	4.8	2.78
		A_3	11-20	5.3	1.52
		B_1	20-29	5.6	0.94
		B_2	29-37	5.7	0.55
		C	37-44	5.8	0.31
Onaway loam	Podzol	A_1	0-5	4.4	3.18
		B_2	6-12	4.2	1.33
Russell silt loam					
C3175	Gray-brown podzolic		2-8	4.1	0.85
C3178			23-36	4.4	0.27
Saugatuck sand	Groundwater podzol	A_1	0-5	4.0	5.67
		B_{21}	17-23	3.8	1.76
		B_{22}	23-34	4.1	0.97
Cherokee silt loam	Planosol	A_1	0-7½	4.3	1.78
		A_{21}	7½-13	4.3	0.97
		B_{21}	16-24	4.2	0.87
		B_{22}	24-36	4.3	0.55
		C_2	47-60	5.2	0.19

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TABLE 2 — *Liberation of carbon as carbon dioxide from 30 grams of various soils upon boiling in 12% HCl for 4½ hours.*

Soil	Horizon or depth	Mg. C liberated	% of total C liberated
Carrington		6.4	1.79
	22-43	2.1	2.19
Chalmers	Ap	11.8	2.19
	B	4.7	2.49
Hagerstown	A_1	5.5	1.61
	B_2	1.7	1.18
Kalkaska	A_1	13.8	0.53
	B_{21}	11.6	2.16
	B_{22}	6.7	2.07
Marshall	A_1	15.8	1.89
	A_3	9.8	2.15
	B_1	6.1	2.16
	B_2	3.2	1.94
	C	1.8	1.94
Onaway	A_1	10.7	1.12
	B_2	8.2	2.06
Russell	2-8	6.3	2.50
	23-36	3.7	4.57
Saugatuck	A_1	10.6	0.62
	B_{21}	7.4	1.40
	B_{22}	5.2	1.78
Cherokee	A_1	12.2	2.28
	A_{21}	6.9	2.36
	B_{21}	6.4	2.43
	B_{22}	4.2	2.58
	C_2	1.3	2.28

TABLE 3 — *Compounds liberating no or only very small amounts of carbon dioxide upon boiling in 12% HCl for 4½ hours (1 gm of compound used).*

Compound	Mg. C liberated
Acetic acid	0.0
Acetyl glucosamine	0.0
Aminophenylacetic acid	1.3
1,4-Benzenedicarboxylic acid (terephthalic)	0.0
1,2-Benzenediol (pyrocatechol)	0.0
1,3-Benzenediol (resorcinol)	0.0
1,4-Benzenediol (hydroquinone)	0.05
1,2,3-Benzenetriol (pyrogallol)	0.1
1,3,5-Benzenetriol (phloroglucinol)	0.0
Benzoic acid	0.6
Catechin	0.0
Cellulose	0.6
Citric acid	0.0
Crotonic acid	0.0
3,4-Dihydroxybenzaldehyde (protocatechualdehyde)	0.7
3,4-Dihydroxybenzoic acid (protocatechuic)	0.2
3,4-Dihydro-2H-pyran-2-carboxylic acid	1.5
3,5-Dihydroxy-2-napthoic acid	0.0
2,6-Dihydroxypyridine-4-carboxylic acid (citrazinic)	1.1
4,8-Dihydroxyquinoline-2-carboxylic acid (Xanthurenic)	0.0
Diphenylglycolic acid (benzilic)	0.5
Formic acid	0.3
Glucose	0.6
d-Glucosamine hydrochloride	0.8
4-Hydroxybenzaldehyde	0.0
4-Hydroxy-3-methoxybenzaldehyde (vanillin)	0.0
2-Hydroxybenzoic acid	0.7
3-Hydroxybenzoic acid	0.0
4-Hydroxybenzoic acid	1.4
4-Hydroxy-3-methoxybenzoic acid (vanillic)	0.4
4-Hydroxy-3,5-methoxybenzoic acid (syringic)	0.2
2-Hydroxyisobutyric acid	0.2
5-Hydroxyisophthalic acid	0.0
Ketomalonic acid	1.5
Kojic acid	1.7
Lactic acid	0.3
Maleic acid	0.0
Maleic anhydride	0.0
dl-Malic acid	0.0
2-Methoxybenzoic acid	0.2
4-Methoxybenzoic acid anisic)	0.05
Mucic acid	0.6
Mucochloric acid	1.0
Muconic acid (trans, trans)	0.8
Orotic acid	0.4
Oxalic acid	1.4
Phenoxyacetic acid	0.0
α-Phenoxypropionic acid	1.1
Phenylacetic acid	1.5
dl-Phenylalanine	1.0
2-Phenylbutyric acid	0.8
4-Phenylbutyric acid	0.8
3-Phenylenedioxydiacetic acid	1.4
Phenylglycolic acid (*d*-mandelic)	0.0
N-Phenylmaleamic acid	0.4
Phenylpropionate	0.6
Phenylsuccinic acid	0.6
Potassium hydrogen phthalate	0.6
2-Pyridinecarboxylic acid (*α*-picolinic)	0.1
3-Pyridinecarboxylic acid (nicotinic)	0.5
Quinoline	0.2
2-Quinolinecarboxylic acid (quinaldic)	0.0
6-Quinolinecarboxylic acid	0.0
Succinic acid	0.0
Tannin	0.7
d-Tartaric acid	0.0
1,3,4,5-Tetrahydroxycyclohexanecarboxylic acid (*d*-quinic)	0.0
3,4,5-Trihydroxybenzoic acid (gallic)	0.6
3,4,5-Trihydroxy-1-cyclohexene-1-carboxylic acid (shikimic)	0.6
dl-Tryptophan	0.4
l-Tyrosine	1.0

studied by previous workers who also found no significant decarboxylation. Of a limited number of keto acids tested ketomalonic lost very little CO_2 while *a*-ketoglutaric and pyruvic acids decarboxylated slightly more. A number of phenyl and phenoxy acids lost very little CO_2 . This was true also of three aromatic amino acids, phenylalanine, its hydroxy form tyrosine, and the heterocyclic acid tryptophane.

Benzoic acid, its 2-,3-, and 4-hydroxy forms, the 3,4-dihydroxy form, and the 3,4-5-trihydroxy form did not decarboxylate appreciably. Neither did methoxy forms of benzoic acid lose CO_2. Polyhydroxy phenols did not lose CO_2. This was also the case of the hydroxy polycylic compounds catechin and tannin. With two exceptions to be noted later heterocyclic N compounds such as various acid forms of pyridine and quinoline did not give appreciable decarboxylation. These included nicotinic acid said by DUBACH [14] to decarboxylate to the extent of 25% of its carboxyl carbon.

As already indicated cinnamic acid has been reported to undergo decarboxylation in the LEFEVRE and TOLLENS procedure. Since derivatives of this compound are abundant in lignin which appears to enter into the formation of soil organic matter, it was of special interest to determine the susceptibility of a variety of these compounds to decarboxylation. The results are shown in table 4. It is immediately apparent that the compounds tested lost from essentially none to almost all of their carboxyl carbon. The extent of decarboxylation was dependent upon the nature and location of substituent groups on the aromatic ring. Since GORTER [22] noted that hydrocaffeic acid did not decarboxylate and hydrocinnamic acid was found in the present work not to decarboxylate, it is probable that the double bond in the side chain is also essential. Cinnamic acid decarboxylated only to the extent of 5.5% of its carboxyl carbon. With hydroxyl groups present on the ring extensive decarboxylation took place except only when the hydroxyl was in the 3-position of the ring. With a single hydroxyl group in the molecule in the 4-position 84% of the carboxyl carbon was lost. This was more than twice that liberated with hydroxyl only on the 2-carbon. The 3,4-dihydroxy form lost only two-thirds as much CO_2 as the 4-hydroxy compounds. A methoxy group on the 3-carbon had almost the same effect in reducing the amount of CO_2 lost. However, the 2,4,5-trimethoxy form liberated CO_2 equivalent to that of the 4-hydroxy-3-methoxy form. With an amino group in the 4-position 28% of the carboxyl carbon was lost. With nitro groups in the 2- or 4-position there was practically no decarboxylation. When allyl, ethyl, or methyl groups were substituted for the hydrogen in the carboxyl group decarboxylation was prevented.

TABLE 4 — *Carbon dioxide liberated from* 1 *gm of various cinnamic acid compounds upon boiling in* 12% *HCl for* 4½ *hours.*

Compound	Mg. C liberated	Percent of COOH-C liberated
Cinnamic (trans)	4.5	5.5
2-Hydroxycinnamic (o-coumaric)	29.7	40.6
3-Hydroxycinnamic (m- »)	2.6	3.5
4-Hydroxycinnamic (p- »)	61.5	84.1
3,4-Dihydroxycinnamic (caffeic)	44.4	66.1
4-Hydroxy-3-methoxycinnamic (ferulic)	43.7	71.9
2,4,5-Trimethoxycinnamic	35.7	70.9
4-Aminocinnamic	20.9	28.5
Hydrocinnamic	0.6	—
Allylcinnamate	1.8	—
Ethylcinnamate	0.2	—
Methylcinnamate	0.4	—
2-Nitrocinnamic	0.1	—
4-Nitrocinnamic	0.5	—

Other compounds which liberated appreciable quantities of CO_2 are listed in table 5. Two of these, dihydroxymaleic and dihydroxytartaric acids, underwent extensive decarboxylation, the former losing 86% of its carboxyl carbon, the latter 48%. Apparently in the dihydroxytartaric acid only one of the carboxyl groups underwent decarboxylation. Three acids, N-carbamylmaleamic, glucosaminic and malonic lost about one-fifth of their carboxyl carbon, the quantities lost varied from 17 to 20% of such carbon. The heterocyclic N compound 2,4-dihydroxypyrimidine-5-carboxylic acid lost 10.7% of its carboxyl carbon while pyridine-2,3-dicarboxylic acid (quinolinic) lost 2.5%. The three forms of pyruvic acid lost between 5.9 and 7.4% of their carboxyl carbon and *a*-ketoglutaric acid lost only 2.0%. Phenylglycine lost 3.2% of its carboxyl carbon.

TABLE 5 — *Organic acids other than cinnamic acid forms liberating appreciable amounts of carbon dioxide upon boiling in* 12% *HCl for* 4½ *hours* (1 *gm of compound used*).

Compound	Mg. C liberated	Percent of COOH-C liberated
N-Carbamylmaleamic (maleuric)	15.8	20.7
Dihydroxymaleic	139.5	86.0
2,4-Dihydroxypyrimidine-5-carboxylic	8.2	10.7
Dihydroxytartaric	63.4	48.1
Glucosaminic	20.0	22.8
4-Hydroxyphenylpyruvic	4.4	6.5
a-Ketoglutaric	6.2	2.9
Malonic	39.6	17.2
Phenylglycine	2.5	3.2
Phenylpyruvic	3.8	5.9
Pyruvic	8.0	7.4
Pyridine-2,3-dicarboxylic (quinolinic)	3.6	2.5

Determination of the rate at which decarboxylation by 12% HCl takes place has been shown to be of value in differentiating uronic from nonuronic compounds (33,51). In rate curves from such data uronides characteristically showed high peak rates very early in the decarboxylation procedure dropping off rapidly to much lower values. On the other hand nonuronic substances decarboxylated at a slow, usually uniform rate throughout the determination. FULLER, BARTHOLOMEW and NORMAN [21] and FULLER [19] have applied this technique to soils finding that they also have a high initial rate of CO_2 liberation with a very rapid decrease similar to that of uronic acid compounds.

In work reported to date HCl has almost invariably been used as the decarboxylating agent. Because of its low volatility H_2SO_4 would seem to have advantages for use in the long refluxing and aerating procedure used for determining decarboxylation although LINK and NIEMANN [28] found it to liberate less CO_2 from uronides than did HCl. Trials with this acid showed that it produced little decarboxylation of uronic compounds but extensive decarboxylation of soils and a number of nonuronic chemicals. It appeared, therefore, that comparison of results of CO_2 release by H_2SO_4 and HCl might be useful in differentiating uronic and nonuronic decarboxylating substances. Parallel determination were made using HCl and H_2SO_4, both at 12% concentration, as decarboxylating agents for soils and compounds known to be decarboxylated to a considerable extent. Data for such compounds were of particular interest since rate curves have not previously been established for them.

Results obtained by use of these two acids with uronic acid and pectin are shown in figure 1. With HCl the typical rapid rise of CO_2 loss to a rather sharp peak followed by a slower decline to low values was found. The peak rate in these determinations occurred between 30 and 40 minutes after the beginning of the determination. This is in fairly good agree-

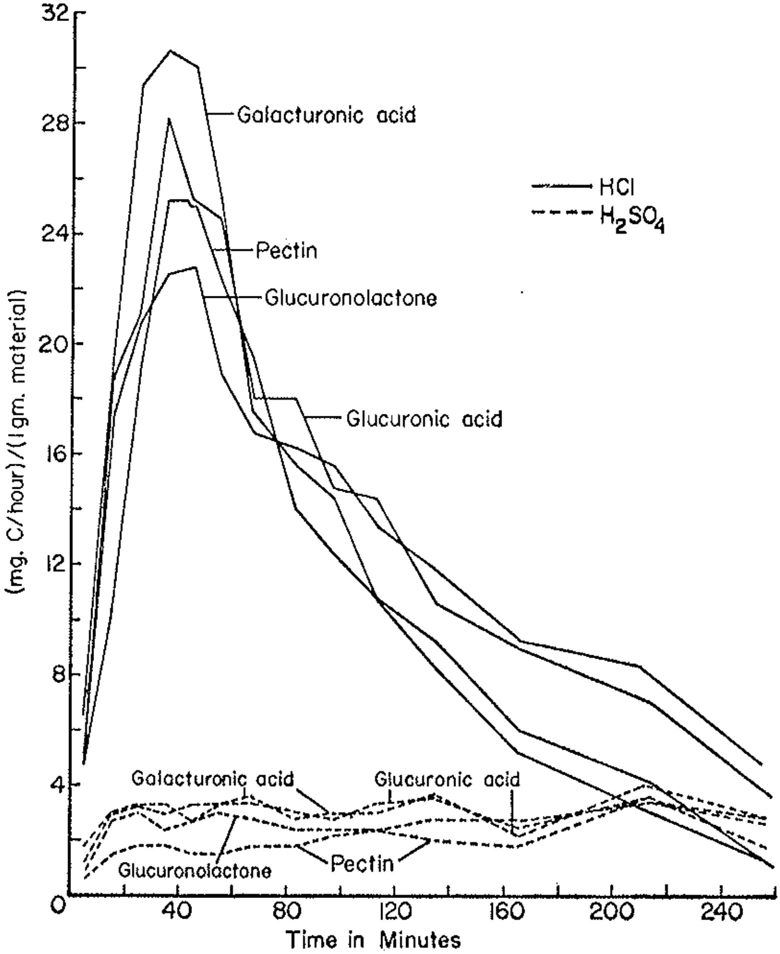
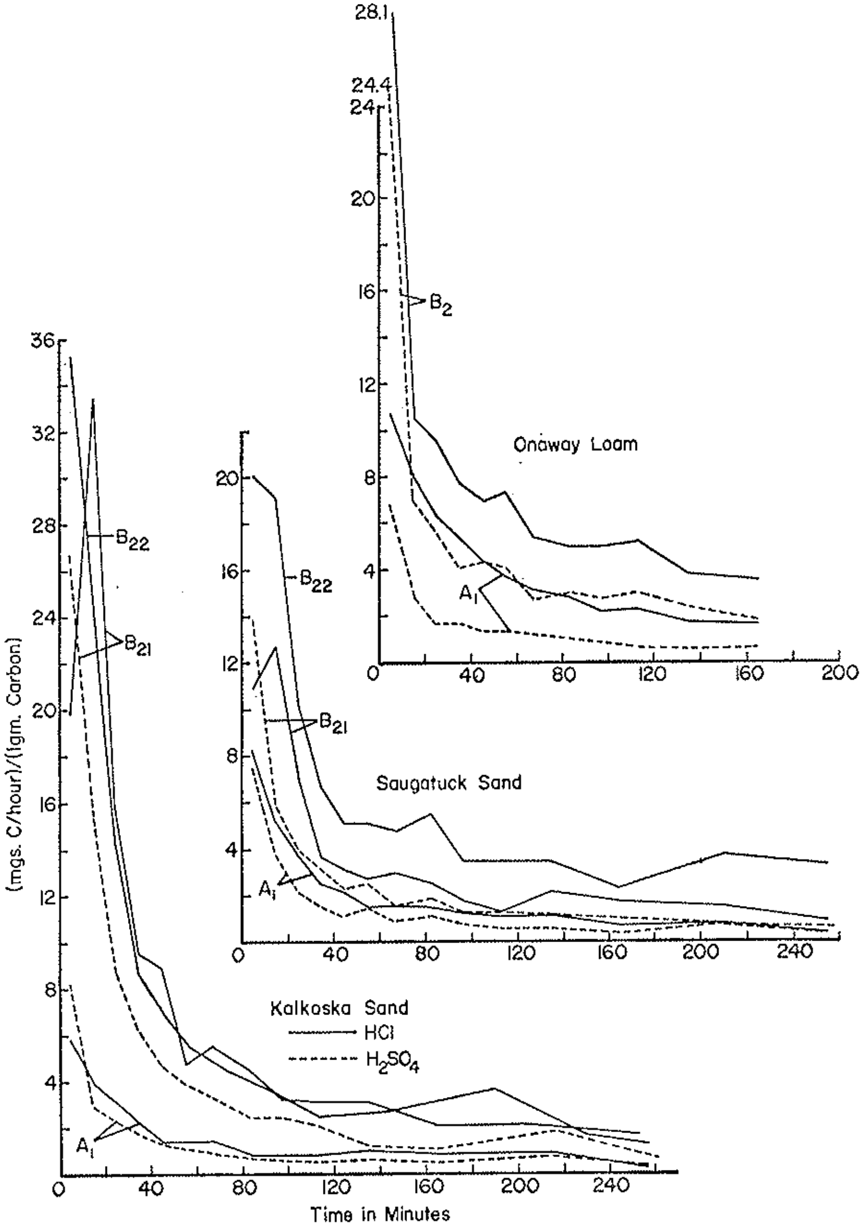


FIG. 1 — The rate of CO_2 liberation from uronic acid compounds.

ment with results reported by others [2, 19, 21] for uronic acid containing substances. H_2SO_4, in contrast, produced only a slow, fairly constant release of CO_2 with no evidence of a distinct peak in rate of release. It seems obvious from these results that a different reaction is brought about on uronic compounds by H_2SO_4 and that it is not capable of producing the decarboxylation of uronic compounds typically brought about by HCl.

In figure 2 are shown results of similar determinations made on three podzol soils. Here, as with other soils shown in figures 3, 4, and 5, a pronounced peak in CO_2 release rate was reached with both acids during the initial period of the determination, that is within 10 minutes after boiling began. Exceptions to this were the B_{21} horizons of the Kalkaska and Saugatuck soils with peak rates in the 10 to 20 minutes period when HCl was the decarboxylating acid. Typically the true podzols were characterized by a high initial rate, 2 to 4 times higher in the B than in the A horizons, which dropped rapidly to low values. The Hagerstown soil, a red-yellow podzolic, had the same pattern in a very pronounced manner. The lower horizons of the Marshall, Cherokee and Russell soils had very high initial decarboxylation rates which decreased rapidly except in the Cherokee. Decarboxylation in all of these levelled off at rates higher than was the case for the podzol soils. The relatively high, persistent rate was particularly marked in the Russel and Cherokee soils and occurred at a lower level in the Marshall and Chalmers soils. These soils particularly appear to have two main components undergoing decarboxylation, one liberating CO_2 very rapidly, the other losing it slowly and constantly over a long period of time.

The total quantity of CO_2 released was less with H_2SO_4 than with HCl. Decarboxylation by H_2SO_4 usually was at a somewhat slower rate than with HCl. Occasionally, however, the situation was reversed in the early part of the decarboxylation period. Curves for the Chalmers and the upper horizon of the Marshall soil suggest that agreement between H_2SO_4 and HCl decarboxylation rates was somewhat closer with the easily decarboxyable component than with the slowly decarboxylating one. The general pattern of decarboxylation was similar for


28.1
24.4
24
20
16
12
8
4
B2
Onaway Loam
A1
0
40
80
120
160
200
Saugatuck Sand
B22
B21
A1
240
36
32
28
24
(mgs. C/hour)/(1gm. Carbon)
Kalkoska Sand
HCl
H2SO4
Time in Minutes

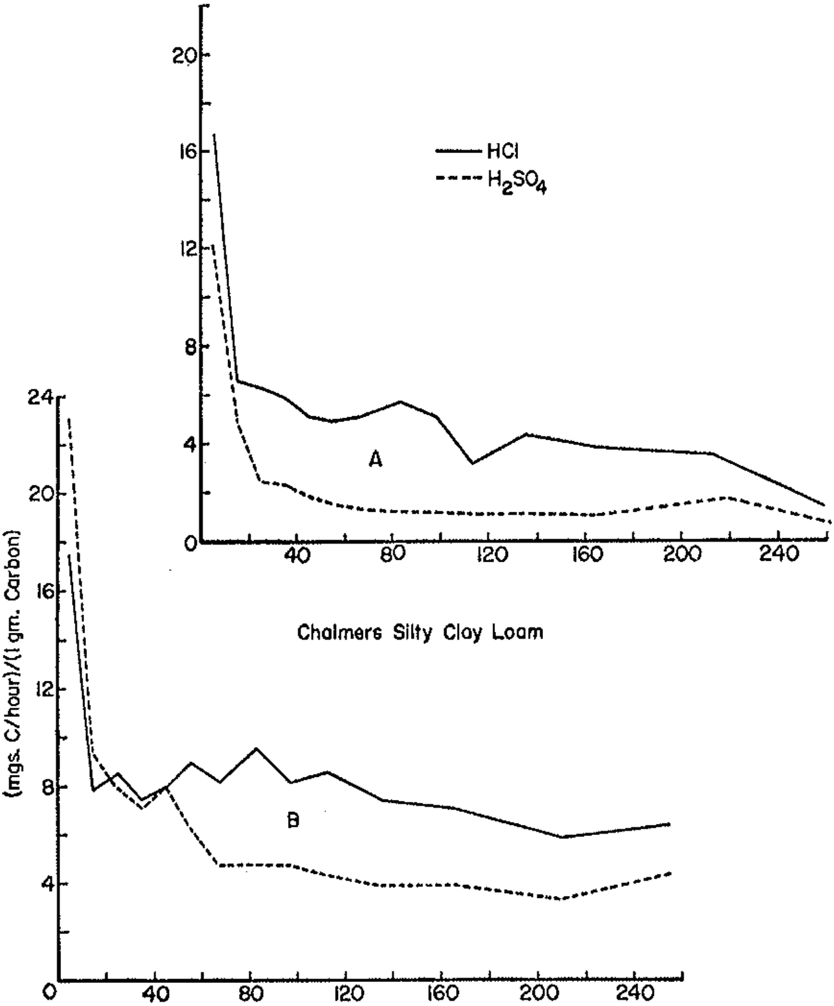


FIG. 3 — The rate of CO_2 liberation from Chalmers silty clay loam soil.

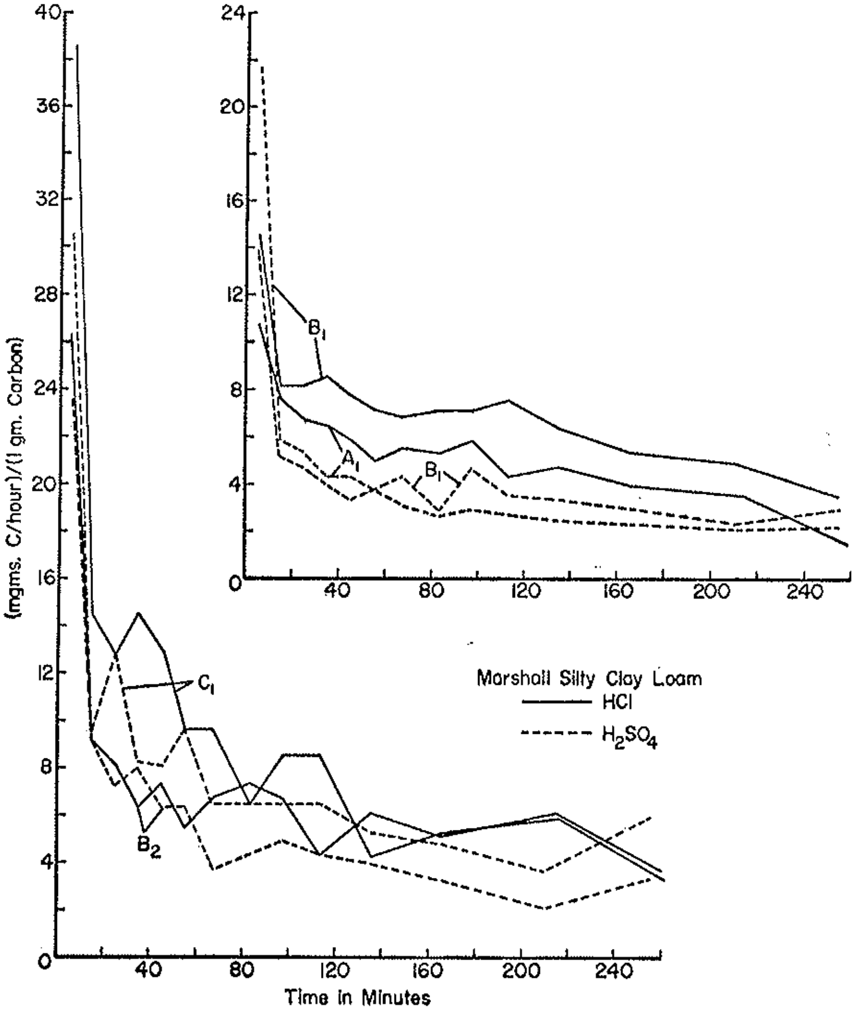


FIG. 4 — The rate of CO_2 liberation from Marshall silt loam soil.

HCl and H_2SO_4 in contrast to their greatly different action on uronic compounds. These results, therefore, are in agreement with others already cited in indicating that uronides are not

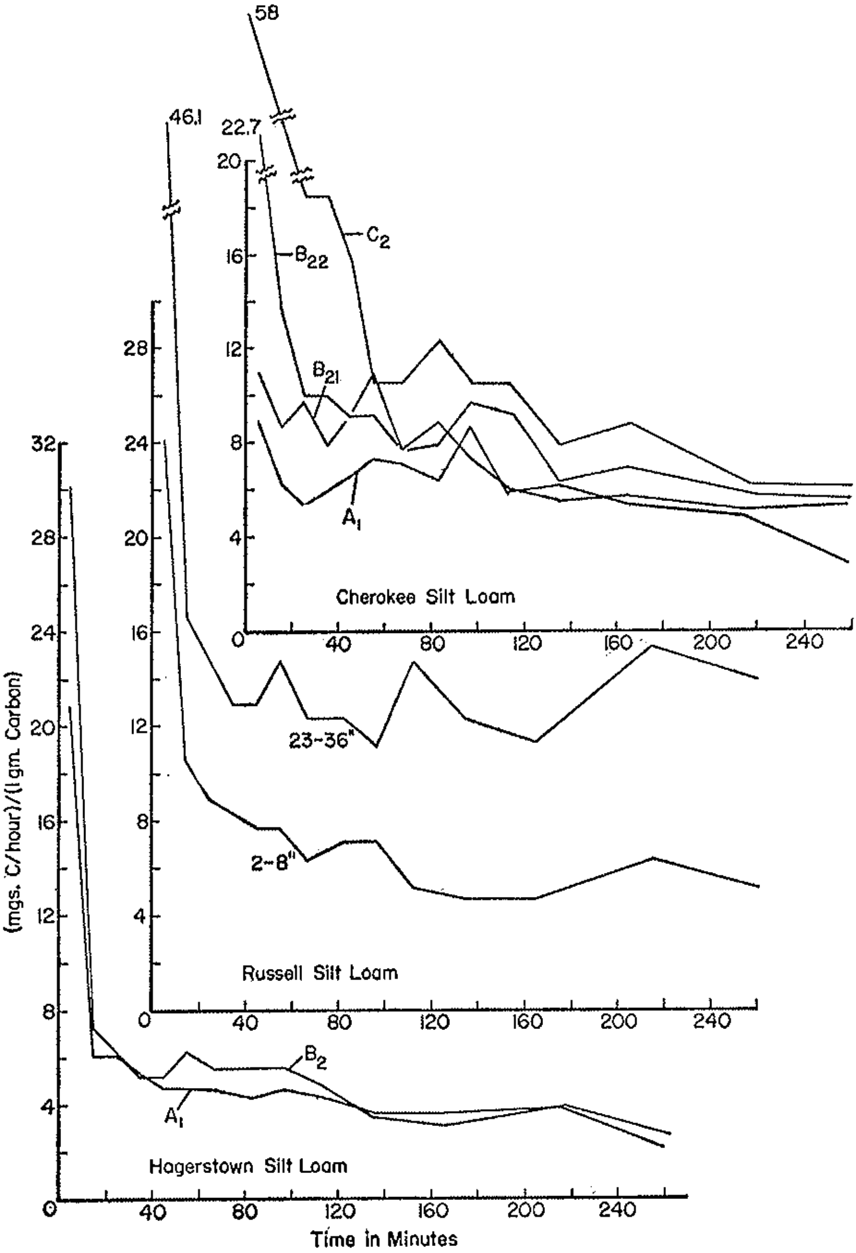


FIG. 5 — The rate of CO_2 liberation from Cherokee, Hagerstown and Russell soils.

the only compounds in soil organic matter decarboxylated in the LEFEVRE and TOLLENS procedure. It appears further that probably a high proportion of the CO_2 released originates from compounds other than uronides.

Rate of decarboxylation determinations were also made on most of the acids listed in tables 4 and 5 as undergoing appreciable decarboxylation. In figure 6 are shown CO_2 liberation curves for those compounds which underwent decarboxylation to a lesser extent than others. A variety of types of decarboxylation rates occur among these compounds. Cinnamic acid and 3-hydroxycinnamic acid lost CO_2 only to a very small extent and at a very slow, almost constant rate although a slight peak existed at the initiation of decarboxylation. α-Ketoglutaric acid had a definite peak of CO_2 liberation in the initial period of the determination and the rate then dropped slowly to low values. The three acids — 4-aminocinnamic, carbamylmaleamic, and glucosaminic — all reacted similarly, rising to a peak decarboxylation rate after 30 to 40 minutes and then maintaining a fairly constant rate for more than an hour afterwards. The rate of carbon dioxide liberation from these acids resembled to a considerable extent that of soils apparently having a slowly decarboxylating component. These compounds differ in molecular structure but are alike in having an amino group present in each. The release of CO_2 from malonic acid had a course somewhat resembling that of the three preceding acids but at a higher rate and showing a definite peak after 40 minutes of boiling. The 2-hydroxycinnamic acid liberated CO_2 in a manner resembling that of the uronic acids but having a broader peak.

The other cinnamic acids losing much CO_2 were decarboxylated with great rapidity, the peak rate for each compound occurring between 10 and 20 minutes after beginning of the determination and the reaction being almost complete after 90 minutes of boiling. The maximum rates of CO_2 liberation were distinctly higher for the 4-hydroxy- and 4-hydroxy-3-me-

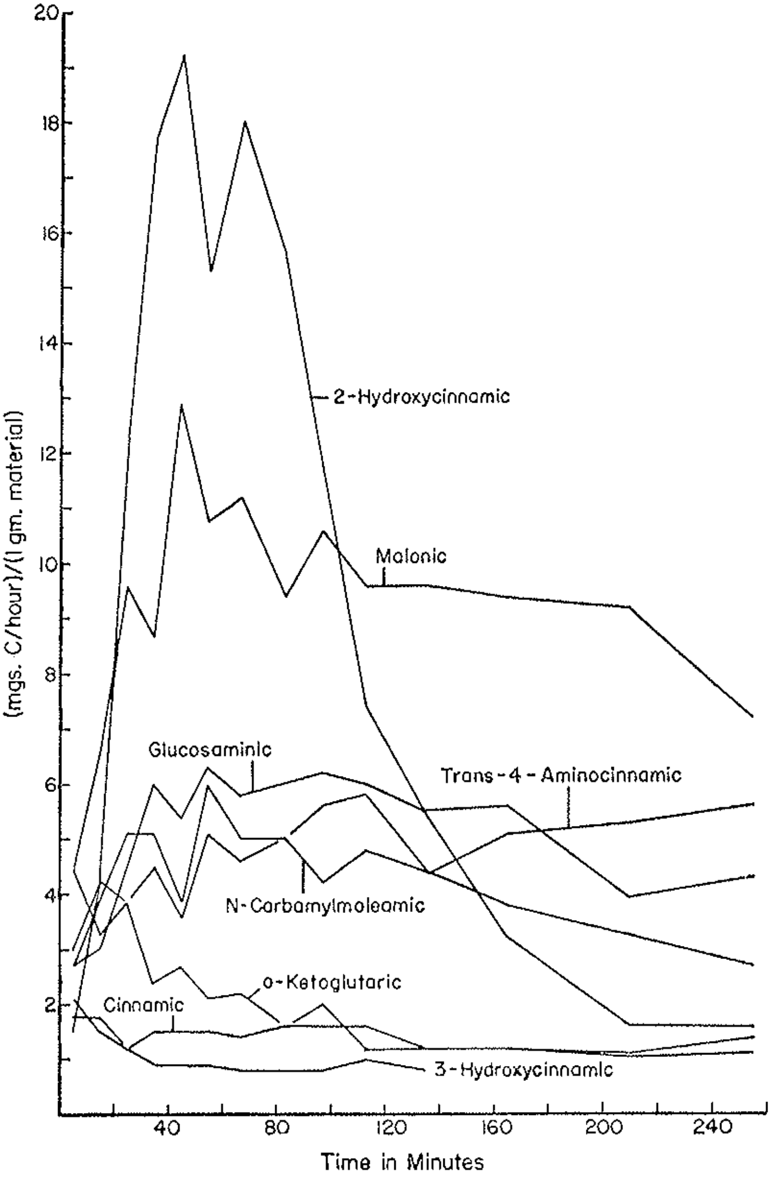


FIG. 6 — The rate of CO_2 liberation from compounds liberating moderate amounts of CO_2.

thoxy than for the other forms. Rate of CO_2 liberation from the cinnamic acids by H_2SO_4 was both qualitatively and quantitatively similar to that by HCl except for the 4-hydroxy form which decarboxylated at a slower rate by H_2SO_4.

Dihydroxymaleic acid lost CO_2 at an extremely high rate (Figure 8). Presumably this was due to the presence of the double bond in the molecule. Dihydroxytartaric acid, very similar in structure but without the double bond, lost CO_2 at a much lower rate although still at a rate high in comparison to most other compounds. Especially marked was the difference in the action of H_2SO_4 upon these two compounds. With dihydroxymaleic acid, curves for the two acids were parallel throughout their entire course and the total amount of CO_2 liberated did not differ greatly for the two acids. On the other hand H_2SO_4 gave a much lower loss of CO_2 from dihydroxytartaric acid than did HCl. CO_2 was released without a pronounced peak but at a fairly high rate for a prolonged period.

The relative effectiveness of HCl and H_2SO_4 as decarboxylating agents for the various compounds and soils can be seen from the data in Table 6. With the uronic acids H_2SO_4 released only one-fourth as much CO_2 as did HCl and the ratio was even smaller with pectin. In the cinnamic acid compounds and dihydroxymaleic acid almost equivalent amounts of CO_2 were liberated by the two mineral acids. H_2SO_4 in some cases causing even more decarboxylation than HCl. H_2SO_4 was definitely less effective than HCl in liberating CO_2 from dihydroxytartaric acid, the ratio between the action of the two acids being nearly that found in soils. In soils the ratios of CO_2 released by H_2SO_4 to those by HCl were intermediate between those for uronic acids and those for the organic acids. The values ranged from a low of 0.32 in the Onaway A_1 soil to 0.90 in the Marshall C horizon. Most of the values fell between 0.6 and 0.7. In general, decarboxylation by H_2SO_4 more nearly approached that of HCl in the lower horizons than in the surface ones. From the standpoint of the course of decarboxylation, the aliphatic acids dihydroxymaleic and dihydroxytartaric more nearly resembled that of soil than did any other compounds. The cinnamic acids, the decarboxylation of which is shown in Figure 7, also bear a resemblance

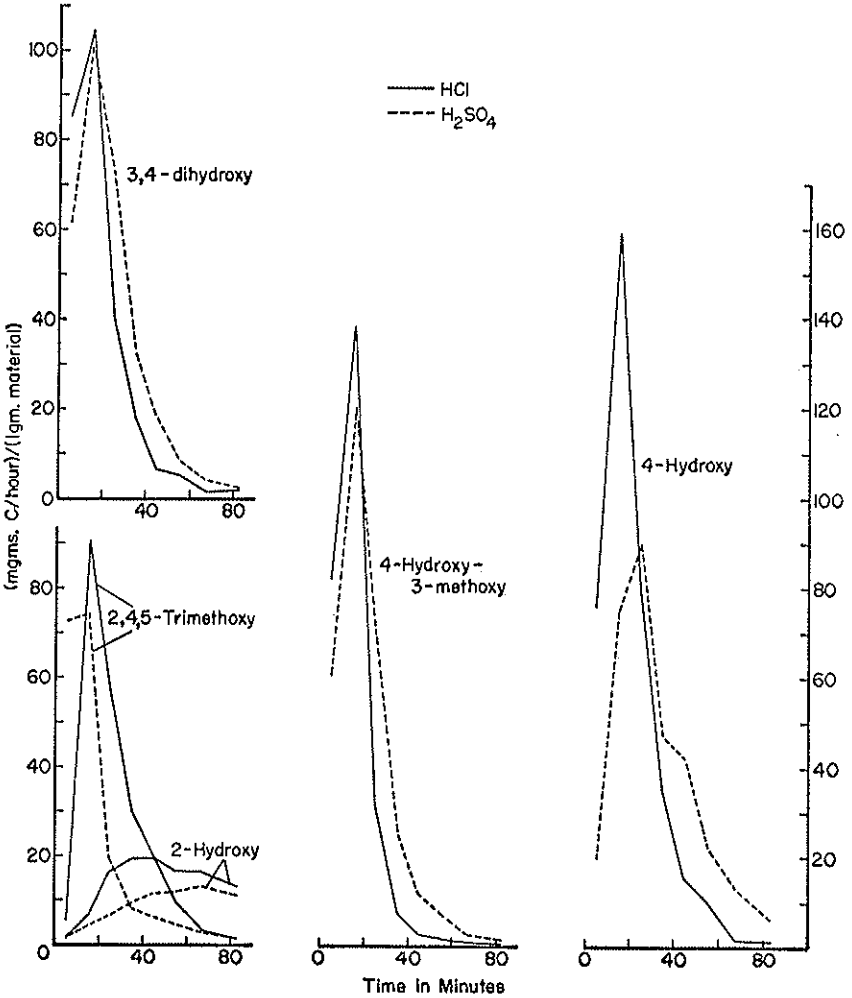


FIG. 7 — The rate of CO_2 liberation from cinnamic acid compounds.

TABLE 6 — *Ratio of the amount of CO_2 liberated by 12% HCl from certain compounds and soils to that liberated by 12% H_2SO_4.*

Substance		Ratio
Glucuronic acid		0.25
Galacturonic acid		0.25
Glucuronolactone		0.24
Pectin		0.19
2-Hydroxycinnamic acid		1.22
3,4-Hydroxycinnamic acid (¹)		1.14
4-Hydroxy-3-methoxycinnamic acid (¹)		1.15
2,4,5-Trimethoxycinnamic acid		0.91
Dihydroxymaleic acid		0.83
Dihydroxytartaric acid		0.61
Chalmers	Ap	0.62
	B	0.70
Marshall	A_1	0.63
	B_1	0.66
	B_2	0.69
	C	0.90
Kalkaska	A_1	0.57
	B_{21}	0.71
Onaway	A_1	0.32
	B_2	0.62
Saugatuck	A_1	0.67
	B_{21}	0.53

(¹) Boiled for 2½ hours, all others for 4½ hours.

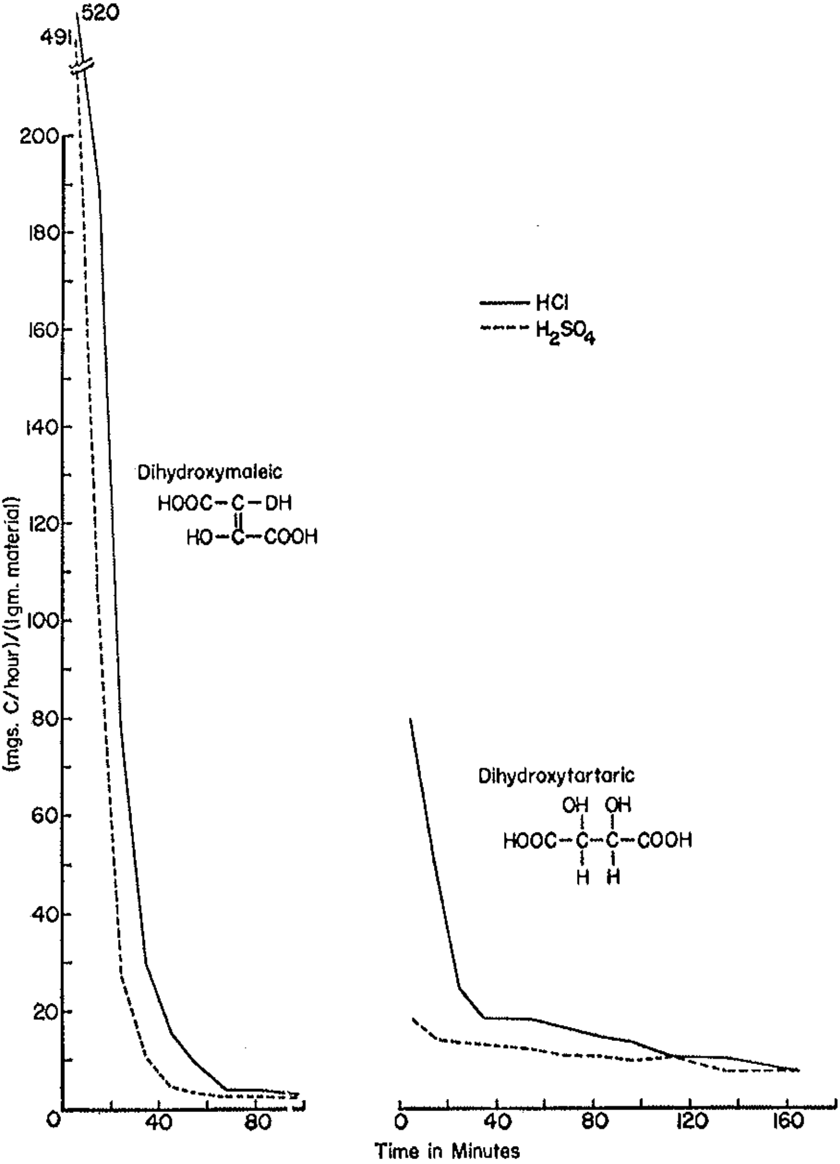


FIG. 8 — The rate of CO_2 liberation from dihydroxymaleic and dihydroxytartaric acid.

to that of soil except that the peak rate of decarboxylation is somewhat later than found in soil.

The decarboxylation of soil organic matter is carried out in the presence of a large amount of inorganic materials a portion of which becomes soluble in the boiling acid. The possibility that the inorganic constituents might affect the decarboxylation of organic materials was early realized. FULLER, BARTHOLOMEW and NORMAN [21] found, however, that soil did not affect the total yield of CO_2 from pectin nor did it appreciably affect the rate at which pectin decarboxylated. NICKERSON [32] found that the chlorides of a number of metals catalyzed decarboxylation of carbohydrates which in HCl alone liberated little CO_2. Ferric chloride was particularly effective in this and in 0.5 M concentration in 9% HCl increased the CO_2 liberated from glucose more than 200-fold.

The reacton of a number of compounds to the presence of 0.5 M $FeCl_3$ in 12% HCl was determined. The susceptibility to decarboxylation of a considerable number of compounds was wholly unaffected as is recorded in table 7. The decarboxylation of 3,4-dihydroxybenzoic, 3,4,5-trihydroxybenzoic, kojic, a-ketoglutaric and 2,6-dihydrozypyridine-4-carboxylic acids was very grealy increased. Decarboxylation of glucosaminic and 3,4-dihydroxycinnamic acids, 1,2-benzenediol and catechin was considerably increased as was that of cellulose and glucose. The amount of CO_2 liberated from Chalmers surface soil was almost doubled.

The effect of soils upon total decarboxylation was also determined for a number of compounds (table 8). Here again, the majority of compounds were unaffected with respect to CO_2 lost. For a few there was an increased decarboxylation in the presence of the Chalmers surface soil. These were 3,4-dihydroxy and 3,4,5-trihydroxybenzoic, kojic, and 2,6-dihydroxypyridine-4-carboxylic acids. B horizon samples of the Saugatuck podzol soil had little effect upon decarboxylation of these compounds. Soil from the B_{21} horizon had no

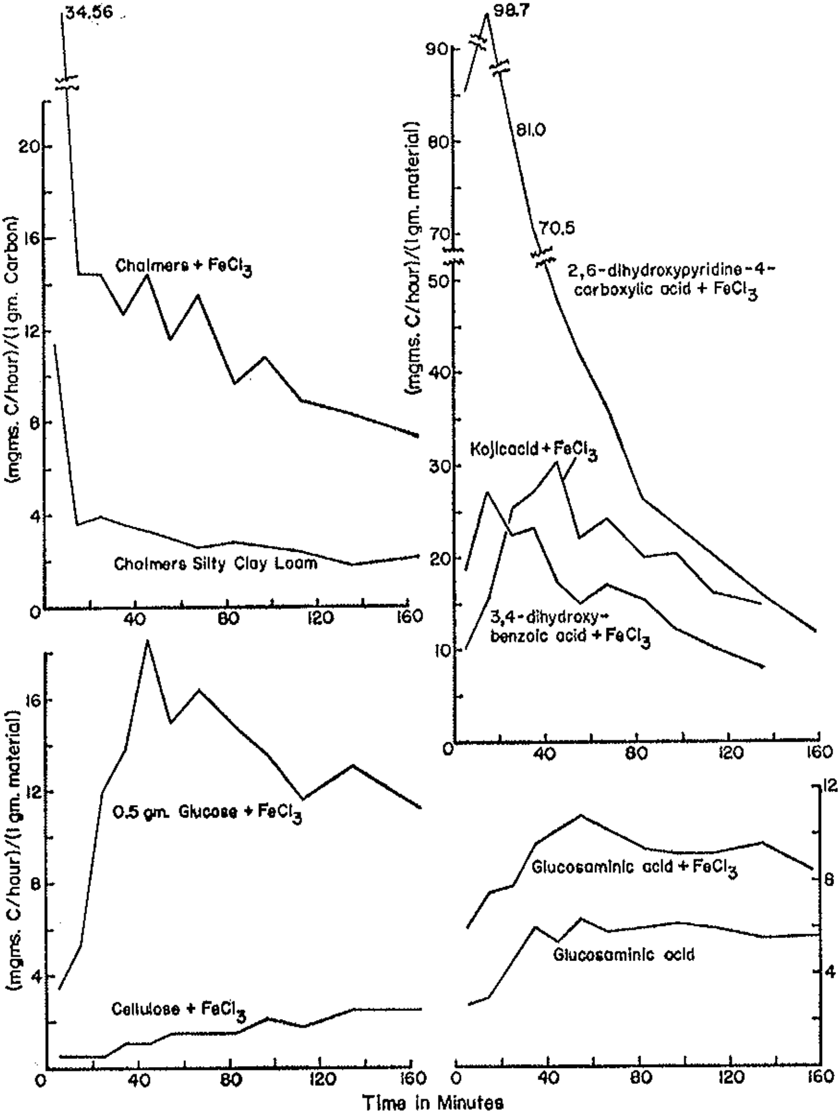


FIG. 9 — The effect of 0.5 M FeCl$_3$ upon the liberation of CO$_2$ from soil and various compounds by boiling 12% HCl.

TABLE 7 — *Effect of 0.5 M $FeCl_3$ upon the decarboxylation of certain compounds and a soil by 12% HCl.*

Compound	Mg. C as CO_2 liberated	
	alone	+ $Fecl_3$
1,2-Benzenediol (¹) (pyrocatechol)	0.0	7.8
Catechin	0.0	15.4
Cellulose	0.6	16.0
3,4-Dihydroxybenzoic acid (¹)	0.0	37.3
3,4-Dihydroxycinnamic acid	44.4	58.0
2,6-Dihydroxypyridine-4-carboxylic acid	0.6	104.8
Glucose	0.6	24.8
Glucosaminic acid	20.0	36.7
a-Ketoglutaric acid	6.2	42.4
Kojic acid	1.7	67.7
3,4,5-Trihydroxybenzoic acid	0.6	81.4
Chalmers Ap soil	11.8	21.4

(¹) Boiled for 2½ hours, all others for 4½ hours.

The following compounds gave no increased CO_2 liberation in the presence of $FeCl_3$: 4-methoxybenzoic, diphenylglycolic, benzoic, N-carbamylmaleamic, cinnamic, 3,5-dihydroxy-2-napthoic, 2,4-dihydroxypyrimidine-5-carboxylic, 4-hydroxy-3-methoxycinnamic, fumaric, 3-hydroxybenzoic, 4-hydroxybenzoic, 5-hydroxyisophthalic, maleic, malic, malonic, 2-methoxybenzoic, orotic, and *a*-picolinic acids and 3,4-dihydroxybenzaldehyde, glucosamine hydrochloride, 4-hydroxybenzaldehyde, and tyrosine. The following compounds gave increases of 1.8 to 2.7 mg. in the presence of $FeCl_3$: 3,4-dihydroxybenzaldehyde, 1,3,4,5-tetrahydroxycyclohexanecarboxylic acid, and 3,4,5-trihydroxy-1-cyclohexene-1-carboxylic acid.

effect while that from the B_{22} only slightly increased decarboxylation. In view of the high proportion of decarboxyable substances usually found in podzol B horizons this result was surprising.

TABLE 8 — *Effect of soils upon the liberation of CO_2 from certain compounds by boiling 12% HCl.*

	Increased liberation of CO_2 due to presence of soil (mg. C from 1 gm. of compound)		
	Chalmers Ap	Saugatuck B_{21}	Saugatuck B_{22}
3,4-Dihydroxybenzoic acid	7.4	0.2	3.0
3,4,5-Trihydroxybenzoic acid	9.5	0.0	1.2
Kojic acid	5.9	0.1	1.8

The following compounds gave no increased CO_2 upon boiling in presence of Chalmers Ap soil: glucuronic acid, pectin, 3,4-dihydroxycinnamic acid, 4-hydroxy-3-methoxycinnamic acid, benzoic acid, 2-hydroxybenzoic acid, 3,4,5-trihydroxy-1-cyclohexene-1-carboxylic acid (shikimic), methyl cinnamate, glucosaminic acid, N-carbamylmeleamic acid, pyridine-2,3-dicarboxylic acid, 2,4-dihydroxypyrimidine-5-carboxylic acid.

A comparison of the rate at which CO_2 was liberated from Chalmers surface soil and from the various compounds when determined separately and when mixed and run together in a single determination is given in Figure 10. The solid lines represent results obtained when the compounds were run separately and the values obtained summed and plotted. The dashed lines represent the values obtained when the compound and soil were mixed and run in the same determination. The differences are assumed to be due to the effect of the soil upon the decarboxylation of the compound. In the uronic compounds

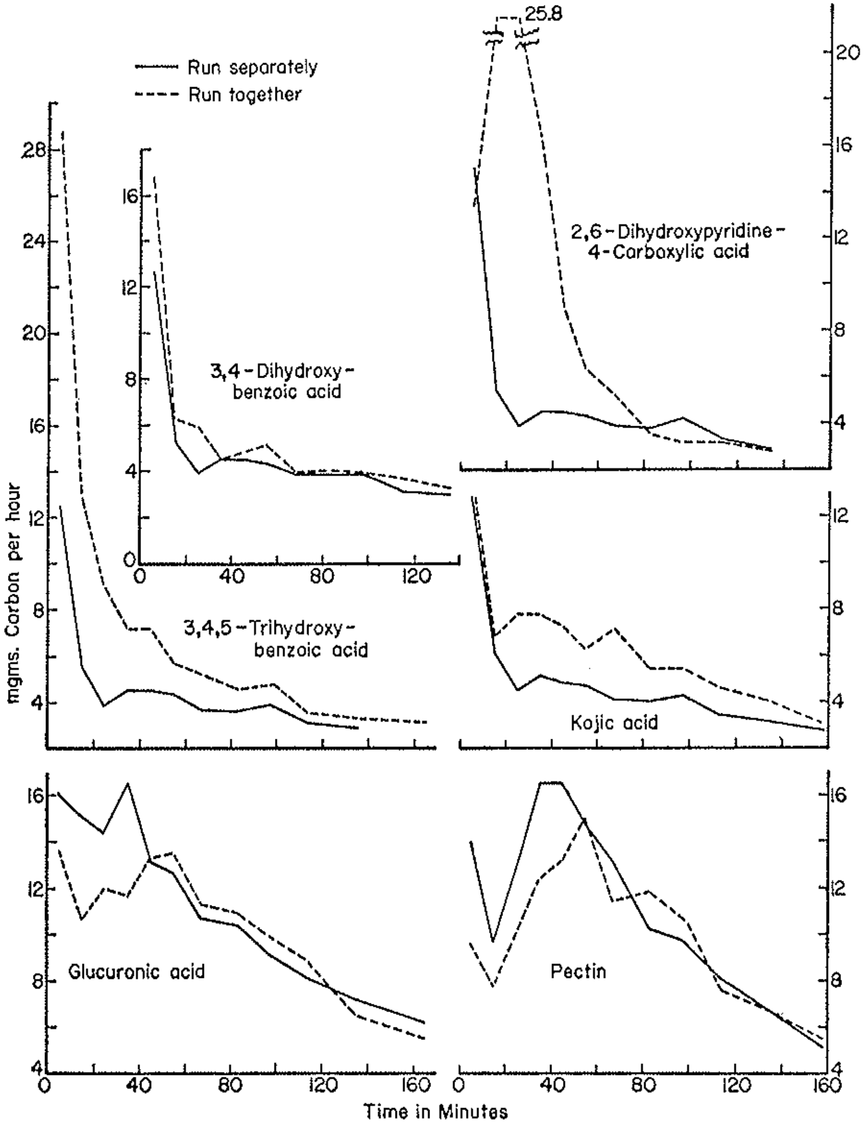


FIG. 10 — The effect of Chalmers Ap soil upon the liberation of CO_2 from certain compounds when boiled in 12% HCl.

soil depressed the release of CO_2 in the early periods of the determination, as a matter of fact, it was usually found that uronic compounds gave slightly smaller amounts of CO_2 in the presence of soil. With the other compounds a variety of effects were found. With the hydroxybenzoic acids there was an initial increase in the decarboxylation rate. This increase was especially pronounced with the trihydroxy forms and was also quite prolonged. With 2,6-dihydroxypyridine-4-carboxylic acid there was a very large increase brought about in the decarboxylation rate with a peak reached and maintained during the 10 to 30 minute period after the beginning of the determination. Presumably this delay was due to a preliminary reaction taking place resulting in the carboxyl group becoming susceptible to decarboxylation. This preliminary reaction apparently limited the rate of decarboxylation in the very early stages of the determination. With kojic acid there was no liberation of CO_2 from the compound until after the 20 minute period, after this it liberated CO_2 at a slowly decreasing rate. These results indicate that some soils have the property of catalyzing the liberation of CO_2 from certain compounds which in the absence of soil do not decarboxylate.

The role which the decarboxyable nonuronic substances may have in the decarboxylation of soil organic matter is not yet clear. Compounds such as cinnamic acid derivatives, hydroxybenzoic acids, and a number of aliphatic acids have been found in their free form in soil organic matter [1, 25, 48, 52]. They appear to be most readily demonstrated in situations where plant residues are still undergoing fairly active decomposition. Such compounds are susceptible to microbial decomposition and because of their solubility they are readily leached from the soil. The actual quantities found are consequently very small and insufficient to account for any appreciably portion of the yield of CO_2 ordinarily found in the decarboxylation of soil organic matter.

In the decomposition of lignin the side chains of the cinnamic acid derivatives appear to be removed to a large extent by microbial decomposition [17]. Present concepts regarding the chemical nature of soil organic matter do not indicate the presence of any very large proportion of side chains attached to the aromatic nucleus [16, 17, 26, 44]. The presence of such chains, while not completely excluded, also does not appear to offer an adequate source of carboxyl for the losses resulting from decarboxylation. The attachment of a high proportion of the carboxyl groups directly to the aromatic nucleus in soil organic matter is indicated by present information. A considerable proportion of the hydroxyl also appears to be attached to the ring [4]. However, the mono-, di-, and trihydroxybenzoic acids used in this work did not decarboxylate. Evidence was found that decarboxylation of the di- and trihydroxy forms was catalyzed by the presence of one soil. Hydroxybenzoic acids of other forms may be more readily decarboxyable as suggested by DUBACH [11].

As already indicated aliphatic acids in free form in the soil would not be expected to be important sources of decarboxyable CO_2. The possibility of formation of decarboxyable acids through the breaking of ring structures in the LEFEVRE and TOLLENS procedure may exist. The great rapidity with which soil organic matter decarboxylates apparently would require a ring structure very easily broken.

One objection to the view that CO_2 resulting from decarboxylation of humus results solely from uronic acid containing polysaccharides is the assumption this necessitates regarding the nitrogen content of the remainder of the organic matter. Thus, if one-third to one-half of the organic matter were polysaccharide this would imply a very high nitrogen content of the remaining portion of the organic matter. From this standpoint the possibility that a considerable portion of the CO_2 might arise from compounds such as glucosaminic acid or possibly uronic acid forms of amino sugars is attractive. However, such compounds have apparently not been demonstrated to be present in soil organic matter. The possibility that certain heterocylic nitrogen compounds may be a source of decarboxyable CO_2 is indicated by the behavior of 2,6-dihydroxypyridine-4-carboxylic acid in the presence of Chalmers soils in the decarboxylation procedure.

The substances in soil organic matter yielding CO_2 in the LEFEVRE and TOLLENS procedure are not yet definitely identified. Information now available indicates more definitely the probably nature of such compounds and will aid in their ultimate identification.

SUMMARY

A number of compounds otber than those containing uronic acids were decarboxylated in the LEFEVRE and TOLLENS procedure for the quantitative determination of uronic acids. Cinnamic acid derivatives having a hydroxyl group in the 4-position decarboxylated rapidly and extensively.

The 2-hydroxy form decarboxylated to a lesser extent and the 3-hydroxy form almost none at all. Addition of hydroxyl in the 3-position of actively decarboxylating forms decreased the liberation of CO_2. Methoxy and amino groups substituted to some extent for hydroxyl groups in bringing about decarboxylation.

Few aliphatic acids underwent appreciable decarboxylation. Dihydroxymaleic acid was almost completely decarboxylated. Dihydroxytartaric acid liberated one-half of its carboxyl, presumably only one of its carboxyl, groups being lost. N-carbamylmaleamic, glucosaminic and malonic acids lost about 20% of their carboxyl in the decarboxylation procedure. 2,4-Dihydroxypyrimidine-5-carboxylic, alpha-ketoglutaric, pyruvic and phenylpyruvic acids lost 10% or less of their carboxyl.

The rate at which CO_2 was liberated from some of these acids more nearly resembled the rate of release from soils than did that of uronic acid compounds.

One soil was found to catalyze the release of CO_2 from 3,4-dihydroxy- and 3,4,5-trihydroxybenzoic acids, kojic acid and 2,6-dihydroxypyridine-4-carboxylic acid but not from a considerable number of other compounds.

Sulfuric acid did not produce a typical decarboxylation curve for uronic compounds. For most other compounds and for soils it usually gave a somewhat lower yield of CO_2 but produced a decarboxylation curve quite similar to that given by hydrochloric acid.

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DISCUSSION

Chairman: W. FLAIG

FLAIG

I am personally interested in these investigations because we intended inorganic oxydative decarboxylation.

WAKSMAN

I would like to ask Dr. REUSZER if he has made similar analysis of microbial cell substance.

REUSZER

I have had some difficulty in growing sufficient quantity of cell substances to make the determinations. I have made some determinations on rhizobia cells. These are the only ones on which I have run determinations. I found the curve of CO_2 release very similar to that of pectin.

WAKSMAN

As you know, there has been recently a great deal of work done on the composition of microbial cell substance and certain definite criteria have been established for certain types of micro-organisms; as a matter of fact, there is even an attempt to classify certain groups of organisms, notably the actinomycetes into different sub groups on the basis of their chemical composition. Have you made any attempt to determine such constituents?

REUSZER

No.

SWABY

Prof. REUSZER, I am wondering whether perhaps, in looking at rather simple model compounds, you might have overlooked the fact that the breakage of carboxyl groups on polymers is much easier than the breakage of carboxyl groups on simple compounds, and this suggests that when you get polymers and polycondensates there is often considerably more ring strain, and strain generally, along the polymers allowing a weakening of the C-COOH bond leading to decarboxylation I am reminded of the fact that when we were making synthetic humates from quinones and amino acids or from catechol and amino acids under slightly alkaline conditions, it is amazing how much carbon dioxide you trap in the alkali. When you precipitate the humic acids afterwards with HCl there is a violent fizzing as you neutralize the carbonate, and I suspect that some amino acids are better at doing this than others, because many years ago TRAUTNER and ROBERTS showed that glycine was very prone to decarboxylate enzymically, but I think that probably Prof. FLAIG has much more evidence than we have on really what has taken place. May I mention one other isolated piece of information we have got recently, and that is that in spite of the fact that you had great difficulty in decarboxylating some of the pyridine derivatives, I think you mentioned in particular nicotinic acid, we have had great ease in doing this simply by heating some of them if they were the chlorinated picolinic acids. It seems that if a large chlorine electron sink occurs in the molecule then electrons forming the C-C bond between the pyridine ring and the carboxyl group are strained so that decarboxylation occurs readily. I wonder if you had thought about these types of molecules occurring in soil organic matter?

REUSZER

I had thought about the polymerized compounds. They are more difficult to obtain. Compounds which I have used have been obtained largely from chemical supply companies. I think it is quite well known that one does get carbon dioxide from some of these polymerized compounds, for instance, the synthetic humic acid formed from glucose through condensation by treatment with sulphuric acid has been shown to yield CO_2 I believe that DEUEL and his group have worked with some polymeric substances such as that, apparently some of them yield CO_2 very copiously. I have not worked with them, I have tried to confine myself to substances where the structure was known. I do appreciate the fact that these substances as such do not occur in soil organic matter. I would have discussed this a bit more had there been time. Some of them occur in very small quantities in soils. Some of them presumably resemble portions of larger molecules in soil organic matter.

NORMAN

I suppose I might be forgiven for wanting to comment on this paper in as much as some of the data referred to were obtained in my laboratory many years ago. I am not going to adopt a defensive position on this because it is quite clear that there is a substantial volume of evidence that indicates that some other conclusions than those which we drew at the time might be correct. I think at the time we did have nervousness about some of the larger figures and used some such phrase as « apparent uronic groups ». I should like to make one or two comments, however. First of all, at the time, the decarboxylation rate figures seemed good to us. In other words, there seemed to be strong presumptive evidence that there was similarity between the compounds in soil and polyuronides, but I do want to point out, however, that the apparent decarboxylation rate is not a constant. It is a function of the equipment of the size of the apparatus, and the flow rate of the gas sweeping out the CO_2. Unless this is maintained completely constant in this sort of experiment one does not have comparable situation at all. My decarboxylation rates and yours could be completely different and both could be quite correct.

Let us go back for a moment to the fact that if one applies these procedures on plant materials one does not have discrepancies in terms of differences between furfural yields and uronic contents. If one runs a careful analysis of decomposed plant residues, this procedure does give what seem to be reasonable figures for the uronic content. So really what we are saying here is that there must be in soils something else which will be decarboxylated under these conditions. But I do not think we can conclude from your data, or from anybody else's data, that there is no uronic material there. What we are saying is that all of what is found cannot come from uronic groups, but I do not believe that it is a fair statement to say that none of it can be from that. So the problem is, what is it coming from? You have worked through a very large array of organic compounds, some looking most implausible to me as soil constituents. Clearly what is in soil is something that moves because if we look at all the profile data we get these higher apparent uronic figures from the lower part of the profile and particularly in the zone of accumulation of classic podzols. This is where those implausible figures showed up.

So, if we look back then we certainly have clear evidence that the conclusions that were reached in my papers a number of years ago were not valid. On the other hand, we have not proved that there was a total absence of uronic material and we are not in a good position to explain what may be the other source of carbon dioxide. Now, I must confess my memory is hazy about some of this work, but I do recollect that for a while we ran a lot of determinations using stannous chloride in the attempt to avoid the oxidative conditions that one gets with iron.

BREMNER

I also recollect that you tested the effect of adding stannous chloride and found that the values obtained with soils were not decreased significantly when this reagent was added.

REUSZER

In my work we have tried using nitrogen as the aerating gas. This does not particularly change the amount of CO_2 released. We have found that with one compound, a heterocyclic nitrogen compound, more CO_2 is given off when aerated with nitrogen than when aerated with air.

I agree with Prof. NORMAN that these results do not demonstrate that there is no uronic acid in the soil. Presence of uronic acids has been definitely demonstrated by colorimetric determinations and in some soils probably appreciable quantities of CO_2 are derived from uronic acids. What the proportion is we do not know, but I think that perhaps the dominant portion of CO_2 comes from sources other than uronic acid.

LORA TAMAYO

What are the compounds in the tables with names dihydroxy maleic and dihydroxytartaric? These compounds, very unstable, are as ketoacids and split off CO_2 very easily.

FLAIG

May I make a short comment on this. Some years ago we investigated with DEUEL and SCHOBINGER lignin fractions isolated from decomposed straw during 400 days. We used also the method with hydrochloride acid and found a special amount of CO_2. But not all CO_2 has been equivalent to the amount of formed furfurol, which could be distilled. The amount of CO_2 which has not been correlated with furfurol increased with incubation time.

We used different labelled and substituted cinnamic acids and studied their oxidative decarboxylation. Decarboxylation occurs only when a hydroxyl group is in 4-position, and depends upon substitution with OH- or CH_3O-groups. The mechanism of this reaction seems to go through semi-quinonoid radicals. This makes the carboxyl group unstable and decarboxylation occurs. Semi-quinonoid radicals are not formed, when the OH-group in 4-position is methylated. No decarboxylation occurs. Also no polymers are formed as in the case of the cinnamic acids with OH-groups in 4-position. In the case of the benzene carboxylic acids also decarboxylation occurs in the presence of phenoloxidases in oxydasing medium and quinones are formed.

REUSZER

In acid decarboxylation the substituent groups on the fourth and the second carbons of the ring seem to be important in promoting CO_2 release.

FLAIG

Our results of enzymatic oxydative decarboxylation of cinnamic acid derivatives are comparable with yours. We labelled these acids specifically at different carbon atoms. The results can be summarized as follows:

1) decarboxylation occurs only when an OH-group is in 4-position of the carboxyl group;

2) the rate of decarboxylation depends upon the substitution of the benzene ring with OH or OH_3-groups;

3) the reactions seem to go through semiquinonoid steps, because in the case of 3,4-dimethoxycinnamic acid no decarboxylation occurs; in this case no semiquinone can be formed.

In the case of 4-hydroxybenzene carboxylic acids quinones are formed by oxydative decarboxylation. Cinnamic and benzene carboxylic acids polymerize under the conditions of oxydative decarboxylation to different polymers. Prof. REUSZER, have you also observed polymerization?

REUSZER

With some compounds we observed the formation of insoluble precipitates upon boiling with 12% HCl. Presumably these resulted from polymerization or other reactions. However, we have not studied these substances.

THE VALUE OF ORGANIC MATTER, PHOSPHATES AND SUNLIGHT IN NITROGEN FIXATION AND FERTILITY IMPROVEMENT IN WORLD SOILS

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ELEMENTS IN SOIL

A fertile soil contains the following elements:

Carbon, hydrogen, nitrogen, oxygen, phosphorus, potassium, calcium, magnesium, sodium, boron, copper, iron, manganese, zinc, cobalt, aluminium, titanium, molybdenum, chlorine, fluorine, iodine, sulphur and silicon.

It is clear that for healthy growth of a crop the soil must contain these elements which form essential ingredients of plant life.

It is well known that soils are formed from the earth's crust. The plants derive their nourishment from the soil whilst animals obtain their food materials from the plant kingdom. Hence, it will be interesting to record here the average composition of the earth's crust, a flowering lucerne and the animal body.

Chemical composition of Earth's crust, plants and Man

Earth's crust	%	Lucerne	%	Man	%
Oxygen	49.2	Water	75	Water	60
Silicon	26	Org. subs.	22.45	Org. subs.	35.7
Aluminium	7.4	Ash	2.45	Ash	4.3
Iron	4.2	Oxygen	77.9	Oxygen	62.81
Calcium	3.5	Carbon	11.34	Carbon	19.37
Sodium	2.4	Hydrogen	8.72	Hydrogen	9.31
Magnesium	2.35	Nitrogen	8.25	Nitrogen	5.14
Potassium	2.35	Phosphorus	0.72	Calcium	1.38
Hydrogen	1	Calcium	0.58	Sulphur	0.64
Titanium	0.5	Potassium	0.17	Phosphorus	0.63
Carbon	0.4	Sulphur	0.104	Sodium	0.26
Chlorine	0.2	Magnesium	0.082	Potassium	0.22
Sulphur	0.15	Chlorine	0.07	Magnesium	0.04
Phosphorus	0.10	Sodium	0.0316	Chlorine	0.18
Fluorine	0.10	Silicon	0.093	Iron	0.005
Manganese	0.10	Iron	0.0027	Fluorine	0.004
Nitrogen, Barium	from 0.01 to 0.90	Aluminium	0.0025	Silicon	0.004
Bismuth, Vanadium		Cobalt	0.00055	Zinc	0.0025
Lithium, Nickel		Boron	9.0007	Rubidium	0.0009
Strontium		Rubidium	0.00046	Copper	0.0004
Chromium		Manganese	0.00036	Bromine	0.0002
Zirconium		Zinc	0.00035	Tin	0.0002
Bromine		Copper	0.00025	Manganese	0.0001
Cerium, Copper		Fluorine	0.00015	Iodine	0.001
Beryllium	from 0.001 to 0.009	Molybdenum	0.0001	Aluminium	0.00005
Iodine, Tin		Titanium	0.00009	Lead	0.00005
Cobalt		Nickel	0.00005	Molybdenum	0.00002
Thorium		Bromine	0.00005	Boron	0.00002
Zinc, Lead		Lithium	0.000046	Arsenic	0.000005
Molybdenum		Vanadium	0.000016	Cobalt	0.000004
Rubidium		Iodine	0.0000025	Lithium	0.000003
Yitrium				Vanadium	0.0000026
				Nickel	0.0000025
Argon, Tungsten	from 0.0001 to 0.0009			(Strontium)	
Tantalum, Caesium		(Arsenic, Tin, Lead)		(Barium)	smaller than 0.000001
Cadmium, Mercury		(Strontium, Barium)			
Hafnium					
		(smaller than 0.000001)			
Lanthanum, Arsenic	from 0.00001 to 0.00009				
Neodymium, Niobium					
Antimony, Silver					
Selenium, Scandium					
Thallium	from 0.000001 to 0.000009				
Tellurium					
Praseodymium					
Gold, Platinum					

It appears, therefore, that there are many elements common in earth's crust, lucerne and the human body. It is clear that the chief constituent of lucerne and man is water which predominates all living matter.

Moreover, V.M. GOLDSCHMIDT and others have reported the presence of the following elements in coal.

ELEMENTS IN COAL

Carbon, hydrogen, oxygen, nitrogen, sulphur, phosphorus, chlorine, silicon, calcium, iron, manganese, sodium, potassium, titanium, zirconium, zinc, lead, cadmium, copper, gold, silver, vanadium, beryllium, germanium, nickel, barium, gallium, strontium, boron, scandium, yitrium, lanthanum, cobalt, molybdenum, uranium, arsenic, antimony, tin, iodine, bismuth, rhodium, palladium and platinum.

Amounts of 18 elements in coal ash, earth's crust and various forms of organic life are as follows:

	Coal ash %	Earth's crust %	Organisms %
1. Calcium . . .	35.6	3.4	1 to 10
2. Iron	10.7	4.7	10^{-1} to 10^{-2}
3. Magnesium .	4.8	2.0	10^{-2} to 10^{-1}
4. Manganese .	0.35	0.1	10^{-3} to 10^{-2}
5. Silicon . . .	3.31	25.7	10^{-1} to 1
6. Aluminium .	1.6	7.5	10^{-2} to 10^{-1}
7. Sodium . . .	2.3	2.6	10^{-2} to 10^{-1}
8. Potassium .	0.2	2.4	10^{-1} to 1
9. Phosphorus .	trace	0.1	10^{-1} to 1
10. Copper . . .	10^{-4} to 10^{-3}	10^{-2} to 10^{-1}	10^{-3} to 10^{-1}
11. Barium . . .	10^{-5} to 10^{-4}	10^{-2} to 10^{-1}	??
12. Lead	10^{-4} to 10^{-3}	10^{-3} to 10^{-2}	10^{-4} to 10^{-3}
13. Strontium . .	10^{-5} to 10^{-4}	10^{-2} to 10^{-1}	??
14. Bismuth . . .	10^{-5} to 10^{-4}	10^{-4} to 10^{-3}	??
15. Nickel	10^{-5} to 10^{-4}	10^{-2} to 10^{-1}	??
16. Zinc	10^{-5} to 10^{-4}	10^{-3} to 10^{-2}	10^{-2} to 10^{-1}
17. Tin	10^{-5} to 10^{-4}	0.5	10^{-4} to 10^{-3}
18. Gold	10^{-6} to 10^{-5}	10^{-6} to 10^{-5}	10^{-6} to 10^{-5}

ORGANIC MATTER IN SOILS FIXES ATMOSPHERIC NITROGEN

When nomadic man settled down and started agriculture almost 20000 years ago, he observed the beneficial effects of the dung of his animals to crop production. The relative merits of the dung of birds and poultry and of the excreta of horses, cows, goats, sheep and men for different soils and crops were fully discussed by the agricultural writers of the Greco-Roman times. The benefit of composts prepared from dung, urine, straw, stalks, leaves, weeds and other trash were emphasised. Green manuring was also recommended by the Roman author, Pliny (23-79 A.D.). The great Greek philosopher, Aristotle (384-322 B.C.) believed that plants derive nourishment through their roots from the organic matter in soil.

Although organic matter has been used as manure from times immemorial and, even today, 97-98% of the world food production has to be attributed to the nitrogen of the soil humus including the nitrogen fixed by legumes, the functions of organic matter in the soil have not been properly understood. It is of interest to record that from ancient times two viewpoints have been advanced regarding the materials effective in plant nutrition. Bernard Palissy (1510-1589), Bacon (1561-1628), Glauber (1604-1668), Boyle (1627-1691) and specially Liebig (1803-1873) were supporters of the theory first emphasised by Paracelsus (1493-1541) that salts were the true nutrients of plants. On the other hand, there were several distinguished scientists, notably, Home (1719-1813), Wallerius (1709-1785), Thaer (1752-1828), T. de Saussure (1767-1845), Davy (1778-1829), de Candolle (1778-1841), Berzelius (1779-1848), Mulder (1802-1880) and others, who were advocates of the Aristotelian doctrine of plant nutrition by soil organic matter.

A. Lavoisier (1743-1794), founder of Chemistry and Physiology, was impressed by the value of growing grass in improving the fertility of land. There is no doubt that both organic and inorganic substances can lead to fertility improvement.

Sir E.J. Russell has unequivocally declared that artificial fertilizers lead to soil deterioration not only in continuous cropping but in rotations as well.

Once richly productive areas like those of North Africa (the granary of Roman Empire), the Valley of the Tigris and the Euphrates and vast areas of India and China, have ceased to grow even sufficient food for the population of the immediate areas or have virtually been turned into desert regions chiefly due to depletion of humus. Richest soils on the earth — the prairie corn belt and the vast mid-western plains, black soil belts of Texas, the Ukraine, Mississippi and Alabama — are essentially grass and legume made, phosphate and lime-rich soils.

The essential plant nutrients, e.g. nitrogen, phosphorus, potash and trace elements are very important assets for agricultural production. Continued loss of these assets from land leads to agricultural bankruptcy and hunger, dire poverty, malnutrition and debilitation set in for the common man, whose welfare depends largely on production from land. The return of nutrients in agricultural and plant wastes and those from cities aided by cheap phosphatic sources to poor agricultural land, as occurs in India, could change a decreasing production to a steadily increasing economy.

It is well known that all soils contain more non-nitrogenous organic compounds than organic compounds containing nitrogen and that the mineral nitrogenous compounds such as ammonium salts and nitrates which are readily absorbed and utilized by plants, are in smaller amounts than organic nitrogenous compounds which are usually unavailable to plants.

From our researches on the problem of atmospheric nitrogen fixation in soils on the addition of various types of organic substances for over 40 years, we have concluded that these compounds not only add colloidal substances to the soil and improve its physical properties, tilth and crumb formation and water retention capacity of the soil, but, they also undergo slow oxidation in soil and liberate energy which is utilized in fixing atmospheric nitrogen and enrich the soil from the nitrogen viewpoint. Moreover, the carbonaceous non-nitrogenous compounds present in soil or added to it act as protectors of soil nitrogenous substances just as carbohydrates and fats act as protein sparers in the animal body. These are very important functions of organic matter in soils. On treading a land trated with organic matter, one can readily feel that the organically treated land is softer than the untreated land.

The productivity of land in rich countries is definitely increasing because of the greater application of fertilizers, better seeds, killing of weeds etc. But unfortunately even in these countries fertility is decreasing chiefly due to the loss of soil organic matter. Prof. W.B. BOLLEN has stated that more crops are being produced in the U.S.A. but lands are losing fertility. The following observations show that even in fertile parts of the U.S.A., application of fertilizers cannot maintain steady crop yields:

Crop every year	Fertilizer treatment	Soil loss in inches: 1894-1935	% of organic matter remaining in soils in 1935	Average yield in bushels	
				1894-1935	1931-1935
Corn . . .	None	10.3	37	26.3	6.5
Corn . . .	Complete 500 lbs. of 10-5-10 per acre	11.1	35	44·4	28.9
Corn . . .	Manure 5 tons/acre	9·5	53	43·1	30.0

The above observations deal with corn cultivation and soil erosions at the Ohio Agricultural Experiment Station at Wooster.

J.H. STALLINGS of the U.S.A. recorded in 1957 that 35 million acres of land in the U.S.A. cannot grow food and have been given up as worthless, 1½ million acres being worn out every year. In the most productive lands in the mid-west and great plains of the U.S.A., much of the organic matter has been lost and the natural fertility is going down. There is no doubt that the organic matter content of a soil is a fair index of its productive power and durability.

Classical Rothamsted experiments show that the nitrogen content of a grassland increased from 0.152% in 1856 to 0.338% in 1912. Similarly, a land permanently covered with vegetation for 24 years showed an increase in total nitrogen content from 0.108% to 0.145%. It appears that this increase in total nitrogen content of these soils is chiefly due to the fixation of nitrogen from air caused by liberation of energy from the oxidation of cellulosic and other carbonaceous substances from grass on soil surface.

Increase of soil fertility, which is the aim of all modern scientific and practical efforts, cannot be attained by mineral fertilizers which help in breaking down the humus. To build up a good soil by incorporation of organic matter should be the aim because it is relatively easy to maintain the fertility of a soil rich in humus. Our researches have clearly shown that all organic substances aided by calcium phosphates can deliver the solar energy stored in the organic matter to the fixation of atmospheric nitrogen and enrichment of the soil.

The original nitrogen in Rothamsted soils was 0.12% in 1843 when the experiments started but in 1914 the nitrogen status, after growing wheat every year was as recorded below:

	Total N in 1914
Receiving no manure or fertilizer since 1843	0.095%
Receiving farmyard manure since 1852	0.256%
Receiving complete artificials including $(NH_4)_2SO_4$	0.099%

Similar increase in total nitrogen of soils and nitrogen fixation by adding organic matter has been reported in Uppsala where the soil temperature is 5°C and also in Denmark and the U.S.A. by different investigators.

OXIDATION VITAL IN LAND FERTILITY

When LAVOISIER in 1781 declared that life is a chemical process depending on oxidation of food materials, he became the great pioneer in man's understanding the phenomenon of life.

Our extensive researches on slow oxidation of organic substances and concomitant fixation of atmospheric nitrogen in soils show that in plant nutrition also the process of oxidation is of vital importance in the supply of nutrients to crops. Our experiments demonstrate that all organic substances created by photosynthesis undergo slow oxidation in soils or oxide surfaces and produce carbonic acid in the end as also some weak organic acids as intermediate products. These render the minerals present in soil and organic substances like lime, magnesia, phosphates, soluble in water and thus available to plants. Moreover, the energy liberated in these oxidation processes, fixes atmospheric nitrogen. This N fixation in soils or chemical surfaces by slow oxidation of organic matter is accentuated by light absorption. Also the phosphates, by stabilising the synthesised amino acids and proteins, increase N fixation. Hence, all organic matter including coal, peat, seaweed, water hyacinth, grasses, municipal wastes could be utilised specially when phosphated for crop production just like animal dung or farmyard manure. Man must therefore conserve and increase production of organic matter on earth's crust. Phosphated straw both in England and India has been found to be an excellent manure. It is necessary to determine quantitatively the waste organic matter including forest litter, grasses, seaweed, municipal waste etc. available on earth's crust and utilise them for crop production, specially by phosphating them with cheap phosphates like mineral phosphates, basic (Thomas) slags etc. Moreover, inorganic and synthetic nitrogenous fertilizers are more effective in presence of soil organic matter. Hence crop rotation, green manuring etc. are important for this purpose. By utilising straw, grasses, forest litters, weeds, municipal wastes and coal wastes and specially by phosphating them, man can continue permanent agriculture without animal dung, which is replaceable by all kinds of organic substances. Hence permanent agriculture is certainly a practical proposition without animals, *provided* straw, grasses, forest litters etc. mixed with basic slag (Thomas phosphate), rock phosphates are ploughed in the soil.

All over the world a serious attempt is being made by the manufacturers and Governments to produce more ammonium salts, urea, nitrates etc., but the progress is slow as the process is costly and difficult and there is considerable leakage of free ammonia from the Haber-Bosch synthetic plants. Even today perhaps only 3% of the food and fodder production in the whole world has to be attributed to artificials as was reported by Sir JOHN RUSSELL in 1948. Industrially backward nations are trying to follow the progressive countries in this respect as in obtaining the atomic energy. Our discovery is that organic matter oxidation is a very good source of soil nitrogen, specially when aided by solar light and phosphates. Man must understand that photosynthesis is not only the supporter of life on this planet but it is also the creator of land fertility required for crop production.

That oxidation is of vital importance in increasing land fertility has been practically demonstrated by R.H. ELIOT in his Clifton Park farming where he produced better crops than with artificials by repeated ploughing up of grasslands without any fertilizer. Similarly, in the Cockle Park experiments in Northumberland by adding basic slags, which are alkaline and contain iron, manganese, vanadium, molybdenum etc. and help oxidation of cellulose and other organic matter, the fertility markedly increased.

STARVATION FACING MAN

In the International Soil Science Conference held at Aberdeen University from 5th. to 10th. September 1966, it was reported that the world population at the end of the present century is likely to be 6000 millions as against 3200 millions which is approximately the present population. Also, the food standards of different nations reveal that majority of human beings are under-nourished and only those living in North-West Europe, North America, Australia and New Zealand are properly fed. It has also been stated that in the present century 800 million human beings may die of starvation.

In a descriptive Guide of the Royal College of Agriculture of Sweden (Agricultural University), it has been stated « The problem of famine in large parts of the world makes agriculture of central importance in most countries. The possibility of cultivating sufficient food is one of the most momentous problems of the immediate future. »

NITROGEN - KEY ELEMENT IN CROP PRODUCTION

The following considerations show the paramount importance of available nitrogen in food, fibre and fodder production when compared to potash and phosphate:

[8] *Dhar* - pag. 10

Estimated average increase in yield in Kgms. in tillage crops and grasslands from 1 Kg. of plant nutrient.

Country	Crops in rotation			Permanent pastures		
	N	P	K	N	P	K
Norway	9	3	5	11	6	4
Sweden	14	11	7	14	11	7
Denmark	18	4	2	12	5	3
U. K.	16	5	5	—	—	—
Ireland	20	8	8	—	—	—
Netherlands	19	6	3	10	6	4
France	19	5	2	.	—	—
Germany	19	8	4	9	10	5
Greece	15	5	3	—	—	—
Italy	11	3	—	12	4	3
Average	17	5	4	11	7	4

Average extra yields from nitrogen fertilizer measured in recent experiments (various sources).

Crop	Regions	lb. of extra dry yield produced per lb. of N
Grasses, temperate (modern strains)	U. K.	15—40
Sub-tropical (coastal Bermuda grass)	Southern U.S.A.	Up to 45
Sugarcane	Trinidad	35—60
Cereals (grain only): wheat and barley	U. K.	10
Rice	Asia	8—20
Maize	France and U.S.A.	15—25
Root crops: potatoes, sugar beet, mangolds	U. K.	10

The Indian Council of Agricultural Research has reported that the average production of paddy in India is ten times the amount of nitrogen applied.

In Rothamsted by using 80 lbs. of N as sodium nitrate, 17 bushels of increased barley yield were produced over 'control' field. This shows that 1 lb. of N as sodium nitrate produces 13.5 lbs. of barley whilst using ammonium sulphate, the value becomes 13.1 lbs.

In Stoneville, Mississippi, by using 30 lbs. of N per acre as sodium nitrate, ammonium nitrate or ammonium sulphate, it was recorded that 1 lb. of N as sodium nitrate gave 14.5 lbs. of cotton while 1 lb. of N as ammonium nitrate gave 13.8 lbs. and 1 lb. of N as ammonium sulphate gave only 11.8 lbs. of cotton.

In a recent publication of the West Bengal Govt. (1962) it has been reported that by adding 30 lbs. of N as ammonium sulphate/acre, the production of paddy increased by 358 lbs. per acre. Production in these lands *without* ammonium sulphate varies from 1378 to 2470 lbs./acre. These results show that 1 lb. of N produces approximately 11 lbs. of paddy grains whilst in Europe the average increase by N in crop production may be 17 lbs.

Generally it has been observed that sodium or calcium nitrate produces higher yields of crops as compared to ammonium sulphate.

A comparison of total yield in lbs. of all crops in a rotation on complete commercial fertilizer plots receiving N as ammonium nitrate and ammonium sulphate.

	24 lbs. of nitrogen		48 lbs. of nitrogen		72 lbs. of nitrogen	
	Sodium nitrate	Ammonium sulphate	Sodium nitrate	Ammonium sulphate	Sodium nitrate	Ammonium sulphate
Average: 1882-1921	18021	16857	18632	16357	18953	14985

PRINCE et al., after 40 years of experimentation in the U.S.A. with different nitrogenous substances, concluded from the foregoing results that the average crop yields are greater when nitrate of soda was used. Longtime Rothamsted results reported by RUSSELL indicate that sodium nitrate produced larger yields of barley and wheat than ammonium sulphate. These results are given as under:

Relative value of sodium nitrate and ammonium sulphate for barley and wheat on the Hoos and Broadbalk fields of Rothamsted Experiment Station, England.

Hoos field		Broadbalk field	
60 year average yield of barley per acre		20 year average yield of wheat per acre	
Carrier of nitrogen	Bu.	Carrier of nitrogen	Bu.
No nitrogen	19.7	No nitrogen	14.4
43 lbs. as sodium nitrate . .	42.7	86 lbs. as sodium nitrate . .	31.4
43 lbs. as ammonium sulphate	41.5	86 lbs. as ammonium sulphate	28.8

Comparison of nitrogenous fertilizers for Barley in experiments done before 1939

	Gain from 22.4 lb. N/acre		
Yield without nitrogen	As ammonium sulphate	As tested fertilizer	
	Cwt. of barley grain/acre		
22.9	2.8	4.6	« Nitro-chalk »
21.1	2.3	2.8	Sodium nitrate
(19.5 (15.4	1.9 3.9	3.1) 4.2)	Ammonium chloride

Similarly, greater yields of cotton have been obtained using sodium and ammonium nitrate as compared to ammonium sulphate in the trials conducted at Stoneville, Mississippi Experimental Station.

Relative crop producing value of Sodium nitrate, Ammonium nitrate and Ammonium sulphate applied to cotton at the Stoneville, Missisippi Experimental Station.

Source of nitrogen	9 year average lbs. seed Cotton per acre Yield	Increase %
Check — no fertilizer	1503.85	—
Sodium nitrate	1950.51	29.70
Ammonium nitrate	1918.33	27.56
Ammonium sulphate	1858.70	23.59

WEBBER compared ammonium sulphate, ammonium nitrate, limestone, calcium nitrate and urea in Yorkshire. Calcium nitrate was best and urea worst with ammonium salts occupying an intermediate position. Yields from ammonium nitrate limestone fertilizer were intermediate between yields from ammonium sulphate and calcium nitrate.

Comparison of nitrogenous fertilizers for winter wheat on calcareous soils in Yorkshire.

Yield of grain (cwt./acre at 85% dry matter)

	Rate (1% N/acre) 45	90	Mean.
Without nitrogen	—	—	29.1
Calcium nitrate	37.0	44.2	40.6
Ammonium nitrate—limestone	36.9	42.4	39.6
Ammonium sulphate	35.7	41.9	38.8
Urea	34.6	42.0	38.3

In the Oxford Economic Atlas of the World (Oxford University Press, 1959) the following increased yields per Kg. nitrogen are recorded:

	Wheat	Rice	Potatoes	Grass (or hay)
Kg per hectare	17	17	84	17

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It appears that humus content of soil determines appreciably the response of crops to fertilizer nitrogen. The United Nations Korean Reconstruction Agency has stated that 1 Kg. of N as ammonium sulphate produces 12 to 14 Kgs. of brown rice and 14-18 Kgs. of rough barley in South Korea. Moreover, 1 Kg. of phosphate as superphosphate can yield 4-5 Kgs. of brown rice.

From a survey of crop production and fertilizer application in different countries it appears that in countries not using large amounts of fertilizers, the nitrogen response to cereals is very marked; the law of diminishing returns is in operation in Holland, Belgium and Norway, where large amounts of nitrogen per acre are applied. But in Japan, China and Taiwan, where composts and other plant and animal organic wastes are largely utilised with fertilizers, better crop yields per unit of nitrogen are still obtained. In presence of soil humus the fertilising power of inorganic nitrogenous compounds is enhanced. Why nitrogen supercedes other nutrients in crop production is not known.

SOURCES OF SOIL NITROGEN - LARGE NITROGEN FIXATION IN SOILS IN THE SLOW OXIDATION OF ORGANIC MATTER INCLUDING COAL AIDED BY LIGHT AND CALCIUM PHOSPHATES

It has been estimated that 1000 million tons of cereals, 800 million tons of pulses, sugars, potatoes etc. and 1600 million tons of grasses are produced in the whole world today as agricultural products. Assuming that crop yield is 12-15 times the nitrogen application, production of world food and fodder requires approximately 350 million tons of available nitrogen per annum. It is well known that at the present moment, artificial nitrogenous fertilizers provide approximately 10-12 million tons of available nitrogen and rain and snow (precipitation) 7-10 million tons and farmyard manure 5 million tons. Legumes have been utilised in cultivation from ancient times.

Practical agriculturists found that when a legume is grown first and is followed by cereals, the cereal production is greater than when grown in the absence of a legume. Even today in various parts of Europe and in North America legumes are grown for land fertility improvement. In fodder lands, generally legumes are also grown for fodder purposes. In 1893 HELLRIEGEL and WILFARTH experimentally proved that Rhizobia bacteria invade the host plant, i.e. the leguminous crop, and the bacteria work symbiotically and grow at the root nodules and multiply from the photosynthesised carbohydrate and in this process nitrogen is fixed at the nodules. A.I. VIRTANEN of Helsinki reported that some of the amino acids produced in this nitrogen fixation pass out of nodules into the surrounding soil which becomes more fertile.

In 1906 A.D. HALL reported that legumes are the suppliers of soil nitrogen and this statement was repeated by Sir JOHN RUSSELL in his address at Bangalore (India) in 1937. Recent studies show that approximately 2 million tons of nitrogen are fixed by legumes in the soils of the U.S.A. and 3 million tons in other parts of the world, making a total of 5 million tons in the whole world.

It appears, therefore, that the well known sources of nitrogen nutrient for world crop production including artificial fertilizers come only upto 30 million tons as against approximately 350 million tons actually utilised in the world production of food and fodder. Hence, the great reliance of the European soil scientists on artificial nitrogenous fertilizers is extremely unsound as the amount available is, keeping in view our present needs, completely inadequate.

As nitrogenous fertilizers produced are not adequate to meet the world food situation, we have developed an alternative method of fixing atmospheric nitrogen directly in soil by ploughingh in all types of organic substances like molasses, straw, leaves, grasses, saw dust, farmyard manure, water hyacinth (Eichhornia crassipes), lucerne, *KANS* (Sacchrum spontaneum), cactus, municipal waste, peat, lignite, bituminous coal etc. mixed with bonemeal, rock phosphate or basic (Thomas) slag. So far organic matter and phosphates have been utilised separately, but, we have discovered that the two together are highly effective. A few of our laboratory experiments and field trials are recorded below:

A Swedish clay soil collected from the fields of the Royal College of Agriculture, Uppsala - 7, containing 0.147% N, 1.207% C, 1.19% CaO, 3.114% MgO, 1.2% K_2O and 0.225% P_2O_5 (of which 0.083% is available), was utilised and the following results were obtained in dishes by mixing organic matter with soil and exposing one set to artificial light for 8 hours daily and keeping another set covered with thick black cloth to exclude light. The moisture content was maintained at 20-25% by adding distilled water on every alternate day:

Fixation of nitrogen in Swedish soil

Period of exposure (days)	Organic carbon %	Total nitrogen %	Carbon oxidised %	Increase in nitrogen %	Efficiency: N fixed in mgm. per gm. of C oxidised
LIGHT		Swedish soil + sucrose			
0	2.3568	0.1470	—	—	—
150	1.4833	0.1656	0.8735	0.0186	21.3
300	1.2723	0.1682	1.0845	0.0262	28.4
DARK					
0	2.3568	0.1470	—	—	—
150	1.7274	0.1554	0.6321	0.0084	13.3
300	1.5036	0.1598	0.8532	0.0128	15.0
Swedish soil + 0.25 % P_2O_5 as Gafsa rock phosphate + Sucrose					
LIGHT					
0	2.3568	0.1470	—	—	—
150	1.4132	0.1862	0.9436	0.0392	41.5
300	1.1518	0.1992	1.2050	0.0522	43.4
DARK					
0	2.3568	0.1470	—	—	—
150	1.6787	0.1608	0.6781	0.0138	20.3
300	1.4612	0.1653	0.3956	0.0188	21.0

Fixation of nitrogen in Allahabad soils

Period of exposure (days)	Organic carbon %	Total nitrogen %	Carbon oxidised %	Nitrogen fixed lb/acre	Efficiency
Allahabad soil + Wheat straw					
LIGHT					
0	0.7356	0.0492	—	—	—
90	0.5358	0.0533	0.1998	—	20.8
150	0.4762	0.0544	0.2594	—	20.6
180	0.4365	0.0553	0.2991	117.6	20.6
DARK					
0	0.7356	0.0492	—	—	—
90	0.5866	0.0507	0.1490	—	10.6
150	0.5417	0.0511	0.1939	43.7	10.1
180	0.5241	0.0513	0.2115	—	10.2
Allahabad soil + Wheat straw + 0.1% P_2O_5 as $Ca_3(PO_4)_2$					
LIGHT					
0	0.7356	0.0492	—	—	—
90	0.4924	0.0566	0.2432	—	30.9
150	0.4181	0.0588	0.3175	213.2	30.3
180	0.3740	0.0602	0.3616	—	30.6
DARK					
0	0.7356	0.0492	—	—	—
90	0.5513	0.0522	0.1843	—	16.3
150	0.4851	0.0532	0.2505	90.0	16.0
180	0.4652	0.0534	0.2704	—	15.8

Using Tata basic slag containing total P_2O_5 7.5965%, available P_2O_5 4.46%, Silicon 23.65%, K_2O 9.0736%, CaO 34.3675% and MgO 5.2870% and cow dung as energy material and Allahabad soil, the following results were obtained:

Soil + Cowdung

	Period of exposure in days	Total carbon %	Total nitrogen %	Carbon oxidised %	Increase in N %	Efficiency N fixed per gm. of carbon oxidised
LIGHT . .	0	1.7262	0.0942	—	—	—
	60	1.5077	0.0990	0.2185	0.0048	22.42
	120	1.3411	0.1044	0.3851	0.0102	26.51
	180	1.2120	0.1083	0.5142	0.0141	27.55
DARK . .	0	1.7262	0.0942	—	—	—
	60	1.5230	0.0970	0.2032	0.0028	15.28
	120	1.4248	0.0988	0.3014	0.0046	15.33
	180	1.2647	0.1015	0.4615	0.0073	15.98
	Soil + Cowdung + Tata basic slag (0.25% P_2O_5)					
LIGHT . .	0	1.7125	0.0925	—	—	—
	60	1.0373	0.0984	0.6752	0.0283	41.93
	120	0.9489	0.1010	0.7641	0.0321	42.03
	180	0.9232	0.1030	0.7893	0.0354	44.54
DARK . .	0	1.7125	0.0925	—	—	—
	60	1.3713	0.0984	0.3412	0.0054	17.56
	120	1.2974	0.1010	0.4151	0.0085	20.34
	180	1.2277	0.1030	0.4848	0.0105	21.76

CALCIUM PHOSPHATE RICH SOILS FIX NITROGEN WITHOUT ADDED ORGANIC MATTER

Moreover, in the soils containing 0.4 to 0.33% P_2O_5 we have observed a very remarkable behaviour that when these soils are allowed to undergo slow oxidation in the air, the carbonaceous matter in humus slowly undergoes oxidation both in sterile and unsterile conditions in light and in the dark, and, there is appreciable fixation of nitrogen as recorded below:

Unsterile	200 gms. soil in dish exposed to light for 100 days		
	Composition of soil P_2O_5 0.418 % CaO 3.402 % Nitrogen 0.2075%		Temperature 30°—50°C
	Initial reading %	After 100 days	Efficiency
LIGHT Total carbon . . .	1.5980	0.9581	62.5
» nitrogen . . .	0.2075	0.2475	
DARK » carbon . . .	1.5980	1.123	32.7
» nitrogen . . .	0.2075	0.223	
Sterile	In test tubes containing 10 gms. soil	After 150 days	
LIGHT Total carbon . . .	1.5315	1.385	109.2
» nitrogen . . .	0.2020	0.218	
DARK » carbon . . .	1.5315	1.396	59.0
» nitrogen . . .	0.2020	0.210	

Unsterile	In dish	P_2O_5 0.3385% CaO 2.38 % Nitrogen 0.044 %	
	Initial reading	After 100 days	Efficiency
LIGHT Total carbon . . .	0.133	0.0430	45.6
» nitrogen . . .	0.044	0.0481	
DARK » carbon . . .	0.133	0.0600	21.9
» nitrogen . . .	0.044	0.0456	
Sterile	In test tubes	After 150 days	
LIGHT Total carbon . . .	0.1350	0.1200	100
» nitrogen . . .	0.0425	0.0440	
DARK » carbon . . .	0.1350	0.1290	
» nitrogen . . .	0.0425	0.0428	50

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The foregoing results show clearly that soils which are rich in calcium phosphate can fix atmospheric nitrogen both in sterile and unsterile conditions when they come in contact with air and undergo slow oxidation, more in light than in the dark.

MECHANISM OF NITROGEN FIXATION

In explaining photosynthesis in plants, DHAR postulated in 1933 that the important photochemical reaction is the decomposition of water by absorption of light according to the following equation:

$$H_2O + 112 \text{ K. cal.} = H + OH.$$

The hydrogen atom thus formed reduces the carbonic acid adsorbed on the leaves forming formaldehyde. In recent years this view of the mechanism of photosynthesis has been supported by the use of carbonic acid containing isotopic carbon. In explaining nitrogen fixation the best mechanism seems to be the same, i.e. the decomposition of water into H and OH by absorption of energy obtained from the oxidation of carbohydrates, celluloses, fats, lignins, coals etc. Moreover, in presence of light, the light energy, whether from the sun or artificial source, is absorbed by the system and utilized in increasing nitrogen fixation. In symbiotic nitrogen fixation also, the same mechanism may be applicable.

For fixing 14 gms. of nitrogen and forming ammonia by the interaction of molecular nitrogen and atomic hydrogen obtained by the decomposition of water as stated above, 336 K. Cals, are needed. Hence, from the oxidation of a gram mol of glucose according to the equation $C_6H_{12}O_6 + 6O_2 = 6CO_2 + 6H_2O + 676$ K. Cals., $\frac{14 \times 676}{336}$ grams of N can be fixed under ideal conditions. In other words, 0.39 gram of N should be fixed per gram of C oxidised. In many of our experiments in soils fairly rich in calcium phosphate, a nitrogen fixation of 100 mgms. with sugar candy and about 150 mgms. with wheat straw has been observed per gram of carbon oxidised. Hence, the efficiency of this type of nitrogen fixation in soils is $\frac{150}{390} \times 100 = 38\%$, with straw in light, and with sugar candy $\frac{100}{390} \times 100 = 25\%$. In sterile conditions, efficiency in light is 21% with wheat straw; in the dark this efficiency is 10%. Hence, the efficiency can be 3 times greater than the industrial methods of fixing nitrogen.

It is well known that in absence of moisture, nitrogen fixation in soils does not take place because water plays a prominent part as postulated in the mechanism of nitrogen fixation proposed above. The ammonia can readily be oxidised to nitrates in soils or nodules. DHAR and MUKHERJI have obtained amino acids readily by the action of nitrates on carbohydrates in presence of light using titania as photocatalyst. In symbiotic fixation the energy required is supplied by oxidation of the carbohydrates photosynthesised by the host plant, and nitrogen fixation takes place chiefly in the nodules. In this process the possibility of the loss of nitrogen by formation and decomposition of ammonium nitrite appears to be less than in our experiments where the facility for the oxidation of proteins, amino acids, ammonium salts obtained by fixation is greater than in nodules. This is certainly one of the reasons why symbiotic nitrogen fixation frequently appears to be more efficient than non-symbiotic fixation.

Ammonia is readily detected in nitrogen fixation by Azotobacter or Clostridia in culture media. In our experiments on nitrogen fixation in sand or soil with soluble carbohydrates or glycerol as energy material, there is marked increase of ammoniacal nitrogen in a short time. Moreover, we have discovered that a mixture of finely-divided basic slag or rock phosphate and organic substances like straw, leaves, molasses, peat, lignite and even bituminous coal, is very effective in reclaiming saline and alkaline soils permanently.

The atomic hydrogen formed from the decomposition of water combines with nitrogen and forms NH_3 which can be readily oxidised to nitrite and nitrate by air or H_2O_2 obtained from OH radicals. Nitrate easily reacts with organic matter and forms amino acids. When these systems are illuminated by sunlight or artificial light, the light is absorbed and nitrogen fixed in presence of light is much greater than that obtained in the dark. In all these experiments, the number of Azotobacter, total bacteria and fungi are always smaller in presence of light which is harmful to micro-organisms, than in the dark although the nitrogen fixed per gram of carbon of the energy material oxidised in light is much greater than in the dark. In presence of calcium phosphates, the nitrogen fixation is greatly enhanced. On photographing the Azotobacter cells it was quite clear that Azotobacter was much bigger and more developed in the dark set than in the set exposed to light.

In our experiments with molasses, sucrose and other soluble carbohydrates, there is marked increase of ammoniacal nitrogen as well as of total nitrogen in a short time but with cellulosic materials like straw, liberation of ammonia from the system takes place in a longer time. Consequently, a time interval of 2-4 months according to soil temperature is needed between incorporation of straw or materials rich in cellulose and lignin in soil and sowing of a crop depending chiefly on soil temperature and humidity. In this process basic (Thomas) slag, being alkaline and containing chemical catalysts, helps in partial oxidation of the organic substances and liberation of ammonia and formation of nitrate.

Value of basic slag and calcium phosphates in nitrogen fixation and crop production.

Analysis of different soil samples from the same field

Treatment	Organic carbon %	Total nitrogen %	C/N ratio
No slag	1.90	0.172	11.0
Tata basic slag	1.77	0.331	5.3
do do do	2.01	0.270	7.4
do do do	1.89	0.279	6.7

Allahabad municipal waste was dumped on a field with or without Tata basic slag containing 8% P_2O_5 with the above results and bumper crops were obtained in this improved land.

KARRAKER, working in the U.S.A., obtained the following results showing marked N fixation and improved crop yield by a mixture of manure and phosphate:

Average of 3 field treatments	Nitrogen in soil (lb/acre)	Corn yield (bushels/acre)
No manure	1600	17
Manure	1760	36
Manure + Phosphate	1990	51

From a survey of the phosphate status of world soils it appears that alkaline phosphates like Thomas slags, rock phosphates and even animal dung containing phosphate, show more residual effect than soluble varieties of phosphates like superphosphate chiefly because calcium carbonate present in the alkaline phosphate and farmyard manure markedly check the washing away of phosphates from soils. Some of our field trials in Bengal with paddy grains (Kg/acre) are recorded below:

Field experiments in paddy and wheat production by organic matter and phosphates.

Treatments	1958-59	1959-60	1960-61	Average
1. Control	322.40	531.60	816.40	556.80
2. Organic matter (straw 10 tons/acre)	362.40	762.40	985.20	703.20
3. Basic slag (40 lb. P_2O_5/acre) .	350.80	745.20	861.60	652.40
4. Superphosphate (40 lb. P_2O_5/acre	325.60	632.80	822.00	610.00
5. Organic matter (straw) + basic slag	390.00	784.00	974.80	714.80
6. Organic matter (straw) + superphosphate	399.20	771.60	918.00	696.00

In the following experiments wheat was grown after harvesting paddy on the same land:

Yield of paddy grain in Anapur (Allahabad) in Kg. per 1/60 acre)

Treatments	Blocks						
	1	2	3	4	5	6	Total
Soil alone (control) ...	11.50	12.25	10.75	11.00	13.00	10.25	68.75
Soil + wheat straw (10 tons/acre)	18.00	17.25	19.50	16.50	18.50	18.25	108.00
Soil + wheat straw + P_2O_5 as Tata basic slag	23.25	22.75	23.50	24.50	21.50	23.50	139.00
Soil + KANS (Sacchrum spontaneum) (10 tons/acre)	16.75	15.50	16.25	17.75	15.00	16.00	97.25
Soil + KANS + P_2O_5 as Tata basic slag .	21.75	21.25	22.25	22.75	20.50	21.25	129.75
Soil + Sunnhemp (Crotalaria juncea) . . .	15.50	14.75	16.75	15.25	15.75	16.00	94.00
Soil + Sunnhemp + P_2O_5 as Tata basic slag	18.75	19.25	17.50	18.50	19.50	18.50	112.00
Total . . .	125.50	123.00	126.50	126.25	123.75	123.75	748.75

Yield of wheat grain (Kg.)

Soil alone (control) . .	8.25	10.50	9.25	8.00	10.50	10.00	56.50
Soil + wheat straw (10 tons/acre)	13.25	13.25	13.50	13.00	14.50	14.50	82.00
Soil + wheat straw + P_2O_5 as Tata slag (50 lb/acre)	19.25	18.50	20.00	17.50	19.00	17.25	111.50
Soil + KANS (10 tons/acre)	12.50	13.00	11.50	14.00	12.25	13.25	76.50
Soil + KANS + P_2O_5 as Tata slag (50 lb/acre)	16.25	17.50	15.50	17.25	18.00	16.00	100.50
Soil + Sunnhemp (10 tons/acre)	11.50	11.50	12.75	11.50	10.25	11.50	69.00
Soil + Sunnhemp + P_2O_5 as Tata slag (50 lb/acre)	15.75	14.25	15.75	16.00	15.25	15.50	92.50
Total . . .	96.75	98.50	98.25	97.25	99.75	98.00	588.50

At my request, Lady Eve Balfour of The Soil Association, New Bells Farm, Haughley, Suffolk, England, performed the following experiment:

A plot of land (5.42 acres) with barley was harvested by a combine harvester on 9/9/57 but the barley straw remained on the land which was ploughed up early in January 1958. To one portion of the land (3.12 acres) ammonium sulphate @ 1 cwt. nitrogen per acre was applied on 17/10/57. To the second portion nothing was added. In the third portion (1.75 acres) 22% Thomas (basic) slag was applied to the straw on 16/12/57 @ 99 lbs. P_2O_5 per acre. On 3/4/58, 1 ton and 4 cwt. of a compound fertilizer (Fison 35), 25 lb. nitrogen, 62 lh. P_2O_5 and 62 lb. K per acre were applied to the whole 5.42 acre plot. Barley was sown on 10/4/58 and harvested on

6/9/58. Lady BALFOUR reported that the plot to which slag was added to the straw contained the largest amount of total and produced the biggest crop of barley. The yield of barley in the 3.12 acre plot (to which ammonium sulphate was applied) was 20.4/5 cwt. per acre. The control plot (to which nothing was added) gave 14 cwt. per acre. But in the third plot containing Thomas (basic) slag, the yield of barley was the highest, that is, 30.2/7 cwt. per acre.

The Inter-African Bureau of Soils are also utilizing straw and basic slag in Africa on a large scale.

It is good for world agriculture that G. BJALFVE of the Royal College of Agriculture, Uppsala, Sweden, has also observed marked nitrogen fixation more in light than in the dark by incorporating straw with soil or sand and that calcium phosphates largely increase this nitrogen fixation. BJALFVE believes that this photochemical and thermal fixation of nitrogen may be of greater importance all over the world than legumes, which are difficult to grow. Crop production in many countries without manures or fertilizers and the marked fertility of prairie lands can be satisfactorily explained from the viewpoint of nitrogen fixation observed by us from the oxidation of plant residues and grasses incorporated in the soil aided by light and phosphates.

As large amounts of plant materials are photosynthesised on the earth's Surface, there is no dearth of organic matter. Moreover, the estimated world reserves of rock phosphate deposits are of the order of 21000 million tons and the world consumption is only 700 million tons per year. The world steel industry is producing increasing amounts of phosphate as basic slag. Hence, large amounts of nitrogen fixation and land fertility improvement on a worldwide scale are possible by adopting this method, by utilising cereal straw, grasses, forest litters, leaves, waste coals, lignites, peats, etc. as energy materials.

In France, the use of Thomas (basic) slag which is cheap is increasing and is taking the place of superphosphate. It has been reported that basic slag appreciably increases available nitrogen in the system and doubles grass yields.

Sir JOHN RUSSELL, has stated that in all countries, even in the most advanced, there is an equally great or even larger gap between the present achievements of the best farmers and the high yields occasionally obtained as the result of the combination of factors which in nature occur only rarely but which, if we could discover and reproduce them, would make these same records a more usual, perhaps even the normal occurrence.

Prof. BRADFIELD of the U.S.A. has also recorded yields of cereals in different parts of the world. A land in Iowa, kept under blue grass for 50 years, when ploughed up and phosphated, produced 224 bushels of corn per acre. It appears therefore that the growing of blue grass creates prairie lands with 0.6% total nitrogen and over 500 lbs. of available nitrogen per acre. In experiments in India, large crop yields of cereals and potatoes have been obtained by adding large amounts of composts aided by nitrogenous fertilizers. These experimental observations in different parts of the world show that humus-rich soils can produce bumper crops. In the 'Fen' soils in England containing 3% total nitrogen and in the 'muck' soils in New Jersey containing 2.7% nitrogen, large crops are produced aided by fertilizers.

VALUE OF PHOSPHATED COMPOSTS CONTAINING COAL

In the composting of the waste organic materials we have observed a very marked effect of phosphate and light in improving the valne of the composts in plant growth. This is evident from the following results obtained in composting dry leaves with and without phosphate in big wooden boxes:

Dry leaves of Guava (Psidium guajava)

Days	Total carbon (gm.)	Total N_2 (gm.)	NH_4-N_2 (gm.)	Available NO_3N_2 (gm.)	Total available N over total N%	C/N ratio	Available P_2O_5 (gm.)	pH	Weight of compost (Kgm.)
0	12163.00	262.36	—	—	—	46.30	—	—	35.00
50	9730.44	311.02	10.136	11.946	7.1	31.28	22.568	6.9	30.68
100	7361.08	348.45	15.826	19.716	10.2	21.12	31.013	6.0	27.11
150	6281.15	374.62	20.443	30.505	13.6	16.76	38.646	5.4	24.28
200	5401.66	365.14	15.707	24.267	10.4	14.79	42.291	6.3	22.04
Dry leaves + 1% P_2O_5 as Tata basic slag									
0	12163.00	262.36	—	—	—	46.30	189.30	—	39.88
50	9536.64	317.84	14.636	17.668	10.1	30.00	238.40	7.8	33.12
100	6655.50	404.51	25.801	34.066	14.1	16.45	269.50	6.4	29.08
150	5415.04	484.62	34.098	48.772	17.1	11.17	181.10	5.8	26.76
200	4780.00	468.62	28.925	41.368	15.0	10.20	290.80	6.9	35.14
Dry leaves + 20% coal									
0	12163.00	262.36	—	—	—	46.30	—	—	42.00
50	13681.25	415.29	8.807	10.075	7.54	32.90	20.708	7.2	38.08
100	11542.63	456.16	13.542	16.874	6.67	25.30	28.553	6.5	34.92
150	1911.55	478.65	17.293	23.778	8.58	25.70	26.118	6.0	32.11
200	8588.08	468.70	14.156	19.278	7.14	18.30	40.065	6.6	30.18
Dry leaves + 20% coal + 1% P_2O_5 as Tata basic slag									
0	16095.75	375.08	—	—	—	42.90	189.30	—	46.88
50	13271.17	437.31	11.777	15.369	6.21	30.30	230.10	8.0	42.13
100	11007.20	479.42	20.648	29.406	10.44	22.90	248.70	7.0	39.34
150	9144.61	501.41	28.912	40.051	13.76	18.30	260.20	6.2	36.01
200	8010.40	493.33	25.154	35.002	12.22	16.20	268.60	7.0	33.27

Yield of Paddy and Wheat grains in POTS from composts obtained from dry leaves mixed with coal and Tata basic slag.

Treatments	Total yield (gms.)	
	Paddy grain	Wheat grain
1. Soil (alone)	89	48
2. Soil + Unphosphated compost	188	102
3. Soil + » » containing 20% coal	208	117
4. Soil + Phosphated compost	257	132
5. Soil + » » containing 20% coal	308	143

The above results clearly show that the addition of bituminous waste coal improves the plant producing power of the compost.

Moreover, in composting Allahabad municipal waste the following results were obtained:

Composition of Allahabad municipal waste compost

	Phosphated municipal compost	Unphosphated municipal compost
Total P_2O_5	1.2156	0.8525
Available P_2O_5	0.3650	0.2453
K_2O	0.8054	0.7521
MgO	0.2615	0.2506
CaO	3.2162	1.8425
Total carbon	4.1600	6.2700
Total nitrogen	1.2500	0.8242

Yield of barley grains in POTS from the above compost

Treatments				Total yield (gm)
1. Soil alone (control)				50
2. Phosphated	municipal waste		(5 tons/acre) . . .	181
3. »	»	»	(10 tons/acre) . . .	253
4. Unphosphated	»	»	(5 tons/acre) . . .	133
5. » »	»	»	(10 tons/acre) . . .	193

From times immemorial organic matter has been profitably applied in crop production. Since 1880 Thomas (basic) slag is being used as a phosphatic fertilizer. But, DHAR and co-workers have discovered that for crop production both, organic matter and Thomas slag, should be ploughed in mixed because the two together are ever so much better than either of them alone. Wheat straw or other cereal straw when ploughed in can fix atmospheric nitrogen and supply available nitrogen, potash and phosphate for crop growth, but, when mixed with Thomas slag, the fixation of nitrogen is greatly increased and more available nitrogen, potash, phosphate and trace elements are supplied to crops. Thomas slag being alkaline due to its contents of CaO, K_2O, MgO etc., oxidation of cellulose and lignin materials in straw is greatly increased when it is mixed with straw and ploughed in the soil. Moreover, chemical oxidation catalysts like Cu, Fe, Mn, Ti, Mo, V, Zn present in the slag also accelerate oxidation of cellulose and lignin. In this process energy is liberated and utilized in fixing atmospheric nitrogen on the soil surface and land fertility is markedly increased. Oxidation of carbonaceous compounds of soil humus and those added by ploughing organic matter like straw, is greatly facilitated by adding Thomas slag and this is a very important function of the Thomas slag. In this way, not only the total nitrogen of the system increases by ploughing in Thomas slag and straw, but, due to increased oxidation in the soil by adding Thomas slag, the available nitrogen, phosphate, potash, lime, magnesia etc., that is, all the important plant nutrients increase considerably making the land more fertile and productive. This happens not only with the phosphorus-poor soils but in all soils and this method is applicable all over the world. Trace elements present in the slag form an important part in plant nutrition. In temperate countries, the interval between the ploughing in of the straw and Thomas slag and in the sowing of the next crop should be 2 to 3 months. By this time, the carbonic acid and the organic acids produced in cellulose and lignin oxidation make more potash, phosphate, lime, magnesia available to crops.

DIRECT PLOUGHING OF ORGANIC MATTER AND PHOSPHATES PRODUCES BETTER YIELDS THAN COMPOSTS OBTAINED FROM THEM

DHAR, in his Presidential address on 15/1/1937 to the National Academy of Sciences, India, first emphasised that direct ploughing in of organic matter is certainly better than the addition of the compost obtained from organic matter because in the direct ploughing in of the organic matter, there is much more nitrogen fixation than in composting where even marked losses of nitrogen have been reported by soil Scientists. In recent years, a very large number of comparative experiments have been carried on.

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Yield of Paddy grain (Kgms)

Treatments	Organic materials added DIRECTLY. Mean of 4 replications	Organic materials added AFTER composting Mean of 4 replications
1. Soil alone	46.3	46.1
2. Soil + Wheat straw	74.3	66.3
3. Soil + Wheat straw + Tata Thomas slag	96.6	88.7
4. Soil + Paddy straw	69.6	61.3
5. Soil + Paddy straw + Tata Thomas slag	89.3	81.8
6. Soil + KANS (Sacchrum spontaneum)	65.3	57.6
7. Soil + KANS + Tata Thomas slag	84.6	76.8
8. Soil + mixed leaves	62.1	54.3
9. Soil + mixed leaves + Tata Thomas slag	81.5	73.5
10. Soil + Jack fruit leaves	60.2	52.4
11. Soil + Jack fruit leaves + Tata Thomas slag	79.6	71.5
12. Soil + Sunnhemp (Crotalaria juncea)	58.6	51.0
13. Soil + Sunnhemp + Tata Thomas slag	77.3	69.4
14. Soil + Cactus	56.7	49.2
15. Soil + Cactus + Tata Thomas slag	75.8	67.6

From the foregoing results it is clear that direct ploughing in of organic matter produces greater yield than from the compost formed from the organic matter.

VALUE OF COAL AND PHOSPHATED IN CROP PRODUCTION

We have carried on field trials by applying coal with or without wheat straw and basis slags in different farmers' fields in the district of Allahabad. Some of the results are recorded below:

Yield of paddy grain in Kgs

Treatments	Replications.				Total yield
	I.	II.	III.	IV.	
1. Soil alone	11.8	12.0	12.3	11.6	47.7
2. Soil + Coal	12.6	12.8	13.3	12.7	51.4
3. Soil + Wheat straw	18.7	19.0	19.4	18.8	75.9
4. Soil + » » + Coal	19.6	20.2	20.2	19.7	79.5
5. Soil + Tata Thomas slag	13.9	14.0	14.5	13.1	55.5
6. Soil + T.T.S. + Wheat straw	21.2	19.8	20.6	21.2	82.8
7. Soil + T.T.S. + Coal	14.8	15.0	15.4	14.6	59.8
8. Soil + T.T.S. + Wheat straw + Coal	21.8	21.4	20.9	21.0	85.1
9. Soil + German Thomas slag	14.0	14.8	15.0	13.8	57.6
10. Soil + G.T.S. + Coal	15.2	15.6	15.8	15.0	61.6
11. Soil + G.T.S. + Wheat straw	21.0	20.0	21.9	22.5	85.4
12. Soil + G.T.S. + » » + Coal	22.0	23.8	21.7	22.0	89.5

N.B. — Addition of coal, slag and organic matter on 15.6.65
Transplantation of paddy on 16.7.65
Harvesting of paddy crop on 14.10.65

Coal	2½ tons/acre
Organic matter	10 tons/acre
Phosphate	50 lbs. P_2O_5/acre.

Yield of wheat grain per plot (Kgs)

1. Soil alone	11.2	9.8	10.6	10.5	42.1
2. Soil + Coal	12.8	10.9	11.9	12.0	47.6
3. Soil + Wheat straw	16.0	18.3	17.4	17.8	69.5
4. Soil + » » + Coal	18.4	20.0	18.2	19.7	76.3
5. Soil + Tata Thomas slag	13.8	11.4	12.0	13.5	50.7
6. Soil + » » » + Coal	14.7	12.6	13.8	15.0	56.1
7. Soil + » » » + Wheat straw	22.8	24.6	23.5	23.0	93.9
8. Soil + T.T.S. + Wheat straw + Coal	24.0	25.0	24.3	24.6	97.9
9. Soil + German Thomas slag	14.2	13.8	12.8	13.7	54.5
10. Soil + » » » + Coal	15.0	14.7	13.9	14.8	58.4
11. Soil + » » » + Wheat straw	24.5	23.0	23.2	23.8	94.5
12. Soil + G.T.S. + Wheat straw + Coal	25.7	25.0	23.8	25.0	99.5

N.B. — Sowing of wheat crop on 10.11.65.
Harvesting of wheat crop on 20. 3.66.

In the above experiments after incorporating the manures, paddy was first sown and harvested. Without further addition of manures or fertilizers, wheat was grown to study the residual effect and the foregoing results were obtained showing marked residual effect of the organic manures in crop production.

PRACTICAL RESULTS BY A MIXTURE OF ORGANIC MATTER AND PHOSPHATES

Our method of land fertility improvement by ploughing in all types of organic matter including peat, lignite, waste coal etc. mixed with basic slag obtained from the expanding steel industries of the world can produce much larger quautities of nitrogen in the soils than in the industrial method.

It has been estimated that 59 billion tons of carbonic acid are utilised by Vegetation per year for producing carbohydrates by photosynthesis. This corresponds to the addition of 16 billion tons of carbon to the surface of the earth every year. If we assume that half of these carbonaceous compounds is oxidised on the earth's surface and 40-50 milligrams of nitrogen are fixed per gram of carbon oxidised, a tremendously largely amount of nitrogen fixation takes place under natural conditions, and, it is much greater than the industrial production of nitrogen. Hence, this method deserves much wider application and adoption.

Recently we have applied basic slag in small lumps to fields attached to the Sheila Dhar Institute and by growing grasses, the total nitrogen went up to 0.075% from 0.25% in 5 years.

We are definitely of the opinion that both calcium carbonate and calcium phosphate should be used as soil improvers. Phosphate rocks or basic slag in a finely divided condition should not only serve as a soil amendment but can also enrich the soil by helping nitrogen fixation caused by the oxidation of organic matter.

According to Collings, low crop yields are more often due to a lack of phosphoric acid than to the lack of any other nutrient. Phosphoric acid has often been called the 'master key' to agriculture. Phosphoric acid appears to be concerned in the production of nucleoproteids and it appears that phosphoric acid influences the production of seed or grain more particularly than does nitrogen or potash. Moreover, Collings has also stated that in all probability the major portion of the cultivated soils of the U.S.A., east of the Mississippi river, would be forced out of crop production within a comparatively few years if phosphate fertilizers were witheld. He has also reported that in the U.S.A. in the east of the one hundredth meridian are found soils whose pH value generally lies between 5.0 and 6.0, although, pH values of 4.5 or 4.0 are not uncommon.

In general, it might be said that the acidity of the cultivated soils of the U.S.A. increases from the Gulf of Mexico to the Canadian border as does also their nitrogen and organic content.

Plot	Fertilizer treatment	Hundred weight produce/acre in 15 years	Pounds per 2 million of soil		N:P ratio
			Phosphorus	Nitrogen	
25	Manure	1396	1220	3240	2.65
20	M - Ca.	1524	1050	2700	2.57
26	N - P - K	1179	900	2660	2.95
31	N - P	959	880	2400	2.72
34	P	634	880	2300	2.61
28	P - K	769	860	2280	2.65
19	N-P-K-Ca.	1206	740	2130	2.88

It is evident that the nitrogen/phosphorus ratios in the soil are fairly constant irrespective of differences in fertilizer treatments or in the amounts of crops removed. Phosphorus apparently is related to nitrogen fixation or to nitrogen conservation, one or both. Consideration of the nitrogen content of the crops removed led to the conclusion that nitrogen fixation estimated at from 20-75 lbs. per acre per year had taken place in the soil of these plots, the higher amount having been calculated in the case of the plots receiving both superphosphate and sulphate of potash.

« The only correlations with nitrogen content which have been established are those of the content of phosphate and of organic matter in soils of the same type and under similar climatic and cultural conditions. »

The following results were obtained by THOMPSON in U.S.A.:

Nmber of soils in each group	Total phosphorus part per million part of soil	Total nitrogen
2	800 - 999	0.375
25	600 - 799	0.325
17	400 - 599	0.226
4	200 - 399	0.151
2	0 - 199	0.111

NITROGEN FIXATION WITH ALGAE AND ORGANIC MATTER

It has been believed from a long time that some blue green algae increase land fertility and reclaim alkali land chiefly by their power of fixing atmospheric nitrogen. Dr. WATANABE of Japan and Dr. P.K. DE and Dr. R.N. SINGH of India are the chief exponents of this point of view. On the other hand, RUSSELL has stated unequivocally that in temperate climates there is no evidence of fertility improvement by the blue green algae. So, in order to throw further light on this subject, comparative experiments have been carried on by inoculating soils with (*a*) Anabaena naviculoides, (*b*) Tolypothrix tenuis and (*c*) Chlorella vulgaris.

250 gms. of black cotton soil collected from the Agricultural College Farm, Indore, Central India, were mixed with algae with and without basic slag. Sunnhemp and wheat straw were utilised as energy materials and 40% moisture was maintained in all the vessels throughout the experimental period and the results obtained are given below:

Analysis of soils, organic materials and basic slags used in the experiment.

Estimation	Soil oven dry basis %	Wheat straw %	Sunnhemp %	Tata basic slag %	German basic slag %
Loss on ignition . . .	—	89.9040	92.9200	—	—
Ash	—	9.0940	7.0800	—	—
HCl insoluble silica . .	57.6600	5.0450	2.9460	15.6846	11.4665
Sesquioxide	28.9451	1.4168	0.7614	—	—
Fe_2O_3	18.6740	0.6172	0.3553	15.5650	14.8760
Al_2O_3	10.3801	0.7996	0.4061	5.4320	3.0678
Total CaO	2.8464	0.8432	1.1080	38.6946	42.3467
Total MgO	1.0567	0.4081	0.3206	4.8486	4.9684
Total K_2O	0.8313	0.8014	0.7824	0.6474	traces
Total P_2O_5	0.1452	0.6036	0.7245	7.1600	17.2600
Available P_2O_5	0.0045	—	—	4.0520	9.9040
Total carbon	0.4800	38.2650	29.8700	—	—
Total nitrogen	0.0458	0.6370	2.2200	—	—
Ammoniacal nitrogen .	0.0014	—	—	—	—
Nitrate nitrogen . . .	0.0018	—	—	—	—
C/N ratio	10.62	60.07	17.96	—	—
$CaCO_3$	3.7500	—	—	—	—

Experiment with Black soil

Treatments	Total nitrogen fixed (mgms.)			
	60 days	120 days	180 days	240 days
Soil alone	0.9	1.6	1.8	1.5
Soil + Chlorella	1.0	1.4	1.8	1.6
Soil + Anabaena	1.4	2.0	2.3	1.9
Soil + Tolypothrix	1.5	2.1	2.5	2.1
Soil + Tata basic slag	1.1	1.8	2.1	1.6
Soil + T.B.S. + Chlorella	1.2	1.8	2.2	1.8
Soil + » + Anabaena	1.6	2.3	2.8	2.1
Soil + » + Tolypothrix	1.7	2.4	3.0	2.4
Soil + German basic slag	1.2	1.9	2.2	1.9
Soil + G.B.S. + Chlorella	1.3	1.9	2.4	1.9
Soil + » + Anabaena	1.8	2.5	3.2	2.7
Soil + » + Tolypothrix	1.9	2.8	3.4	3.0
Soil + Sunnhemp	7.7	11.2	13.7	10.6
Soil + » + Chlorella	7.9	11.5	13.9	11.0
Soil + » + Anabaena	9.9	14.1	19.4	15.3
Soil + » + Tolypothrix	10.3	14.5	20.2	17.3
Soil + Sunnhemp + Tata basic slag	16.0	21.3	25.3	22.8
Soil + » + T.B.S. + Chlorella	18.2	26.9	31.6	29.1
Soil + » + » + Anabaena	16.2	21.6	25.6	23.4
Soil + » + » + Tolypothrix	18.6	27.7	32.4	30.3
Soil + » + German basic slag	16.8	22.8	25.8	23.4
Soil + » + G.B.S. + Chlorella	17.1	23.0	26.2	23.9
Soil + » + » + Anabaena	19.3	23.2	32.4	30.1
Soil + » + » + Tolypothrix	19.8	29.3	34.0	31.5
Soil + Wheat straw	7.9	11.8	14.1	12.3
Soil + » » + Chlorella	8.2	12.0	14.4	12.5
Soil + » » + Anabaena	10.5	16.0	20.2	17.7
Soil + » » + Tolypothrix	11.1	16.6	20.9	18.6
Soil + » » + Tata basic slag	18.2	23.6	26.6	24 4
Soil + » » + T.B.S. + Chlorella	18.7	23.8	27.0	25.0
Soil + » » + » + Anabaena	19.4	28.6	33.2	31.3
Soil + » » + » + Tolypothrix	19.9	28.9	34.3	32.7
Soil + » » + German basic slag	19.1	24.8	27.2	25.1
Soil + » » + G.B.S. + Chlorella	19.4	25.0	27.6	25.6
Soil + » » + » + Anabaena	20.5	30.0	34.2	32.7
Soil + » » + » + Tolypothrix	20.9	30.9	35.5	34.2

The above table shows increases in total nitrogen of the system at different time intervals. These results conclusively prove that the increase in the nitrogen status of the soil is much greater with organic matter, specially in presence of phosphorus than with algae, which produce a very small increase of nitrogen. The above results also show that *after* 240 days, there is appreciable loss of the nitrogen fixed.

We have also carried on field experiments in Ramnagar, Distt. Allahabad, India, with organic matter and phosphate in presence and absence of the two algae — anabaena and chlorella — as recorded above. The experimental results are summarised in the following table:

Increase in yield of Paddy in Kg. due to various treatments (over control)

	Grains (Kg.)	Straw (Kg.)
Yield in control plot	48.4	75.4
Increase in yield due to:		
1. Chlorella	0.5	0.8
2. Anabaena	1.1	1.6
3. Tata basic slag	10.0	14.7
4. » » » + Chlorella	10.3	15.2
5. » » » + Anabaena	11.7	17.1
6. German basic slag	11.6	17.2
7. » » » + Chlorella . . .	11.6	17.3
8. » » » + Anabaena . . .	13.8	20.8
9. Wheat straw	26.7	37.0
10. » » + Chlorella	27.3	37.8
11. » » + Anabaena	29.1	40.8
12. » » + Tata basic slag . . .	49.7	72.3
13. » » + T.B.S. + Chlorella . .	50.5	73.4
14. » » + » + Anabaena . .	52.4	76.3
15. » » + German basic slag . .	49.9	75.0
16. » » + G.B.S. + Chlorella . .	51.8	76.4
17. » » + » + Anabaena . .	53.4	81.3

It is of great interest to record here that the increase in the yield of paddy grains due to the inoculation of anabaena was only 1.1 Kg. whilst the increase due to the incorporation of wheat straw (alone) was 26.7 Kgms. and by a mixture of wheat straw and German basic slag, the yield of paddy was more than double. Hence a mixture of organic matter and phosphate produces far greater beneficial effect in paddy production than anabaena.

Increase in the yield of Paddy (in Kg.) due to various treatments over the « Control »
(« Control »: Paddy grain: 46.4 Kg. and Paddy straw: 69.7 Kg.)

Treatments	Paddy grain	Paddy straw
Soil + Chlorella	0.4	0.4
Soil + Anabaena	0.9	2.0
Soil + Tata basic slag	9.6	13.6
Soil + -do- + Chlorella	10.0	14.4
Soil + -do- + Anabaena	12.0	17.5
Soil + German basic slag	11.9	19.3
Soil + Chlorella + German basic slag	11.9	21.1
Soil + Anabaena + German basic slag	13.9	28.7
Soil + Mixed leaves	23.7	32.3
Soil + -do- + Chlorella	24.3	33.5
Soil + -do- + Anabaena	26.1	37.6
Soil + -do- + Tata basic slag	43.1	64.4
Soil + -do- + Chlorella + Tata basic slag	43.9	65.5
Soil + -do- + Anabaena + Tata basic slag	45.7	69.7
Soil + -do- + German basic slag	46.9	69.9
Soil + -do- + Chlorella + German basic slag	47.3	70.4
Soil + -do- + Anabaena + German basic slag	48.5	74.3

Increase in the yield of Wheat (in Kg.) due to various traatments over the « Control ».
(« Control »: Wheat grain: 37.0 Kg. and Wheat straw: 61.6 Kg.)

Treatments	Wheat grain	Wheat straw
Soil + Chlorella	0.1	0.4
Soil + Anabaena	0.0	0.0
Soil + Tata basic slag	9.7	11.1
Soil + Chlorella + Tata basic slag	9.8	11.1
Soil + Anabaena + Tata basic slag	9.7	12.0
Soil + German basic slag	11.8	14.6
Soil + Chlorella + German basic slag	11.8	14.5
Soil + Anabaena + German basic slag	11.9	14.6
Soil + Mixed leaves	25.4	26.3
Soil + -do- + Chlorella	25.3	26.3
Soil + -do- + Anabaena	25.4	26.3
Soil + -do- + Tata basic slag	43.3	26.4
Soil + -do- + Chlorella + Tata basic slag	43.2	42.9
Soil + -do- + Anabaena + Tata basic slag	43.4	42.7
oSil + -do- + German basic slag	44.7	42.8
Soil + -do- + Chlorella + German basic slag	44.6	47.9
Soil + -do- + Anabaena + German basic slag	44.7	47.8

FORMATION OF FERTILE SOIL FROM EARTH'S CRUST

We have carried on a large number of experiments in the slow oxidation of energy materials when mixed with soils or chemical surfaces like oxides of iron, nickel, aluminium, titanium, silicon etc. These surfaces do not contain any nitrogenous material. We have observed that the efficiency of nitrogen fixation, that is, the amount of nitrogen fixed per gram of carbon oxidised, is greater on the oxide surfaces than in our soil containing 0.04-0.05% total nitrogen. Moreover, by increasing the total nitrogen in soils by the incorporation of nitrogenous compounds and mixing the nitrogen-rich soil with organic materials, there is nitrogen fixation in the slow oxidation of the energy materials. But the efficiency of nitrogen fixation falls off as the initial nitrogen content of the system increases. The higher value of efficiency in nitrogen fixation obtained with oxide surfaces as compared with that obtained in soils, is due to the fact that the phenomenon of nitrogen fixation and nitrogen loss go on simultaneously. The fixation process is opposed by the loss due to nitrification. The unstable explosive substance, ammonium nitrite, which is formed in the process of oxidation of nitrogenous compounds involved in the nitrification of proteins, amino acids and ammonium salts formed by fixation of atmospheric nitrogen or originally present in the system, undergoes rapid decomposition according to the equation: $NH_4NO_2 = N_2 + 2H_2O + 718$ K. Cals. This is the main chemical change involved in the loss of nitrogen always observed in the nitrification of nitrogenous compounds. In soils, there is always a certain amount of combined nitrogen, i.e. to the extent of 0.05% in tropical soils. Hence, the loss of nitrogen is more marked in soils than on oxide surfaces containing no nitrogen, and, the process of nitrogen fixation on oxide surfaces becomes more productive than in soil systems, because, the fixation process and the nitrogen loss go on simultaneously opposing each other, and when the nitrogen of the system increases, the loss may compensate the amount of nitrogen fixed from the energy obtained from the slow oxidation of energy materials. These observations are of fundamental importance in explaining the evolution of fertile soils from the earth's crust obtained from the parent rocks of geological ages. The earth's crust does not contain any appreciable organic matter but may contain small amounts of nitrate or ammonium salts from rain water or snow or dust. These nitrogenous compounds under the influence of solar light and moisture and seeds, form the first set of vegetation or plant life or alga on the earth's crust, the nitrogen need of which is met from the inorganic nitrogen present in the earth's crust in small amount. The energy materials photosynthesised containing cellulose, fat, soluble carbohydrate or other energy material formed in photosynthesis, undergo slow oxidation and liberate energy, causing nitrogen fixation which is markedly aided by light absorption and calcium phosphates present in the system. By the fixation of atmospheric nitrogen, the nitrogen store increases. This, in its turn, leads to a more abundant growth of vegetation and this process goes on by which the carbon and nitrogen status of the system is improved, leading to the formation of a fertile soil. This nitrogen fixation, which in the beginning is a non-biological surface reaction aided by light absorption, as the original earth's crust is poor in nitrogenous compounds, is more efficient in the beginning, but, with the storing up of nitrogen the efficiency falls off and thus the nitrogen and carbon status of the system reaches a maximum limit depending upon the climatic conditions.

But the maximum nitrogen increase can be improved by the incorporation of calcium phosphates which stabilise the nitrogenous compounds and avoid the loss of nitrogen.

Organic matter in the soil may be created by the growth of alga also. It is believed to be valuable in many soils but, on newly formed soils, it is of the greatest importance. The carbon of the algae, when decaying, is slowly oxidised and the energy liberated leads to the fixation of atmospheric nitrogen. Our observations show that the growth of algae is slow and hence the amount of carbonaceous compounds added by the algal growth is not large. Nitrogen fixation by algal growth and decay is smaller than by the addition of carbonaceous materials like farmyard manure, leaves, grasses etc. The greater the carbonaceous matter added to the soil, the greater the oxidation and greater the fixation of nitrogen, as has been recorded in this communication.

Till the beginning of the present century cattle dung or farmyard manure, alone or mixed with chalk, used to be the chief fertilising material in crop production in Europe. It was believed that dung, in its decomposition, supplies the nitrogenous compounds, potash, phosphate lime, magnesia etc., present in the dung, to the crops growing on the land and the chalk prevents the acidification of the land by washing. From our experiments we have established that dung or farmyard manure with C/N ratio of 20 or 22 not only supplies the plant nutrients contained therein but can fix appreciable amount of nitrogen and make the soil fertile, and in this process phosphate rocks, basic slags, bones etc. are of supreme importance and are better than calcium carbonate. Moreover, all organic substances leave a residual effect in the soil because of the humus formation and fixation of atmospheric nitrogen. It is clear that whenever a residual effect of a manure has been observed, e.g. molasses, straw, hay, farmyard manure, grasses, it is chiefly due to nitrogen fixation in the soil and little residual effect is observed with legumes with a C/N ratio much smaller than that of farmyard manure or straw.

JOHN B. ABBOT of Vermont, U.S.A. has stated as follows: « If all accumulated soil wisdom of a hundred generations of master farmers were boiled down to just three sentences, one of these sentences certainly would be: *Provide for regular and frequent replenishment of the supply of organic matter in the soil.* »

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PHOSPHATES HELPFUL IN THE FORMATION OF NITRE BEDS

In a number of publications DHAR has advanced a theory explaining the formation of natural nitre beds in Chile and other parts of the world based on the phenomenon of nitrogen fixation aided by sunlight. It has been reported that phosphates exist in the overlying rocks near the deposits of the Chile salt petre. From our experiments we have observed that when calcium and other phosphates are mixed with all types of organic matter undergoing slow oxidation, there is marked fixation of atmospheric nitrogen and formation of proteins, amino acids and salts of ammonia. This fixation of nitrogen by the slow oxidation of organic matter is much greater in presence of light than in its absence and, actually, light is utilised in producing more nitrogenous compounds. Moreover, in presence of calcium and other phosphates, the fixation of nitrogen is much accentuated.

Hence, all types of organic substances, like sea weeds, planktons when mixed with guano or bird deposits or bones of fishes or animals rich in calcium phosphate, fix atmospheric nitrogen copiously, specially in the presence of sunlight in areas like Chile, Peru etc. These nitrogenous compounds in course of time can undergo nitrification more in light than in the dark and can be converted into nitrates of sodium, potassium, calcium, magnesium etc.

We have observed that when potassium salts, sodium salts or soluble calcium or magnesium salts are mixed with nitrogenous substances undergoing nitrification, the formation and decomposition of the unstable and explosive substance, ammonium nitrite which is always produced in the nitrification of nitrogenous compounds, is decreased due to the formation of nitrites of the alkali and alkaline earth metals. Consequently, the formation of nitre beds may be due to the photochemical, catalytic and bacterial nitrification of the nitrogenous compounds obtained from weeds, planktons, animal bodies and those fixed in the slow oxidation of organic substances with C/N ratios greater than 10 aided by calcium phosphates derived from sea animals, fishes and dung of the birds.

It is quite possible that under certain conditions, the soluble nitrates thus produced may be separated from the calcium phosphate by washing down the highlands and accumulated by the evaporation of water in the valleys. That sea water and sea weeds and materials present in the sea bed play an important role in nitre bed formation is clear from the following composition of an average sample of caliche which contains many chemicals present in sea water and beds: sodium nitrate 8-25%, potassium nitrate 2-3%, sodium chloride 8-25%, sodium sulphate 2-12%, calcium sulphate 2-6%, magnesium sulphate 0-3%, sodium biborate 1-3%, sodium iodate 0.05-0.1%, sodium perchlorate 0.1-0.5% and insoluble matter 23-70%.

NITROGEN FIXATION IN GRASSLANDS

It has been quantitatively estimated by a British Govt. Committee that 2 tons of roots, stems etc. are lost by oxidation from grasslands annually per acre. There is no doubt that this forms the chief source of the increased fertility of land under grass. The oxidation of organic matter derived from grasslands leads to nitrogen fixation in soil. The reported increase of nitrogen in grasslands in Rothamsted and other places can be readily explained. When phosphated, the grass root oxidation @ 2 tons/acre may fix a fair amount of nitrogen every year. The carbon oxidised in 2 tons of roots and stems is approximately 0.8 ton per year. If we assume that 25 milligrams of nitrogen are fixed per gram of carbon oxidised, the nitrogen fixation per acre per year is 40 lbs. In Rothamsted, land under grass without legumes fixes 43 lbs. of nitrogen per acre. But when adequate amounts of basic slag or ground phosphate rock are added, there may be a fixation of 80-100 lbs. of nitrogen per acre. When grasslands are ploughed up and phosphated with basic (Thomas) slag, there is always a probability of fixation of 200 lbs. or more of nitrogen per acre as the quantity of carbohydrate available for oxidation on the soil surface is much greater. This is the reason why phosphating of ploughed-up grassland produced excellent results in the U.K. and other countries. In the famous Cockle Park experiments, the basic slag added to grasslands not only helped the increased growth of white clover as explained by the Cockle Park workers but the grass-root-material oxidation creates more nitrogenous matter than the legume fixation, because, frequently in pastures and leys, grass is more abundant than legumes. There is reason to believe that the fertility of prairie lands all over the world is chiefly due to the fixation of nitrogen by the oxidation of organic matter aided by sunlight and phosphates.

In the U.K., 6.3 million acres are under temporary grass and 13.5 million are under permanent grass while 16.8 million acres are in rough grazing. Assuming the oxidation of roots and stems of grass weighing 2 tons/acre and the nitrogen fixation of 40 lbs./acre, the amount of nitrogen fixed is of the order of 0.27 million tons from the 13.5 million acres. In the rough grazings of 16.8 million acres with a nitrogen fixation of 20 lbs./acre, the total nitrogen fixation becomes 0.168 million ton. In the temporary leys of 6.3 million acres, where legumes and grasses co-exist, there may be a fixation of 50 lbs./acre, causing a total fixation of 0.1575 million ton. These three fixations make up a total of 0.6 million ton per year in the U.K.

The grasslands in the U.S.A. are 66 million acres of crop land used as pasture. There are 633 million acres of pasture and grazing land and 301 million acres of pastured woodland. Hence, the total land under grass in the U.S.A. is approximately 990 million acres. Assuming a nitrogen fixation of 40 lbs./acre in the pasture lands in the U.S.A., 1.32 million tons of nitrogen are expected from the 66 million acres. Taking 20 lbs./acre from the pasture and grazing land, 6.33 million tons of nitrogen fixation is possible in the 633 million acres. Similarly 301 million acres of the pastured woodland can fix 3.01 million tons of nitrogen. Hence, the possible nitrogen fixation in the 990 million acres of grass and pasture lands in the U.S.A. can be 10.66 million tons. But, nearly 10 million tons of available nitrogen are lost from the fields of the U.S.A. producing corn, wheat and other cereals, fodder, fibre, cotton, tobacco etc. Because in crop lands the nitrogen absorbed by the plants has to be in the available form, inorganic nitrogenous matter and precipitation nitrogen are certainly more quick-reacting to the crops. The other sources of nitrogen available to crops are the soil nitrogen, which is the main reservoir of nitrogen, legume nitrogen, nitrogen from composts, plant roots and residues. All these forms of nitrogen seem to be less readily available than the chemical and precipitation nitrogen. In north-west Europe and in North America, grasses make the land fertile. DAVIS has reported that 6 tons of total nitrogen per acre exist in many grasslands of Europe but the available nitrogen is low.

SUNLIGHT INCREASES SOIL NITROGEN CONTENT

Moreover, since 1951 in our publications, the greater nitrogen contents of grasslands than in forest or timber lands have been explained from the viewpoint that in grasslands there is more calcium phosphate and they receive more sunshine than the forest lands. Recently, we have compared the nitrogen status of grasslands and those of neighbouring lands under bushes and shrubs and we have always observed greater amounts of nitrogen in the grasslands than in lands receiving lesser sunshing.

HANS JENNY and S.P. RAYCHAUDHURI have reported that comparison of Indian with American soils, particularly those of California, Texas, Atlantic coast, showed an unquestionable superiority of the former over the latter when sites having equal mean annual temperatures were compared. But the Indian soils had much lower nitrogen and carbon contents than the tropical soils of the Central and South America.

Moreover, the average nitrogen content of soils of Ootacamund and Kodaikanal, which are hill stations in the South of India near the equator, is 0.335% and 0.332% respectively whilst the North Indian hill station of Simla has 0.241% nitrogen and Mussoorie has 0.266% nitrogen. Similarly, Ambala and Aligarh lying in the Northern Indian plains, show a nitrogen status of 0.036% nitrogen and 0.044% nitrogen, whilst Madras and Madura in the South near the equator have 0.054% 0.062% nitrogen respectively. The rainfall and temperature in all these stations are about the same.

The observations showing greater nitrogen status of land near the equator support the photochemical viewpoint of nitrogen fixation. Undoubtedly, world soil nitrogen is created by the fixation of atmospheric nitrogen in the slow oxidation of organic matter aided by sunlight absorption and phosphates.

At the present moment in the U.K. there is a great movement to plough up grasslands in order to mobilise the nutrients present in the humus of the grasslands. There is no doubt that if these lands are ploughed up and phosphated with basic slags or rock phosphates, all the plant nutrients should be available to the succeeding crop. In order to avoid the trouble and expense of ploughing up the grasslands, the farmers are advised to apply large doses of artificial fertilizers. But, as has already been explained, this procedure leads to marked loss of humus and also of soil fertility in the long run.

In the U.S.A. under the leadership of G. SCARSETH heavy doses of N, P, K are applied for producing hig yields of corn but before his death, SCARSETH realised that without ploughing in, after the removal of the grains, all the corn stalks, stubbles, roots etc. amounting to 3 tons per acre of organic matter along with the fertilizers, the corn production decreases. These results of SCARSETH are in strong support of our studies emphasised in this communication.

In Germany, large amounts of artificial nitrogenous fertilizers have been applied for producing grasses abundantly, but without legumes. This is detrimental to soil humus and leads to soil deterioration. Most soils in North-West Europe supporting grasses are certainly rich in total nitrogen created by the fixation of atmospheric nitrogen, but, their humus is inactive and unable to supply the required amounts of plant nutrients as there is small oxidation of the organic matter, specially under acidic conditions prevailing in most grasslands.

PLOUGHING IN OF GRASS SODS WITH BASIC SLAG OR ROCK PHOSPHATES FIXES ATMOSPHERIC NITROGEN AND INCREASES FERTILITY

Land under grasses free from legumes becomes richer in nitrogen, chiefly due to the fixation of atmospheric nitrogen from the slow oxidation of organic matter added to the soil from grasses and preserving the soil nitrogen from rapid nitrification and loss and also improving the physical properties of the soil. It has already been stated that when dung is incorporated in the soil, the nitrogen status considerably improves by the fixation of atmospheric nitrogen. It appears that dung or straw ploughed in the soil performs the same part as the growing of grasses by fixing atmospheric nitrogen, preserving the soil nitrogen and improving the soil physical properties. As organic matter is being constantly added to the soils by photosynthesis, land fertility can be readily improved at a small cost by enriching them with basic slag or rock phosphate which is cheap.

Sir **JOHN STAPLEDON** has stated that the grass sod, properly managed and intelligently converted, must be considered as the most valuable foundation upon which the farmer can build soil fertility. Even in the poorest soils, there is nothing to match the continued ploughing down of sod accompanied by adequate liming and phosphating to build up soil fertility.

NITROGEN LOSS FROM SOILS AND ITS LOW RECOVERY IN CROP PRODUCTION

All over the world practical farmers have observed that the recovery of nitrogen by the application of nitrogenous fertilizers and manures in crop production is usually low and is generally of the order of 25-30% of the applied nitrogen; only in grasslands the recovery has been reported to be better. From a survey of Rothamsted experiments with $(NH_4)_2SO_4$ at 1 cwt. per acre **RUSSELL** reported a nitrogen recovery of not more than 50% (wheat 39%, barley 47%, oats 46%, swedes 35%, potatoes 50%).

O. **FRANK** of Sweden reported the recovery of only 30% of the nitrogen applied for crop production in Sweden. Similarly, **LÖHNIS** and **FRED** have reported the following recovery in field experiments lasting for 4 years in the U.S.A.:

Nitrogen	P_2O_5	K_2O
7.8 to 46.1	10.1 to 75.6	22.4 to 85.1

The recovery of nitrogen is less than that of phosphate or potassium.

For a number of years **DHAR** and co-workers have studied the problem of nitrogen loss from soils and have explained the low recovery of nitrogen from nitrogenous fertilizers and manures from the following considerations:

Under ordinary conditions of cultivation the proteins, aminoacids and ammonium salts present in the soil or added to it as fertilizers and manures undergo slow oxidation by air as in the following scheme:

$$\text{Proteins} \longrightarrow \text{Aminoacids} \xrightarrow{+O_2} \text{Ammonium salts} \xrightarrow{+O_2} \text{No}_2 \xrightarrow{+O_2} NO_3.$$

These are oxidation reactions which are accelerated by increased aeration, absorption of radiation and increase of temperature. In these processes of oxidation an intermediate compound — ammonium nitrite — which is unstable and explosive, is always formed and it readily breaks up into nitrogen and water with evolution of heat: ($NH_4NO_2 = N_2 + 2H_2O + 718$ K. cals.). The formation and decomposition of this explosive substance cannot be avoided in land cultivation and crop production on application of nitrogenous fertilizers and manures.

Nearly 70% of the added nitrogen is said to have been lost when wheat plots in Rothamsted have received 14 tons of farmyard manure containing 200 lbs. of nitrogen per acre.

Fate of nitrogen in farmyard manure applied to wheat at Rothamsted

Plot	Manuring	N in soil 9" deep in 1893		N supplied in manure in 50 years (lb.)	Removal of N in crops in 50 years (1844-93) (lb.)	Surplus of N over plot 3 unaccounted for in crop or soil (lb.)
		per cent	lbs. per acre			
3	Unmanured	0.0992	2570	—	850	—
2	Farmyard manure . .	0.2207	5150	10.000	26.000	5670

The foregoing results obtained with 14 tons of farmyard manure per acre applied every year at Rothamsted and growing wheat on the same land show that only 26% of nitrogen

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was recovered in the crop and approximately 57% of the nitrogen added in the 50 years has been lost since it is not accounted for in crop or in soil.

LIPMAN and BLAIR also observed a marked loss of nitrogen in their experiments at New Jersey and California Experimental Stations. In both the instances, there was an unaccounted-for greater loss of total nitrogen from the soil than that taken up by the crops.

SHUTT in Canada observed a marked loss of nitrogen when virgin prairie soils were broken for cultivation. Though this process leads to the production of more nitrates and available phosphates, it also causes much loss of nitrogen even when there is practically no loss of nitrates by leaching in these experiments. The observations of SHUTT are recorded below:

Prairie soils, virgin or cropped

Locality	Character	History	Organic volatile matter %	Nitrogen %
Portagela prairie Man.	Black, friable loam sandy.	Virgin, uncropped, unmanured	19.43	0.651
—	—	Cultivated, grain for 25 years, fallowed but not manured	14.79	0.506
Indian Head, Sask.	Black, heavy clay loam.	Virgin, uncropped, unmanured	12.83	0.371
—	—	Cultivated, grain for 22 years, fallowed but not manured	10.70	0.254

DHAR and co-workers reported considerable loss of nitrogen in soils and oxide surfaces on the slow oxidation of nitrogenous compounds under aerobic conditions even in the complete absence of micro-organisms. RUSSELL and RICHARDS in the

U.K., VISWANATH in India, BIZELL, ALBRECHT, HIDE and METZGER in the U.S.A. have observed loss of nitrogen in the gaseous state from soils when conditions are favourable for oxidation. These observations are readily explicable from the viewpoint that in the soil, ammonium salts, urea, aminoacids, proteins, in their slow oxidation produce the unstable and explosive substance, ammonium nitrite, as an intermediate product and this breaks up readily into nitrogen and water with heat evolution. This loss is heavy under ordinary conditions of cultivation and when virgin lands are broken for cultivation as reported earlier. Due to this loss, the recovery of applied nitrogen is bound to be low and the production of ammonium salts is smaller than with nitrates which in the presence of soil organic matter are converted into ammonium salts.

DHAR and co-workers have also experimentally established that this loss can be markedly checked by mixing the nitrogenous fertilizers with straw, leaves, grasses, molasses etc. which contain carbohydrates capable of acting as negative catalysts in the nitrification of nitrogenous fertilizers and manures. Thus, the nitrogen is preserved, and increased crop yields are obtained in presence of straw, grasses etc. Animal physiologists observed long ago that body proteins are preserved by the intake of carbohydrate food materials.

LOSS OF SOIL HUMUS ON THE APPLICATION OF NITROGENOUS FERTILIZERS AND MANURES

By taking a fairly rich Allahabad soil containing 0.214% N and 3.145% carbon and keeping it in contact with air at 30°C, we have recently observed that in 200 days 9.5% carbon in the soil is oxidised in light whilst in the dark the carbon oxidation is 7.4%. When mixed with wheat straw and making the carbon content of the system 5.9%, the oxidation of the total organic carbon in light in the same time is

6.8% and 5.2% in the dark. When various nitrogenous substances, e.g. mustard oil cake, hippuric acid, gelatine, glycine, uric acid, creatine, urea, ammonium sulphate, ammonium phosphate, ammonium persulphate and ammonium nitrate were added to the extent of 0.2% as additional nitrogen, it was observed that after 200 days of oxidation in light, the carbon of the system was oxidised from 12 to 46.8% whilst in the dark the oxidation varied from 7.9% to 43.6%. Hence, we have obtained experimental results in support of the viewpoint that humus loss in soils is accentuated by nitrogenous fertilizers. But, wheat straw has been observed to be an excellent fixer of atmospheric nitrogen in the process of its composting or when ploughed in the soil. Wheat straw is also a retarder of nitrogen loss from soils.

Recently DHAR and RISHI have obtained the following results with an Allahabad soil containing 1% carbon, 0.0775% nitrogen, 0.24% P_2O_5 and 1.86% CaO and pH 7.45:

Oxidation of carbon after 300 days in 200 gms. of soil

Treatment: N added %	C oxidised (gm.)		pH		% C oxidised	
	Exposed	Covered	Exposed	Covered	Exposed	Covered
Soil (alone) . . .	0.2877	0.2045	7.25	7.30	15.2	10.8
Soil + Amm. sulphate	0.3452	0.2425	4.95	6.00	18.2	12.8
Soil + Amm. nitrate	0.3708	0.2662	5.50	6.45	19.6	14.1
Soil + Amm. phosphate	0.3959	0.2910	6.80	7.00	20.9	15.4
Soil + Amm. persulphate	0.4566	0.3472	6.85	7.05	24.1	18.4

The greater loss of carbon in presence of ammonium persulphate is explicable from the viewpoint that ammonium persulphate, a strong oxidising agent, when mixed with soil, produces nitric acid which is also an oxidising agent according to the equation:

$$4(NH_4)_2S_2O_8 + 3H_2O = 7(NH_4)HSO_4 + HNO_3 + H_2SO_4 \; .$$

Using organic nitrogenous compounds the following results were obtained by DHAR and RISHI:

Oxidation of carbon after 300 days

Treatments (0.2% N)	Carbon introduced due to nitrogenous substance (gm.)	Carbon oxidised (gm.)		Loss of humus carbon due to nitrogenous substance (gm.)	
		Exposed	Covered	Exposed	Covered
200 gms. soil (alone)	—	0.2877	0.2045	—	—
200 gms. soil + Urea	0.1714	0.5992	0.4711	0.1401	0.0952
200 gms. soil + Uric acid . . .	0.4286	0.7878	0.6569	0.0715	0.0238
200 gms. soil + Hippuric acid . .	3.0864	3.4634	3.3173	0.0893	0.0264
200 gms. soil + Glycine	0.6858	1.0952	0.9560	0.1217	0.0657
200 gms. soil + Creatine . . .	0.4572	0.8493	0.6959	0.1044	0.0342
200 gms. soil + Gelatine . . .	1.0498	1.4511	1.2918	0.1136	0.0375
200 gms. soil + Mustard oil cake	3.6306	4.0749	3.9357	0.1566	0.1006

DHAR and Mrs. CHOWDHRY observed greater oxidation of carbon when nitrogenous compounds were added to aqueous solutions or suspensions of glucose or starch in presence of titania under sterile and unsterile conditions as recorded in the following table:

System containing 6% carbon	% carbon oxidation after 180 days			
	Unsterile		Sterile	
	Light	Dark	Light	Dark
Glucose (alone)	18.87	12.66	9.27	4.56
Glucose + 0.1% N as amm. chloride	20.63	13.11	10.87	5.36
Glucose + 0.1% N as amm. sulphate	21.06	13.35	11.33	5.73
Glucose + 0.1% N as amm. nitrate	25.46	16.50	15.21	7.50
Glucose + 0.1% N as cal. nitrate	30.50	19.93	19.00	9.21
Starch (alone)	13.61	8.77	6.80	3.31
Starch + 0.1% N as amm. chloride	14.86	9.81	7.38	3.53
Starch + 0.1% N as amm. sulphate	15.26	10.05	7.80	3.75
Starch + 0.1% N as amm. nitrate	20.16	13.27	10.15	4.40
Starch + 0.1% N as cal. nitrate	23.91	15.38	11.85	5.63

DHAR and DEO obtained the following results in the presence or absence of algae.

Per cent oxidation of carbon after 240 days
(0.1% total nitrogen added)

Treatments	Without phosphate		With Tata basic slag	
	Light	Dark	Light	Dark
Soil (alone)	15.0	9.5	16.1	11.1
Soil + $(NH_4)_2SO_4$	17.3	10.2	18.0	11.2
Soil + $NaNO_3$	17.5	10.9	18.5	11.3
Soil + Chlorella	10.1	9.1	11.3	10.0
Soil + Chlorella + $(NH_4)_2SO_4$	10.8	9.9	12.5	10.7
Soil + Chlorella + $NaNO_3$	12.2	10.6	12.3	11.7
Soil + Anabaena	11.2	9.2	11.8	10.2
Soil + Anabaena + $(NH_4)_2SO_4$	12.2	10.0	12.7	10.9
Soil + Anabaena + $NaNO_3$	12.9	10.7	13.4	11.2
Soil + Tolypothrix	10.8	9.2	11.5	10.1
Soil + Tolypothrix + $(NH_4)_2SO_4$	11.7	10.1	12.7	10.8
Soil + Tolypothrix + $NaNO_3$	12.6	10.5	12.9	11.9

The foregoing experimental results support the viewpoint that the humus loss in soils by the application of nitrogenous fertilizers and manures is greater than the humus oxidation in presence of air.

Moreover, experiments were also carried out to study the appreciable loss of nitrogen from systems containing the same soils treated with 0.1% N in the form of ammonium sulphate and sodium nitrate and its retardation by organic matter, algae and phosphates.

Loss of N from soils on applying fertilizers and its retardation by organic matter

Nitrogen loss (%) with ammonium sulphate (0.1% total N added)

Treatments	60 days	120 days	180 days	240 days
Soil (alone)	50.1	62.2	70.4	74.0
Soil + Chlorella	47.3	57.0	64.2	70.2
Soil + Anabaena	49.3	59.3	66.7	72.1
Soil + Tolypothrix	48.7	58.5	65.8	71.4
Soil + Tata basic slag	47.8	59.0	65.8	71.7
Soil + T.B.S. + Chlorella	44.6	55.8	62.3	66.2
Soil + » + Anabaena	46.1	57.5	64.6	68.6
Soil + » + Tolypothrix	45.8	56.4	63.7	67.4
Soil + German basic slag	45.6	56.1	63.2	69.1
Soil + G.B.S. + Chlorella	42.1	51.9	58.5	63.1
Soil + » + Anabaena	44.0	55.7	61.5	65.4
Soil + » + Tolypothrix	43.3	53.7	60.1	64.2
Soil + Sunnhemp	40.7	50.3	55.7	60.5
Soil + » + Chlorella	36.9	46.7	50.5	54.9
Soil + » + Anabaena	38.8	49.3	53.0	57.7
Soil + » + Tolypothrix	37.6	48.2	51.7	55.5
Soil + » + T.B.S.	36.6	46.1	51.2	55.4
Soil + » + » + Chlorella	33.4	42.0	47.7	50.1
Soil + » + » + Anabaena	34.8	43.4	48.2	52.6
Soil + » + » + Tolypothrix	34.3	42.9	48.0	51.6
Soil + » + G.B.S.	34.1	43.7	48.9	53.4
Soil + » + » + Chlorella	31.9	38.4	44.8	48.0
Soil + » + » + Anabaena	32.6	40.0	46.8	50.3
Soil + » + » + Tolypothrix	32.3	39.2	45.7	49.0
Soil + Wheat straw	38.9	48.6	54.1	58.4
Soil + » » + Chlorella	32.9	43.5	48.8	52.8
Soil + » » + Anabaena	37.4	47.0	51.3	55.8
Soil + » » + Tolypothrix	35.4	45.8	50.5	54.9
Soil + » » + T.S.B.	35.8	45.2	50.4	53.9
Soil + » » + » + Chlorella	32.8	39.3	44.5	47.8
Soil + » » + » + Anabaena	34.5	41.0	47.6	50.4
Soil + » » + » + Tolypothrix	33.4	40.6	46.2	49.0
Soil + » » + G.B.S.	33.6	43.0	48.0	52.5
Soil + » » + » + Chlorella	31.4	38.2	43.7	47.0
Soil + » » + » + Anabaena	32.1	40.8	46.1	49.7
Soil + » » + » + Tolypothrix	31.7	39.2	45.5	48.3

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Nitrogen loss (%) with sodium nitrate (0.1% total N added)

Treatments	60 days	120 days	180 days	240 days
Soil (alone)	22.8	26.0	28.5	30.3
Soil + Chlorella	18.3	23.0	25.7	27.2
Soil + Anabaena	19.2	23.9	26.6	28.4
Soil + Tolypothrix	18.8	23.5	26.2	28.0
Soil + T.B.S.	20.4	21.2	27.0	28.5
Soil + » + Chlorella	18.0	21.5	23.4	25.0
Soil + » + Anabaena	18.7	22.6	24.2	25.9
Soil + » + Tolypothrix	18.5	22.0	23.8	25.5
Soil + G.B.S.	19.0	22.4	25.1	27.1
Soil + » + Chlorella	16.7	20.4	22.0	23.5
Soil + » + Anabaena	17.3	21.0	22.6	24.3
Soil + » + Tolypothrix	17.0	20.6	22.4	23.8
Soil + Sunnhemp	14.2	17.5	20.0	22.3
Sol + » + Chlorella	12.5	15.0	17.2	19.0
Sol + » + Anabaena	12.9	15.9	18.3	20.1
Soil + » + Tolypothrix	12.8	15.6	17.6	19.6
Soil + G.B.S.	10.9	14.6	16.1	18.5
Soil + » + Chlorella	9.4	11.1	13.1	15.3
Soil + » + Anabaena	10.0	11.6	13.8	16.0
Soil + » + Tolypothrix	9.8	11.3	13.5	15.5
Soil + T.B.S.	12.0	15.4	17.2	19.3
Soil + » + Chlorella	10.6	12.7	14.2	16.3
Soil + » + Anabaena	11.0	13.5	15.3	17.1
Soil + » + Tolypothrix	10.9	13.3	14.8	16.7
Soil + Wheat straw	12.7	15.7	17.9	20.0
Soil + » » + Chlorella	10.8	12.6	14.3	16.1
Soil + » » + Anabaena	11.6	13.3	15.0	17.5
Soil + » » + Tolypothrix	11.3	12.9	14.8	16.9
Soil + » » + T.B.S.	11.1	14.6	16.5	18.1
Soil + » » + » + Chlorella	9.6	11.2	13.3	14.6
Soil + » » + » + Anabaena	10.2	11.7	14.1	15.5
Soil + » » + » + Tolypothrix	10.0	11.5	13.8	15.1
Soil + » » + G.B.S.	10.0	13.3	15.1	17.7
Soil + » » + » + Chlorella	8.9	10.8	12.2	13.3
Soil + » » + » + Anabaena	9.3	11.5	12.9	14.2
Soil + » » + » + Tolypothrix	9.0	11.1	12.6	13.9

The foregoing results clearly show that in all the systems the total nitrogen decreases with lapse of time, but, in presence of algae, the loss is very slightly checked. With phosphates the loss is checked a little more, with organic substances the checking of the loss is more marked. These nitrogen loss experiments can explain the low recovery of nitrogenous fertilizers in crop production.

Thus, it is clear from these experiments that both nitrogen fixation and nitrogen loss in soils are affected more markedly by organic matter than by growing algae.

In his critical examination of the experimental results obtained in the classical Rothamsted and Woburn experiments with chemical fertilizers and farmyard manure, RUSSELL has come to the conclusion that soil deterioration takes place not only in continuous cultivation but in rotations as well when chemical fertilizers are used without any farmyard manure application. This clearly shows that the roots and stubbles left after harvesting of crops cannot supply the adequate amount of carbohydrates necessary for the protection of soil nitrogenous compounds although the amounts of roots and stubbles left in the fertilized fields are greater than in the unfertilized ones. On the other hand, in fields receiving 14 tons of farmyard manure per acre during the 4-year rotation, there was no soil deterioration. In the 14 tons of farmyard manure the amount of total nitrogen added was 200 lbs. and the C/N ratio of the farmyard manure is usually 22:1 or 20:1, the amount of carbon introduced as carbonaceous compounds in the 4-year period is of the order of 4000 lbs. Consequently, in the temperate countries having an average surface soil temperature of 8°-10°C approximately 1000 lbs. carbon per acre (1119.4 Kgs. per hectare) must be applied annually over and above the plant roots and stubbles for maintaining the fertility and the humus status. In other words, approximately 3.5 to 4 tons of farmyard manure per acre annually have to be applied for this purpose. If the amount of carbonaceous compounds is less, the humus will be broken up by the oxidation and there will be a slow fall of soil fertility. With higher soil temperature, larger amounts of organic matter are necessary for stopping soil deterioration on cultivation.

FORMATION OF PRAIRIE LAND

In the Year Book of Agriculture issued by the U.S.A. Govt. in 1941, it has been stated that prairie lands exist in the U.S.A. from the Canadian border to the Gulf of Mexico. Climatically the regions are of strong contrasts. Winters are nearly 50°F warmer in southern Texas than in North Dakota but the great thrusts of polar air that come out suddenly from the Arctic may sweep all the way down into the Mexican Gulf States. The growing season lasts only 3 to 4 months in North Dakota and 8 to 9 months in Texas. Midsummer days in the north may be as hot as in the south. In the whole of this region rainfall does not much exceed evaporation and hence drought is the chief hazard. The rain is almost everywhere concentrated in the warm season, specially in early summer, that is, during the period when the grain needs it most. It is reported that originally the prairies were covered with grasses 3-10 feet high and studded with wild flowers. A few trees were there. In the eastern parts and along the river valleys there were some oaks. Where the sub-soil was moist enough for supporting forests trees were destroyed by prairie fires and grazing buffaloes. In the Western area czernogem soils, which are very rich and deep, occur. In the Eastern side, less fertile prairie soils exist. These prairies formed an agricultural treasure-house for American agriculture.

In various parts of Canada rich prairie lands have been cultivated. When such lands are broken up for cultivation, large amounts of available nitrogen, lime and phosphate are liberated and excellent crops can be grown.

In our investigations we have always observed that grasslands contain more nitrogen and phosphates than the neighbouring forest or shrub lands. This is due to the fact that the washing away of phosphate is greater in forest than in the grasslands and there is more sunshine in grasslands than in the forest lands. Consequently, the formation of prairie lands is a joint effect of sunlight and calcium phosphates in fixing atmospheric nitrogen from the partial decay and oxidation of energy materials associated with grasses. In humid climate grasslands, there is a greater washing away of phosphates than in the prairie and czernogem world soils. The formation of prairie and czernogem soils by the fixation of atmospheric nitrogen must be associated with the slow oxidation of organic matter in grasslands aided by fair amounts of calcium phosphates which should not be washed away by rain or snow, that is, formation of prairie or czernogem soils is possible in phosphate-rich soils in dry areas.

By applying large doses of municipal waste and basic slag, we have been able to produce nitrogen-and-phosphate-rich land resembling the prairie.

Analysis of different soil samples from this field

Treatment	Organic carbon %	Total nitrogen %	C/N ratio
No slag	1.90	0.172	11.0
Tata basic slag	1.77	0.331	5.3
-do-	2.01	0.270	7.4
-do-	1.89	0.279	6.7

Allahabad municipal waste was dumped on a field with or without Tata basic slag containing 8% P_2O_5 with the above results and bumper crops were obtained in the improved land.

Similarly, by growing Kentucky grass for 50 years and ploughing it up and phosphating it, bumper crops have been obtained in the U.S.A. It appears therefore that rich prairie and czernogems are created by nitrogen fixation in soils in dry areas aided by light absorption and calcium phosphates and they readily liberate lime, nitrate, phosphate etc. on cultivation.

Earth's surface is divided into 16 regions. Region I includes most of the Western Europe where the average precipitation is 20″ or more and temperature is mild. This region is rich in timothy, blue grass, orchard grass, rye grass etc. Region II, i.e. the Mediterranean region of Europe and Africa, is characterised by low rainfall and poor soils and the grass cover is smaller in quantity than in Region I. In Region III including the eastern section of the U.S.S.R. with a low rainfall and the whole of Siberia, the winters are severe and the precipitation less than 20″. In this region also the grass cover is less abundant. Region IV including the south-eastern part of the U.S.S.R., Western China, Asia Minor and Afghanistan, is the native home of several cereal grasses. This whole region is very dry and a large part is actual desert. Hence the grass cover is rather meagre. Tibet, western provinces of China and eastern Mongolia comprise the Vth. Region which has high mountains and cold dry plateaux and deserts. Region VI includes eastern Siberia, Manchnria, north-east China and Japan. Region VII consists of south-east China, most of India, Burma, Malaya Peninsula and adjoining islands and is largely tropical and has a heavy rainfall except in north India. The cultivated crops like sugarcane, rice, bamboo, Bermuda grass occur in these parts. Region VIII including Australia, New Zealand and Tasmania has a very distinct vegetation and many of the grasses of this region are not to be found elsewhere in the world. The interior of Australia is very dry like desert but the coastlines have fair rainfall and are favourable for grasses. Region IX consists of the equatorial part of Africa, some of which has heavy rainfall and dense forests. Grasses abound in open places on the timbered areas where rainfall is lower. Region X is composed of South Africa and Madagascar. The annual rainfall varies from 40″ in the northern part to deserts in Bechuanaland in Africa. Region XI consists of Brazil, East Bolivia, Paraguay, Uruguay and north-east Argentina. In this part of South America the rainfall is heavy, that is, 30-70″ and the temperatures are tropical or sub-tropical. An immense area of open park-like grasslands occurs. But the basin of the Amazon with a rainfall of over 80″ abounds in dense jungle-like forests, not important from the grass point of view. Region XII comprises of Chile, Andean sections of Argentina and North Peru. Most of these regions consist of high altitude and low rainfall. Region XIII consists of southern Mexico, central America, West Indies, Columbia, Venezuela, Guiana. This region surrounding the Caribbean Sea and the Gulf of Mexico is largely in the tropics. This region is the original home of many food plants including corn. Region XIV includes western North America and comprises of a broad expanse of rugged mountains, dry plains and plateaux, the flora being rich in native grasses. Region XV comprises of East Canada and north-east U.S.A. It is occupied by hard wood and coniferous forests. Naturally valuable native grasses are scarce. Region XVI is eastern U.S.A., south of the 60° isotherm and is the original home of the corn belt of the U.S.A. Originally, this land was under forests but when the timber was cleared by the early settlers, tropical grasses from Asia, Africa and central America are occupying the clear lands. Napier grass, Bermuda grass etc. provide the bulk of the pasturage. The corn belt area is still rich in plant nutrients because most of it was originally prairie land.

Grasses are extremely useful for increasing land fertility, specially when ploughed in along with basic slags or rock phosphates — the greater the amount of grass covering a land, the greater the fixation of nitrogen and increase of land fertility.

In the U.S.A. as well as in the other parts of the world the problem of utilisation of agricultural by-products is being systematically studied. It has been estimated that they constitute more than 60% of the agricultural products utilised by man. In the U.S.A. the principal farm by-products are corn stalks, corn-cobs, cereal straw, oat hulls, cotton stalks, cotton-seed hulls, flax straw, pea-nut shells, sugarcane bagasse.

GEORGE SCARSETH advocated the ploughing in of all corn stalks and other materials after removal of the corn grains with nitrogenous and other fertilizers. He reported that in this method 3 tons of organic matter, which is helpful in nitrogen fixation and in avoiding soil nitrogen loss, are incorporated in the soil. It has been estimated in the U.S.A. that under favourable conditions, a ton of corn stalks, when ploughed in, may have a fertilizer value of 5-6 dollars. In the U.S.A. potato culls amount to 76 million tons and sweet potato 20 million bushels. Apple culls are produced to the extent of 35 million bushels.

Corn stalks are rich in carbohydrates. They consist of 36% cellulose 30% lignin and 27% other carbohydrates and these on being incorporated with the soil undergo slow oxidation and can fix atmospheric nitrogen. For permanent agriculture all these by-products of agriculture must be incorporated in the soil for humus formation and nitrogen fixation, specially after phosphating them.

Sir JOHN RUSSELL has reported that not only in the classical Rothamsted experiments (which started in 1843) but also in the Saxmundham experimental field, East Suffolk, where comparative experiments dealing with artificials and farmyard manure commenced from 1899, show that the plots receiving farmyard manure annually stood out distinctly from the rest. The soil acquired dark colour, became more friable and could be cultivated earlier. The phosphate status of this land is much higher than in those receiving superphosphate because the lime present in dung protects the phosphate from being washed away.

During 60 years, 5000 tons of nitrogen per acre were applied but at the end and in spite of clovers, the plot contained only 15000 lbs. of nitrogen per acre more than the one which had no manure. The loss is 3500 lbs. of nitrogen out of which 1/3rd. or 1/2 has been taken by crops. This loss is of the same type as that observed at Rothamsted and reported in this paper.

The Egyptian farmers were benefitted not only by the minerals washed down from the mountains of Abyssinia and other regions but the organic matter carried by the flood waters caused marked increase in fertility by nitrogen fixation in its slow oxidation. Today by creation of dams, the floods have been stopped but the lands have lost their fertility and hence N, P, K are being applied in larger amounts.

ORGANIC MATTER AND BASIC (THOMAS) SLAGS PLOUGHED IN SUPPLY ADEQUATELY ALL PLANT NUTRIENTS ALL OVER THE WORLD

In Uppsala, Sweden, the average annual soil temperature is 5°C and the available nitrogen in soil humus is only ½ to 1% of the total nitrogen, which is 0.15%. In Rothamsted the average soil temperature is 8°-9°C and the available nitrogen is 1 to 2% of the total nitrogen which is 0.12% in limed soils.

In Allahabad the average soil temperature is 26°C and the available nitrogen is over 10% of the total nitrogen which is 0.05%. When the humus of these soils is increased by ploughing straw mixed with basic slags, the available nitrogen increases considerably and good crops can be grown in these soils without fertilizers. Hence in Italy and Spain, where the average temperature of the soil is 15°C (Madrid 15°C, Rome 14.8°C), the soil humus increase by incorporating straw and basic slags will lead to increased crop production as in the experiments of Lady EVE BALFOUR in Suffolk, England, as stated before.

It has also been observed that basic slags and tri-calcium phosphates can act as excellent buffers in raising the pH of acid soils. Hence, addition of calcium phosphates is profitable to both, acid and alkaline soils.

Even in this machine age discussions and arguments are going on regarding the feasibility and possibility of continued permanent agriculture on the earth's surface discarding animals and using only machines.

In Europe and America it was empirically observed that legumes like lupines, clover, lucerne and even pulses when followed by cereals, benefit the cereals markedly. The science of the beneficial value of legumes was established experimentally by HELLRIEGEL and WILFARTH in Germany in 1864. They observed from quantitative experiments that atmospheric nitrogen is fixed by legumes in soil with the help of Rhizobia bacteria supported in the plant roots from the energy of the oxidation of carbohydrates photo-synthesised by the legume. This symbiosis of leguminous plants and Rhizobia bacteria has been very fruitful in crop production in temperate countries, specially in the U.S.A. and North-West Europe. It has been estimated that 5 million tons of atmospheric nitrogen are fixed in world soils by legumes. On the other hand, DHAR and his colleagues have emphasized that grasses, when ploughed in, can fix nitrogen in the soil and this nitrogen fixation is considerably enhanced by the absorption of solar light and rock phosphate or basic slags. They have established experimentally that all types of organic matter, molasses, grasses including legumes, city wastes, weeds, saw dust, peat, lignite and even bituminous coal, when mixed with soil, undergo slow oxidation in contact with air and liberate energy which is utilised in fixing atmospheric nitrogen on the soil surface. This process can take place slowly under completely sterile conditions also even in absence of soil but on pure chemical surfaces, e.g. oxides of iron, aluminium, silicon, titanium, vanadium etc. When sunlight falls on soil or the chemical surface, the light is actually utilised in increasing the fixation of nitrogen, which is an endothermal chemical change. Moreover, calcium phosphates, like rock phosphate and basic (Thomas) slag, markedly enhance this nitrogen fixation. From their experimental observations Dhar and co-workers have unequivocally stated that even today the main source of soil nitrogen is the thermal and photochemical fixation of atmospheric nitrogen caused by the slow oxidation of all types of organic matter existing on the earth's surface. Dhar and co-workers have reported that organic matter, creating humus in soils, not only improves the water holding capacity and physical properties, tilth, texture, structure and porosity of soils, but, two very important parts played by organic matter are the fixation of atmospheric nitrogen and the preservation of soil or added nitrogenous compounds. Physiologists have established that in the animal body carbohydrates protect proteins and amino acids. Dhar and co-workers have established that carbohydrates and fats retard the slow oxidation of amino acids and proteins not only in the animal body but also in the plant kingdom and soils. They act as negative catalysts in the ammonification and nitrification of the nitrogenous compounds and these are oxidation reactions markedly retarded by soluble carbohydrates, celluloses, lignins and even fats which, in their turn, undergo slow oxidation in air under sterile and unsterile conditions. The laws governing physiological body reactions are also applicable to soil oxidations on which its fertility depends a good deal.

In the history of man's progress, gun powder has played an important role. It is not exactly known whether gun powder was first utilised in China or early in Greece. Potassium nitrate, which is obtained from the nitrification of animal refuse, has been exported from India to Europe for over thousand years and was known as 'Bengalische Feuer'. A.L. Lavoisier (1743-1794), the founder of Physiology and Chemistry, could produce excellent gun powder, which helped the French army, from the nitrification of animal urine and dung mixed with plant ash containing potassium carbonate. After the guillotining of Lavoisier by the French revolutionaries in 1794, the quality of French gun powder considerably deteriorated.

The existence of sodium nitrate (Chile salt petre) in hot dry areas of the world is certainly due to the fixation of atmospheric nitrogen by a thermal and photochemical oxidation of sea weeds and other organic matter rich in N, P, K and lime aided by bones of animals and guano of birds. DHAR has emphasised that calcium phosphates, which are helpful in nitrogen fixation and stabilisation of nitrogenous compounds, are present in nitre-beds or occur near nitre-beds.

Carbohydrates and other organic compounds retard this process of nitrification and partial loss of nitrogen in the gaseous state and hence humus, which is ligno-phospho-protein, is not only a source of nitrogen but a protector of nitrogenous compounds as well. Inorganic compounds like potassium chloride, potassium sulphate, sodium chloride, sodium sulphate, calcium and magnesium salts including calcium phosphates present in sea water, help in the conversion of the unstable substance, ammonium nitrite, into stabler nitrites of Na, K, Ca, Mg etc. These nitrites undergo oxidation to nitrate in air. Under ordinary conditions, the greater part of nitrogenous fertilizers or manures added to land undergo loss in the formation and decomposition of the unstable substance, ammonium nitrite.

Field trials have also shown that of the 3 plant nutrients, nitrogen, phosphorus and potassium, the recovery of nitrogen by crop is the lowest, i.e. about 40-50% at the most, whereas, the recovery of potassium and phosphorus may be as high as 70-80%.

Sir JOHN RUSSELL, from a survey of the Rothamsted and Worburn experimental results, has concluded that the usual recovery is 25-40% of the nitrogen applied. In Sweden, O. FRANCK reported a normal recovery of 30% of the nitrogen applied.

From our experiments we have established that the slow oxidation of soil humus is appreciably increased by adding nitrogenous fertilizers and manures because nitrates are formed from nitrogenous compounds applied to land which oxidise the humus readily. Even in the highly industrialised country, the U.S.A., soil humus loss is rampant.

Russell has further reported that when 1 cwt. of $(NH_4)_2SO_4$ is added per acre, the recovery of N is as follows:

Crops	Average N recovery %
Wheat	39
Barley	47.5
Oats	46.5
Potatoes	50
Swedes	35.5

Theron and Haylett have reported from Pretoria a recovery of 29-41% of the added nitrogen varying from 200 to 800 lbs. N/acre in grasslands.

Similarly, in the well known Askov experiments starting from 1894, the 4-year rotation including clover and grass supplied enough organic residues to make up partially for the loss of humus from 2.95% to 2.6% in 20 years observed in the unfertilized field. This is evident in the following data:

Nitrogen and humus in the Askov experiments (% in dry soil)

Nitrogen	Unfertilized	Commercial fertilizer	Farmyard manure
Askow loam soil, 1942	0.106	0.118	0.130
Askov sandy soil, 1942: humus (C×2)	0.066	0.076	0.086
Askov loam soil, 1942	2.60	2.86	3.04
Askov sandy soil, 1942	1.58	1.92	2.18

There is reason to believe that the humus was 3.45% when the experiments started in 1894, and, in a century would drop to 1%.

Similarly in the Rothamsted continuous wheat experiments, the original total nitrogen content was 0.122% in 1844 when the experiments started. In 100 years it dropped to 0.09% in the unmanured and to 0.11% in the fertilized plots, whilst by adding 14 tons of farmyard manure per acre per year, the nitrogen status improved to 0.25%.

RECLAMATION OF ALKALI LAND

Reclamation of alkali soils poses a big problem for bringing back millions of acres of such unproductive lands under the plough. Various methods of reclamation by the application of chemical amendments, like gypsum, sulphur, sulphuric acid, alum. etc., have been tried, specially in Egypt, Hungary, Russia, Holland and the U.S.A. with a fair amount of success. Reclamation of alkali land by merely leaching out the salts by flooding with water has been practised in the U.S.A. But these methods, in addition to their being uneconomic, do not appear to bring about a permanent reclamation.

For more than 40 years we have carried out experiments in the lab. as well as in the fields on the reclamation of alkali soils by a mixture of organic matter and phosphates like different rock phosphates or basic (Thomas) slags. Amongst organic amendments we have tried molasses, pressmud, paddy straw, wheat straw, leaves, *KANS* (Sacchrum spontaneum), water hyacinth, coal etc., and, in all the cases we have obtained beneficial results. Increase in the yield of paddy grains and barley grains after incorporating organic matter and phosphate into the saline and alkaline soils of Rajasthan, India, is recorded below:

Organic matter (straw or pressmud) 10 tons/acre and P_2O_5 10 lbs/acre

	Yield (Kg/acre)	
	Paddy grains	Barley grains
Control	45.93	93.75
Organic matter (straw)	126.12	175.60
» » » + P_2O_5 as bonemeal	203.91	241.90
Pressmud	370.18	266.25
» + P_2O_5 as bonemeal	501.62	382.50

Similar experiments on the reclamation of alkali soils were conducted in Phulpur, Allahabad, India, by N.R. DHAR and A.K. RISHI. Three successive crops of gram, paddy and wheat were grown after incorporating straw, *KANS*, coal, water hyacinth and cactus (Phylocladcs) along with Thomas slag and rock phosphate. The results indicated a significant increase in available P_2O_5, exchangeable calcium, water holding capacity and permeability and a marked fixation of N along with bumper crops in the plots treated with organic materials and phosphates. The yields of the grains of gram, paddy and wheat are recorded below:

Yield of 3 successive crops grown on the alkali soil amended with 5 tons/acre of organic matter and 50 lbs/P_2O_5/acre as German basic slag.

	Gram grain (Kgs/acre)	Paddy grain (Kgs/acre)	Wheat grain Kgs/acre)
Controi	45	90	82.5
Wheat straw	270	474	465
» » + German basic slag	381	625.5	607.5
KANS	241.5	453	435
» + German basic slag . .	354	585	577.5
Coal	202.5	450	427.5
» + German basic slag . . .	295.5	570	555

It seems that during the slow oxidation of organic matter in the soil, carbonic acid and organic acids like acetic, citric, lactic, malic, propionic acid etc. are produced which neutralise the alkalinity of the alkali soils. Carbonic acid and organic acids thus produced can also readily convert tricalcium phosphate into dicalcium phosphate and small amounts of monocalcium phosphate which being appreciably soluble can readily supply calcium ions to the alkali soil solutions. Calcium ions brought into solution readily replace sodium ions on the exchange complex of the soil, thus increasing the exchangeable calcium status of the soil.

Moreover, in the nitrification of proteins and nitrogenous compounds present in legumes and other plant materials, nitrous acid and nitric acid are formed which are profitable in the reclamation of alkali soils. Carbonic acid produced by the decomposition of organic matter plays an important role in soils. It is well known that carbonic acid is much weaker an acid than phosphoric acid as is evident from their dissociation constants:

Carbonic acids: dissociation constant $= 3 \times 10^{-7}$.

$$\frac{H^+ \text{ X } HCO_3^-}{H_2CO_3} = 3 \times 10^{-7} \quad \text{(1st. dissociation constant).}$$

$$\frac{H^+ \text{ X } CO_3^{--}}{HCO_3^-} = 6 \times 10^{-11} \quad \text{(2nd. dissociation constant).}$$

Phosphoric acid: dissociation constant $= 1.1 \times 10^{-2}$.

$$\frac{H^+ \text{ X } H_2PO_4^-}{H_3PO_4} = 1.1 \times 10^{-2} \quad \text{(1st. dissociation constant).}$$

$$\frac{H^{+} \text{ X } HPO_4^{--}}{H_2PO_4^{-}} = 2 \quad \times 10^{-7} \quad \text{(2nd. dissociation constant).}$$

$$\frac{H^{+} \text{ X } PO_4^{---}}{HPO_4^{--}} = 3.6 \times 10^{-13} \quad \text{(3rd. dissociation constant).}$$

As the dissociation constant of carbonic acid is much smaller than that of phosphoric acid, calcium carbonate is much more alkaline in its properties than calcium phosphate, although, the solubility of both these calcium salts at 0°C in water is practically the same as recorded below:

Calcium carbonate . . .	$CaCO_3$	0.0013 at 0°C
Mono- calcium phosphate .	$Ca(H_2PO_4)_2.H_2O$	4.000 at 15°C
Dicalcium phosphate . .	$CaHPO_4.2H_2O$	0.0280 at 0°C
Tricalcium phosphate . .	$Ca_3(PO_4)_2$	0.0013 at 0°C

Thus, carbonic acid attacks more readily the tricalcium phosphate and converts it into dicalcium phosphate and small amounts of monocalcium phosphate. The di- and mono- calcium phosphates react with sodium carbonate and bicarbonate present in the alkali soils and neutralise their alkaline property:

$$2NaHCO_3 + Ca(H_2PO_4)_2 = 2NaH_2PO_4 + Ca(HCO_3)_2$$
$$2NaHCO_3 + CaHPO_4 = Na_2HPO_4 + Ca(HCO_3)_2$$
$$Na_2CO_3 + Ca(H_2PO_4)_2 = 2NaH_2PO_4 + CaCO_3$$
$$Na_2CO_3 + Ca_2HPO_4 = Na_2HPO_4 + CaCO_3$$

Consequently, the harmful effects of alkali carbonate are minimised due to the formation of sodium phosphate. Simultaneously, $Ca(HCO_3)_2$, produced in the system, supplies soluble calcium ions along with monocalcium phosphate. They slowly replace sodium ions from the exchange complex of the alkali soil, thereby leading to its reclamation.

This method causes permanent reclamation of alkali land by supplying calcium ions, phosphate, humus and all other plant nutrients.

Recently we have conducted field trials with the acid *Kari* soils of Kerala, South India, and have obtained excellent results by ploughing in straw and German basic slag. The results obtained with the clayey soil having $C = 11.44\%$, total $N = 0.31\%$, total $P_2O_5 = 0.007\%$, $CaO = 0.093\%$ and pH 4.5 are recorded below:

	Yield of paddy grain (Kgs/acre)
Control	300
Paddy straw (1000 Kgs/acre)	390
Paddy straw + German basic slag (50 lbs. P_2O_5/acre)	846
German basic slag (50 lbs. P_2O_5/acre)	436
Superphosphate (50 lbs. P_2O_5/acre)	345

These results show that a mixture of organic matter and basic slag (Thomas phosphate) produces more crops than the additive values of the two ingredients applied separately. This has been our general experience and supports that nitrogen fixation and increase of available phosphate increases the yield.

We have carried on hundreds of experiments for over 30 years in increasing the fertility of lands all over the world by ploughing in straw + Thomas phosphate (basic slag) and we are confident that this method can fix more nitrogen in the world soils than the fertilizers produced in the whole world. This mixture of slag + organic matter supplies all plant nutrients for crop growth and can capture sunlight falling on soils for increasing the amount of nitrogen fixation. This utilisation of solar energy in land fertility improvement is next in importance to carbon assimilation and photosynthesis in the plant kingdom. This photochemical discovery is supremely important for land fertility improvement and increased crop production all over the world.

Recently LYON and BUCKMAN have reported that a soil under a grass ley free legumes, gained 4 lbs. of nitrogen per acre a year. Similarly, WHITE, HOLBEN and RICHER in Pennsylvania observed that the soil under a grass ley not containing legumes gained 15-30 lbs. of nitrogen annually, even though they were unable to isolate Azotobacter from the soil.

Experiments carried on in Rothamsted and Woburn with a soil temperature 10° show that there is no loss of soil humus if 14 tons of farmyard manure are applied in a 4-year rotation period along with artificials in crop production. In other words, roughly 4 tons of farmyard manure containing 1000 lbs. of carbon have to be added to keep up land fertility in addition to the roots and stubbles weighing up to approximately 1 ton per acre of land as a permanent measure in temperate countries. But due to the mechanisation of agriculture the amount of farmyard manure added is much less than 1000 lbs. carbon per acre per annum. In England, only 15.7 million tons of organic matter are available for the 13.5 million acres of arable lands and 11 million acres of grasslands, i.e. only 0.65 ton per acre of land, which is certainly smaller in requirements from the humus point of view. In Holland, the requirement of carbon in the total agricultural land, which is 2.34 million hectares, is nearly 2.6 million tons in Dutch agriculture. But the supply of carbon from farmyard manure is approximately 0.6 million ton. Hence, a steady loss of humus is sure to take place in the soils of these industrially advanced nations. But, Holland is leading in compost production from city wastes.

In the U.S.A. it has been observed that 2½ tons of organic matter are oxidised annually from an arable land but the supply of farmyard manure is approximately 1 ton per acre of agricultural land.

COOKE (1959) has recorded as follows:

« With continuous cereals grown with fertilizers but no farmyard manure, the percentages of organic carbon in the soil fell from 1.5% in 1876 when the experiments started at Woburn to about 1% in 1927. Results in 1959 show that organic matter has been lost at about the same rate or a little faster from 1927 to 1959 as between 1888 and 1927 on the plots that had inorganic fertilizers in which $NaNO_3$ supplied the nitrogen. With $(NH_4)_2SO_4$ organic matter was lost more quickly in the recent period. Organic matter may have oxidised more rapidly in the $(NH_4)_2SO_4$ plots because they have been fallowed more. On the nitrate plots the annual loss of organic carbon between 1888 and 1959 was about 0.009% C, twice the amount with old organic residues on one of the plots (7-1) of heavier soil on the Hoosfield Permanent Barley Experiment at Rothamsted. The soils of both sets at Woburn now contain very little organic carbon; the barley site is lower than the wheat and the lowest values (0.56% C) are on the plots that received $(NH_4)_2SO_4$. Soil is now lost from these sites by water erosion, perhaps because the soil contains too little organic matter.»

The availability of plant food from the decomposition of humus depends on the pH as well as on the soil temperature. It has been reported by E.J. RUSSELL (1932) and other European soil scientists that the available nitrogen in the Rothamsted soil is only 1-2% whilst in Uppsala (Sweden) it is reported to be half per cent by TORSTENSSON (private communication). But, in India soils, the available nitrogen may vary from 7 to 30%. Consequently, an adequate supply of humus can easily maintain crop production more readily in tropics than in cold countries.

In Rothamsted, the total nitrogen in some of the plots in which farmyard manure has been added every year is believed to be 0.274%, that is, the humus capital is 5.2%. Assuming that 0.05% total nitrogen corresponds to approximately 1100 lbs. of nitrogen per acre upto a depth of 6 or 7 inches (as in the Allahabad soil), in the Rothamsted dunged fields the total nitrogen is approximately 5800 lbs. per acre upto a depth of 6 or 7 inches; if 1 to 2% of this nitrogen is in available condition, the available nitrogen in the Rothanmsted dunged soils is of the order of 58 to 166 lbs. per acre. This explains the excellent crop production in the farmyard manured plots. Due to the addition of farmyard manure every year, the other plant nutrients besides nitrogen seem to be adequate. Phosphating of the farmyard manure would have led to much better results.

On the other hand, in our Indian soils, the plant roots and the residues obtained after harvesting of crops seem to be the chief supplier of plant nutrients in addition to rain water. If the roots and stubbles are phosphated with basic slag obtained from the neighbouring steel factories, more profitable results are sure to be obtained.

The thermal and photochemical fixation of nitrogen in the oxidation of organic matter aided by phosphates and light can supply a fair amount of nitrogen, but, unless some outside inorganic fertilizers or organic substances are applied in addition to the plant residues, there is very little prospect of increase in crop production. Large scale incorporation of organic matter from all sources and green manuring, which need not be legumes, reinforced by slags and a fair amount of artificial fertilizers are certainly needed for crop production in the poor tropical countries.

The functions of organic matter in soil require more investigation. There is no doubt that it increases porosity, water retention capacity and makes the soil ploughable and suitable for root penetration. A large supply of water and organic matter aided by chemical fertilizers seems to be necessary for enormous crop production in temperate countries as discussed in the previous pages and by LUTHER BURBANK. But in the hot countries where the availability of nitrogen from organic matter is considerable, humus and water in large amounts should be able to produce big crop yield as was obtained for several years in our fields manured by municipal waste and basic slags for white gourd melon (Benincasa cerefera or B. hispida) production.

In the fen soils of England containing 3% total nitrogen, and, in the muck soils in New Jersey containing 2.7% nitrogen, large crops are produced aided by fertilizers.

In ordinary crop production in the temperate countries, not only the commercial fertilizers supply the plant nutrients but the humus capital in the process of decomposition also contributes plant food. There is no doubt that by supplying inorganic plant nutrients, the crop production increases and the roots and stubbles left on the land after harvesting, the crop is greater than that in the unfertilized land. But, our researches show that nitrates produced in soils by adding nitrogenous fertilizers can react with the humus organic matter and deplete the humus content of the soils. This can be rectified by adding straw or other plant residues. Consequently, when large doses of nitrogenous fertilizers are applied in modern agriculture without using the manures, there is always the danger of the humus decrease and fall in crop production.

After visiting and studying the land fertility problem in the U.K., Holland, France, Germany, Sweden, Spain, Italy, U.S.A. (1960), Yugoslavia (1961) and Rumania (1964), I have no doubt that soil scientists are becoming reckless and are not saving the humus capital (i.e. fertility) of soil due to lack of farmyard manure. From our research for 40 years on the problem of nitrogen fixation and nitrogen loss in soils all over the world, I believe that in the absence of farmyard manure, caused by mechanisation of agriculture, a mixture of straw and basic slag should be ploughed in not only to fix atmospheric nitrogen but also to supply available nitrogen, phosphate, potash and trace elements required for crop production. There is no doubt that basic slag, being alkaline and containing catalysts, helps oxidation of organic matter, nitrification of humus and supplies available nitrogen. Even Europe, which still leads the world in experimental sciences, cannot continue to feed the increasing population unless organic matter is ploughed in the form of plant residues and other sources along with mineral fertilizers. It has been definitely established in the U.S.A. where applied science is well studied, that approximately 1/3 of the humus capital of most of the fertile prairie and other lands has been lost by excessive cultivation in 100 years although Canadian prairie lands have been better handled and their humus retained by legumes and manures as shown by the important publications of SHUTT (1910, 1925). American soil scientists know very well and have acknowledged that more corn, wheat and other crops are being produced per acre chiefly by better soil management, improved seeds and larger doses of artificials, although, the humus capital and crop productivity power are certainly decreasing. I am afraid the conclusion of the U.K. Zuckerman Committee of 1954 on the use of town waste in agriculture that as the yield of crops per acre in U.K. is appreciately increasing, the land fertility is also increasing or has not decreased, is certainly faulty. There is reason to believe that organic matter is not being incorporated as much as in the past to maintain the humus capital of the U.K. soils.

A Parliamentary and Scientific Committee of Britain in 1944 regarding Policy for British agriculture has recorded: « The highly complex part, played by organic matter in soils, is, however, still only imperfectly understood. It may truly be said to constitute one of the greatest of all the ultimate problems of the use of the land all over the world; possibly it is the greatest of all. »

This is the main problem in which the Sheila Dhar Institute of Soil Science, University of Allahabad, India, specialises.

In Europe 7 million tons of basic slag containing 1 million ton P_2O_5 are used per year.

The Year Book of U.S. Department of Agriculture, 1948, contains the following lines on page 91: « What I try to do is to keep increasing the amount of organic matter in the soil so that as much of this and other organic acids as possible will be released into soil. These acids will then attack the rock particles they cling to and from them they will obtain plant-food materials in quantities proportional to the amount of such acids given off by organic decay. You can see, then, that if I have 4 to 5% of decaying organic matter in my soil — instead of the usual 1% or less — 4 or 5 times as much mineral plant foods will be released into the soil by the acids from all this decay. »

Straw plus basic slag ploughed in can supply available N, P_2O_5, K_2O and trace elements almost as readily as composts. These two form valuable sources of plant nutrients and should be largely used in permanent agriculture.

STALLINGS (1958) of the U.S.A. Department of Agriculture has stated: « Organic matter helps growth all round including soil fertility. »

Similarly, H.B. VANDERFORD, Professor at the Mississippi State College, has reported in a private communication that farmers who have been trying for high yields have found manure to be quite helpful.

In a recent publication of India's West Bengal Government (1962) it has been reported that by adding farmyard manure and 30 lbs. nitrogen as ammonium sulphate per acre, the production of paddy increases by 358 lbs. per acre. The production in these lands without ammonium sulphate varies from 1378 to 2470 lbs. per acre. These results show that 1 lb. of nitrogen produces approximately 11 lbs. of paddy grains whilst in Europe the average increase by nitrogen in crop production is 17 lbs.

BRADFIELD (1960) recorded the following high yields of cereals in different parts of the world:

High yields of cereals Potentialities World record yields

Crop	Yield bushel/ acre	Kg/HC	Grower	Location	Year	Reference
Corn (field)	304.38	19100	L. Ratliff	Baldwin Prentice Co., Missouri	1955	Farm J., Nov. p. 16
Corn (Green House)	390	24400	H.G.M. Jacobson	Conn. Ag. Expt. Sta., New Haven, Connecticut	1948	P. Physiol. *23*, 636
Rice	266	13400	K. Velliah, Gourder	Thattanpatti village, Madras, India	1950 1951	The Rec. U.S. Dept. State; March-April, 1952, p. 26
Wheat	131	8800	Turrell Bros	Norfolk, England	1952	N. Y. Times, Dec. 8, 1952
Wheat	144	9600	—	U.S.S.R.	1944	-do- -do-

These very high yields were obtained in lands rich in humus.

It is well known that tall grasses growing for a very long time create fertile prairie or chernozem soils in different parts of the world rich in available nitrogen, phosphate, potash and lime. Some of these soils contain 1% total nitrogen as against 0.05% in average Indian soil and 0.15% total nitrogen in north-west European countries. These prairie soils on ploughing prove to be very fertile and produce bumper crops.

From the foregoing considerations it appears that soil organic matter can act as a steady supplier of N, P_2O_5, K_2O, CaO and other plant nutrients. Hence, lands rich in humus do not need any artificial fertilizer. This is evident from the following lines of MCKILLICAN and COOPER (1925):

« The prairie farm garden will rarely, if ever, require the application of commercial fertilizers. The soil is well stored with the elements of plant food. Under special circumstances some benefit may be derived from the use of special fertilizers but if farmyard manure and good cultivation are made use of, the owner of the home garden on prairie may safely ignore commercial fertilizers. »

The average yield of wheat in Britain was 8 bushels (1 bushel = 80.82 lb.) in the 18th. century. By introducing Norfolk Rotation, it increased to 20 bushels per acre by 1840. Today it is nearly 40 bushels or more. In the famous Morrow Plots at Illinois in 1955, after 80 years of continuous corn without soil treatment, a modern treatment involving lime and commercial fertilizers was applied, and, in the 1st. year of this treatment, 80 bushels/acre of corn were produced. In 1956, 113 bushels/acre, that is, twice the average in the State of Illinois was produced. Hence, it appears that the humus-rich soils of Illinois can respond well to artificial fertilizers.

In the U.S.A. the Land Grant College Act of 1862 established an Agriculture College in every State. In 1912 Extension Service was introduced, but, until 1927, the average yield of crop was disappointing.

Salter, LEWIS and STOPHER (1936) studied crop yields in the State of Ohio and reported that in spite of all of the experimental work that has been done in the State in the preceding half century, the yields of the more important crops had remained practically constant.

JARVIS (1931) stated: « It is significant that in spite of the amazing progress in genetics, in knowledge of plant diseases and insects and their control in soil surveys, in increased use of fertilizers during the last 40 years, average yields per acre have shown no appreciable increase in this country. » But much increased production has been demonstrated in individual farms and experimental plots. « Research had disclosed that it is not one or two environmental conditions which govern plant growth and crop yields but a coincidence or combination of interactive factors and that one factor cannot be considered irrespective of the others. There is a definite coincidence of these conditions under which every plant finds optimum environment and produces optimum yields.

KELLOG (1960) reported to the VIIth. Soil Science Congress that the efficiency of soil used on a sustained basis greatly increased in the U.S.A. between 1927 when the 1st. Soil Science Congress met and the VIIth. International Soil Science Congress of 1960. The total crop production in the U.S.A. has gone up by 65% although the area under cultivation is slightly less. Fertilizer use increased fivefolds and man hours of labour went down 50%. The principle of interactions for developing alternative combinations of practice for each kind of soil and their application to individual farm planning the economic development of highly productive arable soils from formerly unproductive kinds of soils by using unique combination of practices suited to the specific kinds of soils. These principles are applicable to the under-developed countries. Soils are individual, three dimensional bodies. This concept of soil from that of a profile to one of a three-dimensional body has helped basic and applied soil science.

In South Sweden and Denmark no difference is found in the placement of fertilizers as is found in England. This difference may be due to the maintenance of the pH of the soil by liming.

In Portugal, owing to the climatic conditions and the nature of the soil, the cultivation of permanent pasture on fallow land in southern Portugal is very difficult. For this reason particular attention is being paid to encourage farmers to introduce annual pasture in their crop rotations for increasing soil humus and satisfactory results have been obtained.

FAULKNER (1953) has recorded as follows:

« One can grow soil while he is growing his crops. »

« Father never used fertilizer alone. We always had quantities of farmyard manure and applied it heavily. »

China is the largest user of organic material and utilizes 70% of the 200 million tons of available night soil. 50% of agricultural land receives night soil and stable manure, 20-30% compost and 10 to 15% green manure. It has been estimated that the Chinese utilize over a million ton of N, ½ million ton of K and ¼ million ton of P as organics per year. Their crop production is higher than in many countries, although, the lands have been cultivated for thousands of years. This is possible because in China the quantities of plant nutrients introduced in the soil along with humus in the form of organics exceed the amounts applied as commercial fertilizers.

Similarly in Japan, along with large doses of artificials, a great amount of humus is produced by organic manures and utilised in crop production.

It appears that in intensive cultivation a large dose of organic matter is absolutely necessary for crop production with increasing amounts of chemical fertilizers. This is being realised all over the world.

It has been claimed in Norway that only the Netherlands and Belgium use commercial fertilizers in larger amounts than this country as is evident from the following table:

	N	P	K
The Netherlands	67.1	18.2	57.1
Belgium	46.1	20.4	67.6
Norway	33.1	15.3	36.9
West Germany	27.4	14.6	42.5
Denmark	23.0	11.7	35.3
Luxembourg	21.7	14.5	22.2
Sweden	15.3	10.4	12.9
U. K.	14.6	9.8	11.4
Switzerland	7.4	12.1	10.0
France	9.3	6.9	11.5

It is certain that prior to World War II far greater quantities of nutrients were added to the soil in the form of farmyard manure than in the form of commercial fertilizers. Today, the picture has changed. Nitrogen and potassium in commercial fertilizers added are of greater importance to the crops than in the farmyard manure and twice as much phosphorus added as fertilizer as in farmyard manure.

Total application of plant nutrients in farmyard manure and fertilizers in Switzerland. (Kg per hectare of agricultural area).

	Fertilizers			Farmyard manure			Total		
Country	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
The Netherlands .	59	52	63	25	13	25	84	65	88
Belgium	43	50	54	22	11	22	65	61	76
Denmark	19	25	26	37	16	41	56	41	67
Switzerland . . .	7	23	10	77	29	114	84	52	124

Among the commercial phosphatic fertilizers, basic slags are by far the most dominating. They are mainly applied to winter cereals on acid or neutral soils and to pastures.

Like Norway, Switzerland is also a country of pastures. The natural pastures, the permanent pastures for grazing and the leys cover 75% of the cultivated area. This proportion is only 55% in the Netherlands, 50% in Belgium and 35% in Denmark. In relation to the area utilized, Switzerland has the largest livestock, not only in Europe but in the world.

In Denmark, the Netherlands and Belgium the livestock graze from the end of April to November, but, in Swiss agriculture, the livestock is fed in the stables apart from the period in Spring and Autumn and this method results in a great production of manure and urine and thus the farmers recover a large quantity of plant nutrients, specially nitrogen and potassium.

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Fertilizers used in Kg per hectare in Switzerland

	1938-39	1956
N	2.3	10.7
P_2O_5	22.1	35.9
K_2O	10.0	22.3

100% of the farm manure is used and supplies the bulk of plant nutrients:

Total N	135.7 Kg/ha	of which 92% from farmyard manure
» P_2O_5	87.9 Kg/ha	of which 59% from farmyard manure
» K	254.5 Kg/ha	of which 91% from farmyard manure.

Hence, there is no soil humus loss in Swiss agriculture which is extremely sound.

Fertilizer consumption in Spain has always been small as farmers fear that it will involve unproductive expenditure because of the low and badly distributed rainfall during the period of growth of the principal crops. Another reason was the inadequate means of the small holders.

To promote the production of organic manures in Holland 10 million florin was made available from Marshall Aid funds for the construction of composting plants, the subsidisation of municipalities in respect of the construction of composting plants and further for researches on and publicity for composts. Demand for cheap compost for horticulture and arable holdings on light sandy soils is increasing.

The application of phosphatic fertilizers and specially basic (Thomas) slag or ground phosphates by liberating nitrogen and removing phosphate deficiency has improved and frequently doubled the yields in France.

Experiments with anhydrous ammonia show that in Denmark it will hardly be possible to supply this nitrogenous compound at a price very much below the cost of ordinary nitrogenous fertilizers. The value of NH_3 is about the same as that of $Ca(NO_3)_2$.

Farming without or with little livestock and without good crop rotation schemes is causing a deterioration to the soil in Sweden.

In Austria it has been observed that for maintaining and further increasing the fertility of the soil, it is indispensable that it be supplied with stable manure.

As Belgian agriculture is one of the most intensive, the farmers attach great importance to good soil composition, which is maintained by sound crop rotation combined with proper manuring.

There is no doubt that Rhizobia by symbiosis with leguminous plants and utilising the carbohydrates synthesised, Azotobacter by the utilization of organic matter and blue green algae by utilizing the carbohydrates photo-synthesised by them, fix atmospheric nitrogen, but, our researches show clearly that on a soil surface all organic substances undergo slow oxidation by the help of micro-organisms, chemical surfaces, catalysts, light absorption and create large amounts of nitrogenous substances in the soil. This amount of nitrogen fixation on the soil is ever so much greater than the industrial nitrogen.

SOILS POOR IN LIME CAN BECOME ACIDIC BY SUPERPHOSPHATES

There has been considerable controversy regarding the power of superphosphates in increasing the acidity of soils. This is clear from the following lines:

SKINNER and BEATTIE in 1917, working at the Arlington, Virginia, farm of the United States Department of Agriculture, reported that the lime requirement of the surface 6 inches of the soil was increased following 5 annual applications of superphosphate @ 200 lbs. per acre, but, BURGESS (1922) of the Rhode Island Experiment Station concluded that there is foundation for the statement that soils will become acidic following the continuous use of superphosphate. His results, which show the accumulated influence for a period of 27 years, are recorded below:

Relative influence of the continued use of various phosphates on the lime requirement of the soil.

	Total crop grown last 5 years (tons)	Lime requirement (Jone's method) lbs. CaO per acre
Check	17.6	2700
Floats	29.4	2520
Superphosphate	31.5	2346
Extra superphosphate	42.2	2250
Ground bone	33.4	2160
Thomas slag	32.7	2070

The discrepancy between the results of SKINNER and BEATTIE and BURGESS is explained in the following manner.

When superphosphate is added to an acid soil very poor in calcium carbonate, the superphosphate is likely to react on the soluble salts of Fe, Al and Ti according to following equations:

$$Ca(H_2PO_4)_2 + Fe_2(SO_4)_3 = 2FePO_4 + CaSO_4 + 2H_2SO_4$$
$$Ca(H_2PO_4)_2 + Al_2(SO_4)_3 = 2AlPO_4 + CaSO_4 + 2H_2SO_4$$
$$2Ca(H_2PO_4)_2 + 3TiCl_4 = Ti_3(PO_4)_4 + 8HCl + 2CaCl_2$$

It is clear, therefore, that in such acid soils the liberation of sulphuric or other mineral acids makes the soil more acidic and their lime requirement markedly increases. This may explain the observations of SKINNER and BEATTIE who reported an increase of soil acidity by fertilizing with superphosphate.

On the other hand, with soils rich in calcium carbonate, superphosphate causes the following reactions to take place:

$$Ca(H_2PO_4)_2 + 2CaCO_3 = Ca(HCO_3)_2 + 2CaHPO_4$$
$$Ca(H_2PO_4)_2 + 2CaCO_3 = Ca_3(PO_4)_2 + 2H_2O + 2CO_2 .$$

In certain cases, small amounts of calcium, i.e. equivalent to calcium introduced in the superphosphate existing as calcium monophosphate, may be washed away from soils as $Ca(HCO_3)_2$. But, because $CaHPO_4$ is sparingly soluble and is not as readily converted into soluble calcium monophosphate by the action of carbonic acid as the ready conversion of calcium carbonate to the soluble bicarbonate by the action of carbonic acid in soil, the acidity and the lime requirement of a soil may decrease. This viewpoint has recently been emphasized by DHAR and co-workers and it has been clearly established that addition of soluble and insoluble phosphates decreases the leaching of lime and, hence, the lime requirement of such a soil decreases.

In Rothamsted, most soils contained nearly 5% calcium carbonate when the classical experiments were started in 1843. The regular addition of superphosphate has not increased the acidity and lime requirement of these lands as explained here.

Moreover, the addition of farmyard manure improves not only the nitrogen status of lands by fixation of atmospheric nitrogen but also improves the calcium phosphate contents. On an average, 1 ton of farmyard manure adds 130 lbs. of calcium oxide along with phosphate present in the manure.

IRON ORES IN HUMID COUNTRIES RICHER IN PHOSPHATES THAN ORES IN DRY REGIONS

Since the dawn of civilization metals have been utilised for everyday life. Perhaps copper came in the field earlier than iron, but, the part played by phosphate in determining the quality of copper is not known as much as the part of phosphate in influencing the quality of steel which depends a great deal on its phosphate content.

In cold and temperate countries, the water present in soil from rain and snow has a lower temperature than the temperature of water present in the soil of tropical countries. Therefore, the amount of carbonic acid in the soil aqueous solutions is greater in cold countries than in tropical ones. The element, phosphorus, is widely distributed in the earth's crust which contains 0.142% phosphorus chiefly as calcium orthophosphate. Our experimental results clearly show that orthophosphate of calcium dissolve appreciably in carbonic acid solution forming calcium di- and mono- phosphates. Hence, washing away of these phosphates becomes more prominent in cold country soil conditions than in warm countries. Moreover, the vapour pressure of water increases considerably with increase of temperature. Hence, the moisture present in warm countries after a shower of rain volatilises more quickly than in cold countries where the removal of water by drainage is a big problem.

The eminent French chemist, HENRI DE CHATELIER, in his lectures at Sorbonne in 1917-1919, stated several times that the steel prepared in India and used in the *KUTUB MINAR* near Delhi is of excellent quality. The analysis of the steel used in the KUTUB MINAR as reported by Sir ROBERT A. HADFIELD is recorded below:

Iron 99.72%, nitrogen 0.032%, manganese 0%, phosphorus 0.114%, silica 0.046%, sulphur 0.006% and carbon 0.08%. Friend recorded the composition of Konarak (Orissa) beam as 0.11% C, 0.10% Si, 0.024% S, 0.015% P and 99.72% Fe.

According to LE CHATELIER, the production of such steel was possible in Europe at a much later period. The quality of the steel depends a good deal on its phosphorus content. From a survey of the iron ores utilised in the world steel industry, it is apparent that the iron ores utilised in India, Egypt and other comparatively drier parts of the world contain less phosphorus than the ores utilised in Lorraine, Kiruna (Sweden), which are wet parts of the world. Sir THOMAS HOLLAND, Director of the Geological Survey of India, recorded as follows regarding the iron ore deposits of Salem and Trichinopoly (Madras): « It is still probably true that Salem magnetite is comparatively free from phosphorus. » These ores contain 31.2 to 42.15% Fe_2O_3, 9.5 to 11.2% FeO, 42.85 to 50.30% Sio_2 and 0.086 to 0.136% P. Similarly, the Kanjmalai (Madras) ores contain 75.2% Fe_2O_3, 20.1% FeO and 0.062 to 0.3% P. Following is the analysis of Lorraine, Kiruna (Sweden), Cleveland (Yorkshire) and limonites in swamps and lakes (Swedish bog iron ores):

Lorraine iron ores: Fe 30%, CaO 5-12%, SiO_2 7-20% and P 0.5-1.8%;

Kiruna (Sweden) iron ores: Fe 56-71% and P 0.03 to 1.8%;

Cleveland (Yorkshire) iron ores: Fe_2O_3 1.77%, FeO 36.9%, SiO_2 8.5% and P_2O_5 1.3%;

Limonites in swamps and lakes (Swedish bog iron ores): Fe_2O_3 62.57%, Mn_2O_3 5.58%, SiO_2 12.64%, Al_2O_3 3.58%, CaO 1.37%, MgO 0.19%, P_2O_5 0.48% and SO_3 0.07%.

It is interesting to record here that the mineral, Vivianite ($Fe_3(PO_4)_2.8H_2O$) occurs in bogs and swamps.

In the Southern States of the U.S.A. the ores contain 30.55% Fe. They are high in Al_2O_3, SiO_2, P and Mn, but, low in S. The ground ores of North East Texas in a washed condition contain 42-48% Fe, 10-12% SiO_2 and less than 0.12% P. In the U.S.S.R., brown iron pliocene haematites are high in their phosphorus and silica contents. But, the Lake Superior Region iron ores of the U.S.A. contain 50-60% Fe, 7-8% SiO_2 and P averages 0.09%. They are low in sulphur also. Also in Korvies (U.S.S.R.) ores containing small amounts of P occur: 57% Fe, 8% SiO_2 and 0.05% P. The haematite-quartzite ores of India resemble those of Lake Superior (U.S.A.). Similarly, in Brazil, Cuba, Venezuela, the iron ores contain very little phosphorus but most European and Newfoundland ores have high phosphorus content. It has also been reported that Chinese ores are low in phosphorus and sulphur. Bog iron ores are abundant in glaciated Northern regions of North America and Europe.

Clay iron stone which is argillaceous sideritic concretions and beds is found in the coal measures of the U.K. and U.S.A. It occurs as layers of nodules or beds and is found to overlie coal seams. The Wabana ores of Newfoundland consist of haematite 50-70%, chamosite 15-25%, siderite 0-50% and calcium phosphate 4-5%. Most of these ores are high in phosphates. It has already been stated that the iron ores utilised in the Lake Superior district of the U.S.A. are low in phosphorus and they contain ferrous carbonate and silicates.

EXPLANATION OF THE GREATER AMOUNTS OF P_2O_5 IN EUROPEAN BASIC SLAGS IN COMPARISON WITH THOSE OF INDIA AND THE U.S.A.

From the above survey of the phosphorus content of the iron ores available in different parts of the world, it appears that in wet and cool parts of the world the iron ores contain more P_2O_5 than the ores collected from the dry and warm parts. Consequently, the basic slag obtained from the phosphorus-rich ores is richer in P_2O_5 than the slag obtained from the steel industries of India and U.S.A. This is clearly evident from the analysis of the various slags given below:

Analysis of different basic slags

	Tata basic slag	Kulti basic slag	Durgapur basic slag	Rourkela basic slag	German basic slag	Belgian basic slag
Sio_2 etc. . .	15.6846	16.9677	20.1640	22.4600	11.4665	11.9867
Total iron	10.3265	9.8100	12.1884	11.5966	9.1263	10.0216
Fe_2O_3 . . .	3.3000	4.1000	5.2967	5.6466	4.1233	4.9888
FeO	10.4678	8.8967	10.8764	9.8000	7.9999	8.3688
Al_2O_3 . . .	5.4320	6.4860	6.8748	6.3646	3.0678	2.9646
CaO	38.6946	40.1800	37.7785	40.0000	42.3467	41.6846
MnO . . .	2.9076	2.9978	4.6633	3.1674	4.8736	4.1844
MgO . . .	4.8486	4.1346	5.6726	6.0174	4.9684	4.6788
K_2O	0.6474	0.3364	0.5644	traces	traces	traces
V_2O_5	0.4881	0.4136	0.3468	0.3394	0.6438	0.5488
Cr_2O_3 . . .	0.3973	0.3688	0.2988	0.2767	0.4678	0.3999
TiO_2	0.3126	0.2566	0.2333	0.2188	0.4784	0.2999
CuO	0.0053	0.0044	0.0044	0.0038	0.0048	0.0088
ZnO	0.0064	0.0056	0.0086	0.0047	0.0056	0.0060

It is interesting that in general the iron ores of Europe are richer in P_2O_5 than those of India and the U.S.A. Hence, the amount of P_2O_5 in many European basic slags varies from 17-20% whilst in the U.S.A. the P_2O_5 content of basic slags is of the order of 8-10%. In India, the Tata Steel Works are producing 1 million tons of basic slags containing 8-10% P_2O_5.

The U.S.A. consumes only 40,000 tons of basic slag. A typical American slag has the following analysis: P_2O_5 11.01%, SiO_2 10.16%, CaO 42.6%, MgO 6.15%, MnO 3.78%, Fe_3O_4 24.0%, Al_2O_3 0.45%; TiO_2 0.17%, K_2O 0.14%, Na_2O 0.6%, S 0.09% and Zn, Cu and B are presented in traces.

The cold water obtained from precipitation in temperate countries rich in carbonic acid remaining much longer on the soil surface can leach the phosphates to a greater extent than in warm countries. The phosphate-rich water, when coming in contact with the oxides of iron present in the iron ores loses a part of the phosphate which is readily adsorbed by the iron oxides, which are excellent adsorbers of P_2O_5. This seems to be the main reason of the greater contents of the Lorraine and Kiruna ores than the Indian ores. Consequently, the composition of basic slag will depend on the phosphate contents of the ores. The greater the phosphate content of the ore, the greater is the phosphate content of the basic slag.

The three principal slags used in modern agriculture are: blast furnace slag, basic slag and the slag obtained in the production of phosphorus in the rock phosphate reduction furnaces. Basic slag is valuable not only as an important source of phosphate but can be used in neutralising the soil acidity whilst the other two slags are used chiefly for liming the land.

Basic (Thomas) slag is a very important fertilizer because it supplies not only small amount of phosphate ions slowly in presence of water but it is rich in lime, magnesia, potash and trace elements which are valuable for crop production. Moreover, basic slag being rich in lime and magnesia can slowly convert the very sparingly soluble phosphates of ferric, ferrous iron, aluminium and titanium present specially in acidic soils, converting them partially into tricalcium phosphates, which are more readily assimilated by plants than ferric or ferrous phosphates. Moreover, basic slag is alkaline and helps in the slow oxidation of organic matter present in the soil or added to it. We have always observed that wheat straw, after the removal of the wheat grains, can be ploughed in along with basic slag and there is considerable fixation of atmospheric nitrogen in the slow oxidation of wheat straw on the soil surface and available nitrogen, phosphate, potash, magnesia and trace elements are readily obtained from this mixture. Hence, organic matter, when mixed with basic slag, is very valuable in crop production not only in tropical countries but also in temperate ones.

INDIAN BASIC SLAG AS GOOD AS AMERICAN BASIC SLAG AND PROFITABLE FOR CROP PRODUCTION IN CONJUNCTION WITH ORGANIC MATTER

India possesses large amounts of basic slags produced from the expanding steel industry and these slags remain utilised. From a large number of analyses, it has been found that the Tata basic slag contains 7-8% P_2O_5 which compares favourably with the phosphate content of basic slags in the American markets. The Tata basic slag and other phosphates, when used with organic matter, not only fix atmospheric nitrogen and supply available phosphate and increase the crop production and improve the fertility of normal soils but they also reclaim the USAR and alkali soils permanently.

SUPPORT OF SOIL SCIENTISTS TO THESE RESEARCHES

Lady EVE BALFOUR has recorded as follows: « Dr. DHAR's work on behalf of soil fertility is known in many countries. Particularly valuable to world agriculture is his discovery that crude organic matter such as straw left by combine harvesters can be safely ploughed in with it. Dr. DHAR is deeply concerned at the declining humus status of so much of the agricultural soils of the world, which is at its worst of course in the big grain producing areas, and it is there that Dr. DHAR's discovery is of such special importance in that it provides a practical alternative to the burning of straw. Here at Haughley, we use Dr. DHAR's method when ploughing in straw on our stockless section. We have done so regularly since our first experiment with it in 1957-58. »

Lady L.E. HOWARD has stated: « In India's sunny climate fixation of atmospheric nitrogen is a most advantageous factor. Prof. DHAR's researches on this point have opened up new possibilities of the greatest importance. Fixation is greatly increased if the material is treated with phosphates, preferably in the inorganic form as phosphate rock or Thomas (basic) slag; if so phosphated, percentage of nitrogen in municipal wastes when composted rises from 0.64% to 1.02% and the available phosphate from 0.13% to 0.18%. On world basis, Prof. DHAR has also estimated that as much as 8 to 10 million tons of nitrogen, 4 to 5 million tons of phosphate and about the same amount of potash could be recovered from municipal wastes. »

Sir JOHN RUSSELL commented on these researches as follows in « Nature », April 11, 1936, page 629: « Prof. DHAR leads the school of thought which believes that nitrification in soils and nitrogen fixation from the atmosphere are, specially in the tropics, photochemical, at least as much as bacterial action. Prof. DHAR has produced strong evidence in support of his theories. The practical facts of Prof. DHAR's researches are that Indian soils are generally deficient in nitrogen, that more than half a million tons of molasses from the sugar industry are annually wasted in India, and that the application of molasses to the soil can double, and may treble, the soil nitrogen content with a consequent large increase in crop yield. Prof. DHAR has produced indisputable evidence of increase in available soil nitrogen and crop yields following the application of molasses. Under temperate conditions the converse results would be expected as it is well known that the addition of carbohydrate-rich material to the soil tends to reduce the amount of nitrogen available to plants, the nitrogen becoming fixed as microbial protoplasm or as humus. An essential difference, however, between temperate and tropical soil requirements is that whereas in temperate regions the limiting factor to crop growth is often the slowness, in the tropics it is the rapidity with which the soil nitrogen is made available to plants, soluble nitrates being formed and leached from the soil before they can be absorbed by the crop. The general effect of molasses on the soil should be the same everywhere, but only in the tropics will its 'braking' effect on the mobilisation of soil nitrogen be a positive advantage to the cultivator, and only in the tropics will its stimulation of atmospheric nitrogen fixation, whether bacterial or photochemical, be appreciable, since temperate regions lack the heat necessary for bacterial and the light for photochemical stimulation. From these reasons the potentialities of carbohydrate manuring — of which molasses manuring is an example — have perhaps been overlooked by agriculturists. If Prof. DHAR can substantiate his claims, he may effect a revolution in agriculture in India where supply of the ordinary organic manures is far below the demand. Prof. Dhar suggests that a most valuable use can be made of molasses in reclaiming alkali land. The acids produced in the decomposition of molasses neutralise the alkalis, and at the same time and contrary to experience when land is reclaimed with gypsum or sulphur, soil nitrogen is increased. There are 4 million acres of infertile land in India and irrigation practices are increasing the area. The economic reclamation of these lands is one of the country's greatest agricultural problems to the solution of which Prof. DHAR's work is pointing the way. »

Similarly, J.I. RODALE of Pennsylvania has stated in « The Farmer » (1949 Winter issue, page 10) as follows: « To say that this is an exciting situation is to put it mildly. But if Dr. DHAR is right, and he seems to have done the experimental work to prove it, we seem to be on the threshold of something spectacular. The first phase of work was accomplished by Sir Albert Howard in India. Here is another phase which was done in the same country. Since Dr. DHAR is the Head of an important Department in a recognised University, I feel certain that there must be some snbstance to the letter just quoted. The new method is a combination of Sir ALBERT HOWARD and Dr. DHAR. What is the significance of this letter? In the case of making compost by the aeration method, some of the nitrogen is lost. At any rate, the total nitrogen content of the compost is not very high, about 1 to 2%. By placing our organic matter in a thin layer in the field and discing it in the upper 4 inches, there is much slower oxidation than in the composting process, and in the field, says Dr. DHAR, more nitrogen is fixed. A careful perusal of his papers gives confidence in his methods and findings. »

The Editor of « Farmer », Mr. NEWMAN TURNER, has also recorded as follows: « ... But Dr. DHAR's findings are thoroughly sound. We have practised them for nearly 7 years at the Goosegreen Farm with great success. »

Dr. CHARLOTTE M. HOAK of 1125 Stratford Avenue, South Pasadena, California, U.S.A., has put the position as under: « ... It is with profound interest that I have read and digested, as far as possible with my limited experience, the helpful chemical research in agricultural fields done by your leader, Dr. N.R. DHAR. Head of the Chemistry Department of the University of Allahabad. The various reprints of the Proceedings of the National Institute of Sciences of India and his invaluable book on Biochemistry should be in the hands of every progressive agriculturist. Of special interest to us in the semi-arid Southwest is the "Reclamation of USAR (alkaline) Land by treatment of Molasses and Pressmud". Of great interest throughout the country is the new light thrown on the direct nitrification of the Soil. »

Dr. A.C. HILDRETH, Superintendent, U.S. Deptt. of Agriculture, Agricultural Research Service, Crops Research Division, Cheyenne Horticultural Field Station, P.O. Box 1250, Cheyenne, Wyoming, U.S.A., has stated thus: « The copy of your presidential address *Calcium phosphates and their importance in nitrogen fixation and alkali soil reclamation* has just been received. This work is a great contribution to agricultural science. Your experiments on photochemical fixation of nitrogen are most interesting. They do much to explain the continued productivity of land in parts of Asia that have been farmed for thousands of years. More important, they offer hope for the future. Thank you very much for making the results of this valuable research available to me. »

Dr. F.W. WENT, California Institute of Technology, U.S.A., says: « Your problem of the effect of light on nitrogen fixation in soil is really a very important one and should receive much more attention than it generally does. I would like very much to aid in your research on this subject but I should point out that the Earhart Plant Research Laboratory to which you are referring in your letter is not a good place to study soil problems. »

Prof. F.C. MILLER, Prof. of Plant Physiology, Kansas State College, Manhattan, U.S.A., has stated as below: « It strikes me that you have made a very important discovery and one that needs further investigation. The results may be due somewhat to the conditions under which the experiments were performed and that of course can only be determined by investigations by people in regions remote from yours. »

Dr. ALF ASLANDER of the Royal Institute of Technology, Stockholm, Sweden, writes as under: « Your discovery of this kind of nitrogen fixation will certainly be counted among the most important ones regarding soil fertility. When you get the "Nobel Prize" for your discovery of the nitrogen fixation, you are very welcome to inspect the results. »

Under the caption « Phosphates and Nitrogen Fixation », Mr. JORIAN JENKS has reviewed the research work of Dr. N.R. DHAR in « Mother Earth » (Oct. 1957, page 1067) as below:

« In the April 1957 number of this Journal, we included a brief appreciation of the work of Prof. DHAR and his colleagues at the Sheila Dhar Institute of Soil Science, University of Allahabad. This refered chiefly to the photochemical fixation of atmospheric nitrogen, a material process which can be intensified by the incorporation in the surface soil of organic matter together with some phosphates. We have since received from Prof. DHAR the full text of his presidential address at a Symposium on the "Role of Phosphates in the Soil, Plant and animal kingdom" held at Lucknow in December 1956. This is a most comprehensive document comprising many thousands of words and a large number of experimental results. Professor DHAR begins by stressing the importance of Phosphates in all vegetable and animal life; it is specially interesting to note the high phosphate content of bacteria and other micro-organisms including those of the ocean. The latter, Dr. DHAR points out, is a vast source of natural calcium phosphate. His estimates of world reserves of phosphate rock are surprisingly large — high-grade 10,622,000,000 metric tons (mostly in the U.S. and North Africa); low-grade 6,245,000,000 metric tons (nearly all in Russia).

Dr. DHAR then goes on to discuss the role of calcium phosphates in soil fertility, more specially the important part they play in the fixation of atmospheric nitrogen. Photochemical fixation by the oxydation of organic matter, maintains, is far greater than bacterial fixation, whether symbiotic (as in the case of leguminous plants) or non-symbiotic, specially in tropical countries. Taking the world as a whole, he estimates that of a total of 110,000,000 tons nitrogen fixed annually, at least 50% can be attributed to the absorption of solar light. Whereas it is generally believed that Azotobacter are mainly responsible for nitrogen fixation, numerous experiments at the Sheila Dhar Institute have shown that the amount of nitrogen fixed is double or more in the presence of light, which reduced greatly the number of Azotobacter.

Taken in conjunction with the work of Prof. VIRTANEN in Finland, Prof. DHAR's researches demonstrate how relatively insignificant is the contribution of artificial nitrogen fertilizers to world agriculture (it has been estimated at about 3% of total nitrogen supply). Prof. DHAR quotes a calculation that the nitrogen content of the humus in the top 12 inches of the cultivated lands of the world is 40,000,000,000 tons, and cites experimental evidence from Rothamsted and elsewhere to the effect that large doses of mineral nitrogen fertilizers accelerate the loss of this nitrogen from the soil, an interesting confirmation of the indications obtained at Haughley. This work in India is of great significance in relation to the problem of feeding the world's growing population. »

Recently, very important communications have been received from Canada and the U.S.A. Dr. C.T. JONES of the Interprovincial Patents Ltd., Ste. 314-718, Granville St., Vancouver 2, B.C., Canada, has stated as below:

« We are quite interested in your work and firmly believe that its application in this country would be of great benefit... The soils are mostly alkaline and large areas are subject to erosion brought about by over-cropping and lack of humus. It has been the practice to burn off the straw residues after combining, so little organic matter has been returned to the soil... It can be readily seen that while any synthetic fertilizers are used under these conditions, it is only a matter of time before these lands become dust bowls, which in fact, some already are... We would welcome a suggestion from you whereby your background of experience in this field may be used to further enhance the value of our products on some mutually satisfactory basis. »

Dr. RICHARD K. HOUSTON of Kansas City, Missouri 64112, U.S.A., states:

« I have read with great interest your research on chemical fixation of nitrogen. I am interested in the application of these principles to agriculture in the United States, particularly lawns... Some of the Coal Companies I am in contact with are interested in using coal agriculturally. It is quite possible that in researching the use of coal for a turf market in the

United States, we may well be of service to one another... I feel your work to be very important because if we can increase the nitrogen conversion of crop residues from 10 lbs. of nitrogen per 1000 lbs. of carbon to 60 lbs. of nitrogen, this would allow the small farmer with no capital to produce his own nitrogen. I believe the U.S. Government would be very interested in helping finance research on this approach with counterpart funds. »

Dr. O. ARRHENIUS writes: « You are quite right in your idea in using Thomas phosphate and ploughing down the straw, thus keeping up the humus content in the soil. During the last years I have done this myself. The only trouble has been that it is still very hard to obtain Thomas in grains instead of a powder. Nobody is willing to spread the powder as they are more black than chimney sweepers after a few minutes work. Now the factories have gone over to producing it grained but it is still hard to obtain. *The results of Thomas have been very good on my soils here.* Now these soils have been in the hands of tenants for about 30 years and have not received any lime for this time. Therefore, the need for alkaline fertilizers as Thomas is very great. At the same time the soil is improved with regard to minor elements. »

SUMMARY

Elements present in soil, earth's crust, plants, coal, human body are recorded.

Organic matter fixes nitrogen of the atmosphere in soils and its oxidation is vital in land fertility.

Nitrogen supply markedly increases soil productivity.

The main source of soil nitrogen is the nitrogen fixed by the oxidation of organic matter aided by light absorption and calcium phosphates.

Calcium phosphate-rich soils can fix nitrogen from the slow oxidation of the humus present in such soils. Hence, the C/N ratio of phosphated soil becomes smaller than 10 as in the ordinary soils.

Population explosion creates starvation.

It has been reported that the world population will reach 6000 millions and 800 million people may die of starvation by the end of the present century. Hence, famine is facing man who must produce more food at any cost.

Yield of crops by adding nitrogenous fertilizers is much greater than that obtained by applying phosphate or potash. But the world utilisation of industrial nitrogen today is about 12 million tons only, whilst the food, fodder and fibre production requires 350 million tons of available nitrogen. Hence, soil humus is supplying most of the nitrogen requirement of crops in the world.

A new method of fixing atmospheric nitrogen in soils by the slow oxidation of all types of organic matter has been discovered by us. This nitrogen fixation has been found to be accentuated by light absorption and addition of phosphates. Excellent crops have been obtained in normal and acidic and alkaline soils all over the world by this method.

Experimental results show that direct ploughing in of organic matter with or without phosphates produces more crops than from the compost obtained from the same organic matter. This is due to the fact that direct ploughing produces more nitrogen fixation in the soil than in composting where marked losses of nitrogen have also been reported. Plant leaves, all kinds of straw, grasses, peat, lignite and waste coal and specially forest litters form valuable sources of energy materials for fixing atmospheric nitrogen aided by calcium phosphates.

In composting all types of organic matter including waste coal, the addition of phosphates including phosphate rocks and basic (Thomas) slags produces richer composts than the ordinary Howard compost. In this process also, the absorption of sunlight increases the nitrogen content of the compost. Phosphated composts containing coal have more total nitrogen and produce more crops than composts without coal which, when directly ploughed in with basic slags, fixes nitrogen and increases crop production.

Moreover, humus-rich or compost-rich soils can produce large crops by applying nitrogenous fertilizers.

Comparative experiments on nitrogen fixation by blue green algae show clearly that they produce a small increase of nitrogen in the soil. But, organic matter increases the nitrogen status more markedly than the blue green algae. Field trials show small increase of crop production by Anabaena or Tolypothrix but large increase with straw and basic (Thomas) slag.

Experiments have been carried out by us on the loss of total nitrogen from soils mixed with either ammonium sulphate or sodium nitrate. Our observations show that in all the systems, the total nitrogen decreases with lapse of time. But, in presence of algae, there is a slight checking of the nitrogen loss. With phosphates, the loss is checked a little more, but, organic substances like wheat straw retard the loss of nitrogen markedly. These nitrogen loss experiments can explain the low recovery of nitrogenous fertilizers in crop production all over the world. We have obtained experimental results in support of the viewpoint that humus loss in soils is accentuated by applying nitrogenous fertilizers. But wheat straw is an excellent fixer of atmospheric nitrogen in the process of its composting or when ploughed in the soil, and it is also a retarder of nitrogen loss from soils.

Only in Swiss agriculture adequate amounts of organic matter are applied as farmyard manure. But, in other countries the addition of organic matter is inadequate for permanent agriculture which is feasible by ploughing in straw and basic slag in modern agriculture carried on without animals.

When nitrogenous fertilizers or manures are applied in crop production, normally, 25-30% of the applied nitrogen is recovered in crops and majority of the added nitrogen is lost. This loss is caused by the formation and decomposition of the explosive substance, ammonium nitrite, as an intermediate product in the process of nitrification of nitrogenous compounds. This loss is also observed when virgin soils are first broken up for cultivation. Experimental results show that on the application of nitrogenous fertilizers and manures, the soil humus carbon is oxidised at a greater speed than its oxidation by air. This is a world phenomenon created by the application of nitrogenous fertilizers and manures. This loss can be avoided by the incorporation of organic matter like straw, leaves or grasses.

All over the world, farmers have reported that artificial fertilizers, even when applied in large amounts for crop production, cannot prevent soil deterioration and decrease of crop yield with lapse of time. This can be prevented by applying farmyard manure along with artificials. Our researches have explained that manures, grasses etc., when ploughed in specially along with calcium phosphates, fix atmospheric nitrogen in the soil and retard nitrogen loss from soils by slowing down the formation of the explosive substance, ammonium nitrite, which readily decomposes as in the equation: $NH_4NO_2 = N_2 + 2H_2O + 718$ K. cals. Hence, permanent agriculture without animal dung is a practical proposition when grasses, straw etc., which behave like farmyard manure, are ploughed in to fix atmospheric nitrogen and retard nitrogen loss.

All over the world, marked losses of nitrogen have been recorded from soils treated with artificial fertilizer nitrogen or animal dung and in nitrogen-rich virgin soils. In the nitrification of nitrogenous compounds and ammonium salts, there is always the formation and decomposition of the unstable explosive substance, ammonium nitrite, which breaks up according to the equation mentioned above. This marked loss of nitrogen is the cause of the low recovery (25-30%) of nitrogen in crop production generally observed in the world. The recovery of phosphate and potash is generally greater than that of nitrogen in crop production.

There is considerable nitrogen fixation in grasslands. In temperate climates, grasses are the best suppliers of soil nitrogen.

The total nitrogen in grasslands is greater than in forest lands. HANS JENNY and S.P. RAYCHAUDHURI have reported that comparison of Indian with the American soils, particularly those of California, Texas, Atlantic coast, showed an unquestionable superiority of the former over the latter when sites having equal mean annual temperatures were compared. But the Indian soils have much lower nitrogen and carbon content than the tropical soils of the Central and South America.

Moreover, the average nitrogen content of soils of Ootacamund and Koidakanal, hill stations in South India near the equator, is 0.335% and 0.332% respectively, whilst the North Indian hill station of Simla has 0.241% nitrogen and Mussoorie has 0.226% nitrogen. Similarly, Ambala and Aligarh, lying in the Northern Indian plains, show a nitrogen status of 0.036% nitrogen and 0.044% nitrogen respectively, whilst Madras and Madura, in South India near the equator, have 0.054% and 0.062% nitrogen respectively. The rainfall and temperature in all these hill stations are about the same. These observations showing greater nitrogen status of land near the equator and those showing greater nitrogen in grasslands than in forests support the photochemical viewpoint of nitrogen fixation. Undoubtedly, the world soil nitrogen is created by the fixation of atmospheric nitrogen in the slow oxidation of organic matter aided by sunlight absorption and phosphates.

Calcium phosphates act as buffer for increasing the pH of acidic soils and also can reclaim the saline and alkaline soils all over the world when ploughed in with all types of organic matter including agricultural and crop by-products, peat, lignite, and coal. These organic substances, when ploughed in with basic (Thomas) slags or rock phosphates, can supply quite adequately all plant nutrients all over the world. Organic matter carried by flood waters has maintained soil fertility by nitrogen fixation in various parts of the world.

By the addition of superphosphate to temperate country soils, there is the possibility of increase of acidity of such soils and hence greater utilisation of basic (Thomas) slag in all agriculture is highly desirable.

Rich prairie and czernogem lands appear to be created by nitrogen fixation in grasslands rich in calcium phosphates.

Iron ores in dry areas of the world contain smaller amounts of P_2O_5 than those in the wet and cool parts of the world because of the greater amounts washed down in cold countries. Hence, the P_2O_5 content of basic (Thomas) slags obtained in Europe is higher than the slags obtained from India and in the other warm and dry parts of the world.

INDIAN BASIC SLAGS AS GOOD AS AMERICAN AND PROFITABLE FOR CROP PRODUCTION IN CONJUNCTION WITH ORGANIC MATTER

India possesses large amounts of basic (Thomas) slags produced from the expanding steel industry and these slags remain unutilised. From a large number of analyses it has been found that the Tata basic slag contain 7-8% P_2O_5, which compares favourably with the phosphate content of basic slags in the American markets. The Tata basic slag and other phosphates, when used with organic matter, not only fix atmospheric nitrogen and supply available phosphate and increase the crop production and improve the fertility of normal soils but they can also reclaim the USAR and alkali soils permanently.

DISCUSSION

Chairman: W. FLAIG

FLAIG

Thank you very much, Prof. DHAR, for your interesting lecture. You have given us much data for an important problem. The discussion is open.

PRIMAVESI

The fact that prosperous grassland improves the soil more than any other vegetation type was well known. It is therefore interesting to learn that it also improves most the N-level. How do you intend atmospheric N fixation by straw? Over the activation of fixing micro-organisms?

DHAR

Well, as I said, bacterial growths are very useful. I do not contest this. But they are not the only things that are good on the surface of the earth; there are other things. Light is good, catalyst is good. In the animal body oxidation enzymes take part but no microbes. Hence when you add straw — as I say proof of the pudding is in the eating — you get a good crop. We explain this from the viewpoint that the straw is slowly oxidized on the soil surface by the help of light, of iron oxide, of aluminium oxide, etc. Also with the help of micro-organisms; but in all our experiments we have observed that there is more nitrogen increase in light but less bacteria in light than in the dark. So I am not contesting at all that there is no bacterial process; what I contest is that nitrogen fixation is not essentially a bacterial process. Light certainly helps. Chemical nitrogen fixation in soils has been experimentally proved by us for the first time in the history of science.

PRIMAVESI

What is the pH of your soils?

DHAR

Well it depends on rainfall. Lime has been washed away by plenty of rain in Kerala soils where pH is about 5. pH is 7 in Allahabad with a temperature of 26°. But as I said, even in acid soils of Kerala with pH 5, which is worse than many European soils, we can get good nitrogen fixation and increased paddy yield because of the addition of the paddy straw and basic slag, which removes acidity.

PRIMAVESI

Ca is known as a humus consumer, like N, as you also mentioned. Can you explain the fact why $CaHPO_4$ or any phosphore rich basic slag slows down organic decomposition? On the other hand, we also made the experience that organic matter and calcium plus a fertilization with all lacking elements reclaimed as well acid as alkaline soils.

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DHAR

It is well known that nitrogenous compounds like purine, amino acids, with phosphoric acid form phosphorylated compounds, which are stable proteins. We have made hundreds of physico-chemical experiments on phosphorylation. If you take phosphoric acid, determine the hydrogen ion concentration or determine the boiling point elevation and a purine or amino acid is added to it, complex formation takes place and stable compounds are produced which do not undergo nitrification, and that is why the decomposition of nitrogenous compounds is slowed for the benefit of crops. The phosphate plus organic nitrogenous compound amino acids or proteins form stable compounds, which nitrify slowly and nitrification loss is checked. The nitrogen loss on adding nitrogenous compounds to land is checked by phosphates.

WAKSMAN

When you put into the soil the straw and the slag, suppose you plant the crop right away, what would happen to the crop?

DHAR

Not right away, but in six weeks or two months' time in our country we get a good result due to nitrogen fixation and increased crop growth.

WAKSMAN

Two months time?

DHAR

Sometimes six weeks time.

WAKSMAN

What happens in these six weeks or two months time?

DHAR

There is enough oxidation and fixation of nitrogen. In every experiment we determine the carbon and the total nitrogen, ammoniacal nitrogen, nitric nitrogen after 15 days, after 20 days, after a month, and so on for six months.

WAKSMAN

Is it not possible to give a totally different explanation from what you are presenting. For instance, when you put into the soil straw or molasses, the bacteria and fungi and actinomycetes that decompose the straw or the molasses use up the nitrogen that might be lost otherwise; they fix it in their bodies and then after a certain period of time especially under proper conditions of aeration and temperature these microbial cells will decompose and liberate the nitrogen as ammonia which the plants will now be using. I am speaking of the total population of fungi and other soil microorganisms.

DHAR

The Azotobacter and total bacteria we have counted and their increase is good, but the total nitrogen increase is very much greater in light than in dark, although the Azotobacter and total bacteria are greater in the dark than in light.

WAKSMAN

Personally, I do not agree with you; I do not accept your explanation because the processes involved are more complex. You know there was a time notably during the early part of this century, when it was believed that plant proteins do not decompose readily. The reasons for that belief were that when you put straw into the soil, a certain amount of protein is synthesized and the nitrogen is not liberated, but it was found later that the reason for this is that the nitrogen is picked up immediately by the fungi in the rest of the population that decompose the cellulose and the hemicelluloses and use that nitrogen for their body structure. Gradually as the carbon/nitrogen ratio is narrowed down the nitrogen will become liberated through the decomposition processes and that is why you have to wait six weeks under tropical and semi-tropical conditions before this takes place.

DHAR

No, that does not explain the point of view I stated. As I say, after 15 days and later on we estimate the total nitrogen of the system that includes the bacteria cell nitrogen. We carry on these experiments for two to three years estimating the total nitrogen, ammoniacal nitrogen after the addition of the carbohydrate. We find that the total nitrogen of the system increases up to 200% specially when phosphated, and this increase is due to the fixation of nitrogen.

WAKSMAN

Has any experimental laboratory confirmed your results?

DHAR

Write to Herr G. BJÄLFVE of Uppsala. He has published his results supporting us in Sweden and he has given the data of the increase of nitrogen with straw and phosphate. He holds the view that even in Swedish conditions photochemical nitrogen fixation is more important than legume fixation.

WAKSMAN

Why do you need fixed nitrogen, then? Why do you need factories for producing fixed nitrogen?

DHAR

It is exactly what I do not want. I fix tons and tons of nitrogen in all countries by my method; you can also do this and we have established the science of this method of nitrogen increase. It is science, it is not one man's property. Others have tested it. You can do it yourself if you carry out proper experiments.

BRADFIELD

I would like Prof. DHAR to tell us how widely this process is being used in India at the present time.

DHAR

Well, Prof. BRADFIELD, you have been in our country, you know it. I am here to convince you gentlemen that if our processes are adopted by Europeans they will be adopted in India. You know this perfectly well, so I have been moving about to have it accepted by Europe and as a matter of fact I have to give great credit to my countrymen. GHANDI totally accepted this idea and he insisted that this method must be adopted in India and the shortage of food would be met. He wrote this two years before he was killed, and of course Mr. NEHRU also tried, but we lack proper education and hence the progress is slow.

CHAMINADE

Il y a en région tropicale — et mon collègue et ami le Prof. DHAR le sait mieux que moi — de très nombreux sols dont l'état actuel de fertilité est extrêmement bas, quasi nul. Le problème est donc de donner à ces sols une fertilité. Ces sols sont caractérisés en particulier dans quatrevingt-dix pour cent des cas — et peut-être davantage — par une carence très marquée en phosphore. Est-ce que le Prof. DHAR pense que la correction des carences en phosphore non pas seulement par des scories mais également par les phosphates naturels dont il y a des ressources en région tropicale, en Afrique en particulier — est susceptible d'amener par les mécanismes que vous indiquez à un niveau suffisant la teneur en azote du sol pour que ces sols deviennent des sols suffisamment productifs?

DHAR

It is quite possible. I am in touch with your Inter-African Bureau of Soils. They have tried straw plus phosphate and where there is no basic slag I am using rock phosphate. Phosphate has been acknowledged by agriculturists all over the world to be the bottleneck of cultivation. In many American publications we have read that phosphates increase fertility. Phosphate is of vital importance, there is no doubt. Whatever form of phosphate, it has been found to be useful for hundreds of years. Similarly, rock phosphate is very good. But superphosphate is no good for the oxidation of straw because it is acidic, it does not help oxidation unless lime is also added. The oxidation process of the cellulose must be facilitated by alkaline medium. So if you can put in neutral phosphate or Thomas phosphate, even rock phosphate or bone, the fertility of tropical land increases enormously.

HENIN

Dans votre expérience vous employez essentiellement de la paille de riz, mais il y a bien des cas où, au moment où l'on retourne un champs, par exemple couvert d'herbe, ou qui possède une réserve de matière organique, un simple apport de phosphate, doit donner le même résultat.

DHAR

You are quite right. You have humus rich acid soils in your country, and if you add basic slag to the humus, you get nitrogen fixation and improvement of crop production. In Kashmir there is peat rich in organic matter and I have applied basic slag and straw, ploughed it and got a good crop. All organic matter, even finely powdered coal we have tried, mixed with basic slag can fix nitrogen and fertility is increased. American magnates have written to me that they are anxious to utilize our discovery.

SWABY

I wonder how much light penetrates an opaque material like soil to catalyse some of your reactions. I have never actually taken a selenium cell or a photo cell and put in into soil to see how much light gets through, but I imagine it would not penetrate more than a few millimeters. This means that you have to put your straw in the first few millimeters of soils to get this reaction that you speak of, if light plays an important part in its catalysis. You don't normally put straw into the first few millimeters of soil, you put it deeper than this, therefore, a lot of your straw is presumably wasted. Have you any thoughts on how you might better utilise the straw?

DHAR

This question was asked thirty years ago in a lecture I gave in the London University. Prof. PANETH, the great physical chemist, asked me the same question. As you know when you plough the land, you break the particles and in all cultivation, especially in our country, we plough the land two or three times so the soil is broken and a fair amount of increase of porosity is produced and light can penetrate. And there is not the slightest doubt that by cultivation, the land is opened; it becomes porous; it becomes more available to oxygen, and light can penetrate.

ALEXANDER

Approximately 25 years ago, the use of ^{15}N for demonstrating nitrogen fixation was proposed, and the method has now been used in many investigations. Is there any instance where ^{15}N-labeled N_2 has been used and has it been shown under natural conditions that such labeled N_2 is fixed into soil as a result of the photochemical fixation of nitrogen.

DHAR

We have taken up lately this isotopic work with ^{15}N and ^{14}C to convince modern men, and some people in Stockholm are also trying to test this with isotopic nitrogen.

Prof. JENNY who has analysed soils in all parts of the world, yesterday assured us that soils in Tropics are richer in nitrogen than in non tropical Asia. This supports our photochemical theory of nitrogen fixation.

Discussion closed for the morning.

HUMUS OF THE MAIN SOIL TYPES AND SOIL FERTILITY

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The importance of soil organic matter is determined by its active participation in weathering and soil formation, as well as by its manyfold influence on chemical and physical properties and fertility of the soil.

Being in conjunction with pedology, agronomy, microbiology, plant physiology, chemistry and biochemistry and other sciences, the problem of soil organic matter attracts more and more attention of scientists using various methods in their investigations.

However, even the many-sided and deep study of separate questions in this problem, must not overshadow its main principles, among which the process of organic matter transformation under different natural conditions is one of the most important.

Being very complex, this process, as a whole, includes a series of more private processes which may be regarded as two opposite links: accumulation of organic residues and strictly humus substances and their decomposition with the formation of intermediate organic compounds and the products of complete mineralization.

Both links of the process occupy the most important position in the total turnover of substances in nature, the necessary cause and effect of life on the earth.

In this paper we aim to elucidate the peculiarities of organic matter accumulation and decomposition in soils which are formed under various natural conditions. Let us begin from the sources of the soil organic matter.

1. THE SOURCES OF SOIL ORGANIC MATTER

The main sources of the soil organic matter are the plant residues, the amount of which varies under different plant associations. Data characterizing the total biomass (airial mass and roots) and the annual litterfall are given in Table 1; the data are taken from the works of L.E. RODIN and N.I. BAZILEVICH (1964, 1965).

Assuming that the coefficient of plant residue humification is about 0,3 (HENIN et DUPUIS, 1945; KONONOVA, 1966) we have calculated the possible amount of humus which could be formed at the expense of the annual litterfall.

The comparison of the quantities of newly-formed humus substances with the total humus reserves in the 1 m. soil layer under appropriate plant associations allows to suppose that a period of about 1-2 hundreds of years is necessary for the accumulation of humus reserves, provided all humus substances are kept in the soil. It is known, however, that the new formation of the humus substances is accompanied by their decomposition. A much longer period is therefore necessary for the accumulation of humus reserves.

This period may be more precisely defined by the radiocarbon method to determine the age of organic matter. PAUL, CAMPBELL et al. (1964) found that when the content of organic matter in a grey forest soil is 3,36%, its age is 360±60 years and in chernozem-like soils on lacustrine-glacial deposits the content of organic matter of 9,65 and 10,10% corresponds to the age of 990±60 and 1130±70 years respectively; these values are approximately four or five times as much as the

TABLE I — *Biomass amounts, annual litterfall and possible formation of humus substances at the expense of the latter.*

Main vegetation types / Indexes	Arctic tundra	Taiga spruce forests	Oak-groves	Moderately arid steppes	Arid steppes	Low bush semideserts	Arid Savannah	Subtropical forests	Humid tropical forests
Total biomass T/ha .	5,0	100-300	400	25	10	4,3	26,8	410	500
Annual litterfall (of aerial mass and root) T/ha	1,0	3,5-5,5	6,2	11,2	4,2	1,2	7,2	21	25
Possible humus substance formation on expence of the litterfall T/ha	0,3	1,05-1,65	1,95	3,36	1,26	0,36	2,16	6,3	7,5
Humus resources in 0-100 cm. layer T/ha	73	99	215	426	116	62	—	282	—

calculated by us data (1-2 hundred years) for the analogous soils (gray forest soils with 3-4% of humus under oak groves and chernozems under moderately arid steppes with 9-10% of humus). It may be supposed, therefore, that the most part of the newly formed humus substances (up to 80%) decompose with the formation of intermediate decomposition products and the products of complete mineralization; many of the latter (containing N, P_2O_5, K_2O, S and others) plays an important role in plant nutrition. The lesser part of the newly-formed humus substances (about 1/3) are kept in soil, forming humus reserves whose amount and nature are determined by the soil forming conditions.

2. THE NATURE OF HUMUS IN THE MAIN SOIL TYPES

Geographical regularities of humus formation are one of the important parts in the problem of soil organic matter. This question was raised by V.V. DOKUCHAEV in his classic work *Russian Chernozem* (1883). Isohumus bands of the equal humus content in the upper soil layer were plotted by him on a chernozem zone soil map of the European part of Russia. It followed from the distribution of bands that maximum humus content occurred in central parts of the chernozem zone, gradually diminishing to the north-towards podzolic soils and to the south-towards dry steppe and semidesert soils.

DUKUCHAEV explained this character of humus distribution by the influence of bioclimatic factors; the accumulation of humus in chernozems is due to the development of perennial grass-heteroherbaceous vegetation and climatic conditions favouring a moderate decomposition of plant residues. The role of climate in humus formation was discussed in HILGARD's works (1893). He indicated that soils of arid regions were low in humus but their humus was rich in nitrogen; soils of humid regions were high in humus, but their humus contained a low percentage of nitrogen.

But already in those years at the junction of two centuries, the question arose about the existence of a more complex dependence of the humus state on soil forming conditions. We want to remind of P.A. KOSTYCHEV's objections (1886) directed against V.V. DOKUCHAEV. KOSTYCHEV stated that humus content in the soil depended not only on vegetation and climate, but also on other factors: topography, soil texture and, especially, on parent material.

Later on, the comparative results obtained by many research workers in studying humus of different soils, gave rise to a conclusion that the state of soil organic matter is determined by many factors: plant cover, micro-organisms and animals activity, climate, physical and chemical soil properties and parent material.

Such a trend of investigations was and is developed by several prominent pedologists and their followers: MUSIEROWICZ (Poland), CERNESCU (Rumania), ALBAREDA (Spain), KUBIENA (G.F.R), EHWALD (G.D.R), DUCHAUFOUR et DOMMERGUES (France), KANNO, KAWAGUCHI and KYUMA (Japan), JENNY (USA) and others.

In the USSR a great initiative in carrying out investigations, characterizing geographical principles of humus formation, belonged to I.V. TYURIN. The materials obtained by him (they entered the post humously edited collection of his works in 1965), supplemented by many Soviet pedologists at present, allow to trace regular differences in humus and nitrogen contents, in the C:N ratio, in humus composition and in the nature of humus substances for the main soils of the USSR. Some data of these materials are presented in Table 2. They characterize humus of soils of the following natural zones of the European part of the USSR: tundra; taiga-forest, broad-leaved forest; forest-steppe and steppe; dry steppe and semi-desert. Besides, data on soil humus of moist subtropical forest

TABLE 2 — *Natural zones, soils, humus types (in the upper rich in humus layer).*

Zone	Vegetation	Soil	Humus type			
			Humus, % in soil	Hum. ac. to ful. ac. ratio	Mobile (1) forms of hum. ac.	E_4/E_6 hum. ac.
Taiga-forest northern part of the zone	Coniferous species with moss and lichen cover	Strongly podzolized	2,5-3,0	0,6	100	5,5-5,0
Taiga-forest southern part of the zone	Coniferous and deciduous species with heteroherbaceous cover and mosses on the soil surface	Sod-podzolic	3-4	0,8	100	5-4,5
Broad-leaved forest	Broad-leaved (oak) forests	Grey forest	4-6	1,0	20-30	4,5-4
Forest steppe	Grass-heteroherbaceous-steppe	Thick chernozems	9-10	1,7	20-15	4-3,5
Steppe	Heteroherbaceous grass steppe	Ordinary chernozems	7-8	2-2,5	10-15	3,5
Dry-steppe southern subzone	Artemisia-stips-festuca sulcata	Light chestnut	1,5-2,0	1,2-1,5	10	4-3,5
Semidesert	Graminae-artemisia semidesert	Brown semidesert	1-1,2	0,5-0,7	10	4,5
Moist subtropical forest	Broad-leaved subtropical forests	Krasnozems	4-6 and above	0,7-0,9	90-100	5,0
Tropical forest	Tropical forests	Ferrallitic soils	4	0,3-0,4	100	5, 0

(1) % of their total amount.

(USSR and China) and forest tropical (North Vietnam) zones are given.

For humus characteristics we have used the following data:

1) humus percentage in soils;

2) the content of the main groups of humus substances-humic -and fulvic acids, extracted from soil with 0,1 *n* NaOH after pretreatment with a weak H_2SO_4 (« decalcification »), the $\frac{\text{hum. ac.}}{\text{fulv. ac.}}$ ratio has been calculated;

3) the quantity of the humic acids extracted by treatment with 0,1 *n* NaOH without « decalcification »; this quantity characterizes the mobile part of humic acids (free and probably combined with mobile hydrates of R_2O_3);

4) optical density of humic acids, which has been determined in a spectrophotometer with the wave length 665 and 465 mμ (the so called E_4/E_6 ratio). This ratio characterizes the degree of humic acids aromatic ring condensation. These methods and results of the study are described in the author's book (KONONOVA, 1966).

Comparative data characterizing the soil humus are given in Table 2. It is possible to summarize them into three types.

The first type of humus is characteristic of podzolic, krasnozem and ferrallitic soils, developing on original acid rocks under forest vegetation. Excessive precipitation, percolative soil moisture regime and acid reaction retain the formation of humus substances at the initial stage — the fulvic acids; the $\frac{\text{hum ac.}}{\text{fulv. ac.}}$ ratio is less than 1.

Humic acids occur in soils either in a free state or (presumably) are combined with mobile hydrates of R_2O_3; they have a slightly condensed ring (this is evidenced by the broad E_4/E_6-ratio) and approach the fulvic acids by their properties.

The humus substances of this soil group as a whole take an active part in the weathering process, and readily form complex compounds with R_2O_3. This is especially well expressed in podzolic soils, where R_2O_3 are present in the form of hydroxides and under the defense of organic substances they move within the soil profile favouring the development of podzol forming process. Absence of a clearly expressed podzolic process in ferrallitic soils is not clear to pedologists up to the present.

The presence of R_2O_3 in crystalline forms, which impede their reaction with organic substances and their movement in the soil profile in the form of complex compounds, may be regarded as one of the possible reasons.

The second type of humus is characteristic of chernozems and dark-chestnut soils. The development of these soils takes place under the grass-heteroherbacens steppe vegetation with deeply penetrating, finely branched root systems. A moderate character of water and temperature regimes, the neutral reaction of the soil, the sufficiently intensive biological activity — all these conditions favour the formation of a thick rich in humus layer. The formation of humus substances occurs with the formation of humic acids. The $\frac{\text{hum. ac.}}{\text{fulv. ac.}}$ ratio is more than one. The humic acids are tightly combined with the mineral part of the soil; only 20-10% of the total humic acid content can be extracted by a single treatment of the soil with 0,1 *n* NaOH without preliminary decalcification. A condensed aromatic ring is a characteristic feature of these humic acids: the E_4/E_6 ratio is 4-3,5. All above stated features determine slight mobility and inertness of the humus of chernozems.

The third type of humus is characteristic of brown semidesert soils, developing under sparse Gramineal-Artemisia semidesert vegetation. A scanty admission of organic residues into soil from the poor vegetation cover, the lack of moisture in the soil during high temperature periods — decrease the intensity of biological activity. As a result the soils of this zone are low in humus. The higher content of fulvic acids in the humus composition ($\frac{\text{hum. ac.}}{\text{fulv. ac.}} < 1$) is explained by the inhibition of humic acid formation. The humic acids have a less condensed (than in chernozems) aromatic ring. At the same time humic acids are tightly combined with the mineral part of the soil (like in chernozems) and are extracted by the 0,1 *n* NaOH only after acid pretreatment. The formation of humus substances is accompanied by neutralization due to the presence in these soils of large amounts of Ca (and Mg), this being the reason of their weak effect on the mineral part of the soil.

The humus of grey forest and light chestnut soils occupies an intermediate position; of the former between the soddy-podzolic soils and chernozems, of the latter the humus approaches that of the brown semidesert soils.

The data stated above characterise the geographical features in humus formation due the zonal position of soils. But at the same time in many cases a departure from geographical factors is observed. For example, the soils of microdepressions of dry regions are usually richer in humus than the adjacent soils, located under smooth upland conditions. This is explained by better development of vegetation and a more favourable for humification water regime in microdepressions.

Parent material exerts a great influence on humus formation. There are known some instances when the development of podzolic soils on a near to the surface occuring carbonaceous moraine is accompanied by intensive humus accumulation with a growing content of humic acids. However, these changes occur mostly only in upper soil horizons and the humus as a whole keeps features characteristic of the given soil type humus. (Similar examples are stated in the book by KONONOVA, 1966).

Interesting examples of departures in the humus type are also found among tropical soils. Comparative data are given in Table 3 for a typical ferrallitic soil on basaltic weathering products and for a ferrallite-margalitic soil developing on volcanic ashes and tuffs. (North Vietnam, see V.M. FRIDLAND, 1964). The latter soil is higher in humus content; humic acid content is higher than that of fulvic acids and the $\frac{\text{hum. ac.}}{\text{ful. ac.}}$ ratio is more than one. The humic acids have a more condensed aromatic ring; the E_4/E_6 ratio is 3,4-3,5.

Apparently these differences in the humus of ferrallite-margalitic soils, as compared with ferrallitic soils, may be explained by a less acid soil reaction, which is due to the neutralizing action of alkaline weathering products of ashes and tuffs. But these peculiar features are chiefly found in the upper soil horizons like in the sod-carbonate soils.

Similar peculiarities have been stated for the humus of black tropical soils and moist subtropical zones in Asia, Africa (I.P. GERASIMOV, 1959). A high fraction content (with predominance of montmorillonite minerals), base saturation and, subsequently, a neutral reaction of the soil are characteristic of the black soils. Possibly moisture relationships also play an important role in the black soil humus formation. Irrespective of a high precipitation in tropical and moist subtropical zones the black soils are insufficiently moist due to a low permeability. A prolonged droughty period is also a most important feature of the climate of this zone, where the black soils are distributed.

The conditions mentioned above (the neutral reaction, the alternative moistening and drying of the soil, the abundance of clay minerals) promote the formation of a humic acid with a fairly condensed aromatic ring, distinct from humic acids of typical tropical soils. Data characterizing the humus of the black tropical soils (« regurs », India) are given in Table 3.

TABLE 3 — *The influence of soil-forming rocks on humus content and composition of some forest tropical soils.*

Soil and depth, cm. / Indices	Ferrallitic soil (Northern Vietnam)		Ferrallite-margalitic soil (Northern Vietnam)			Black tropical « regurs » (India)		
	0-5	5-18	0-13	13-25	25-40	0-10	10-20	150-160
Humus, % in soil	3,22	2,83	5,72	4,92	2,07	1,08	0,80	0,38
C-hum. ac., % of total C in soil	4,30	4,9	28,4	22,1	4,5	23,8	31,8	—
Hum. ac. (mobile forms) - % of their total amount	100	100	100	100	100	—	—	—
C-ful. ac., % of the total C in soil	21,8	21,9	16,6	19,5	24,6	23,8	29,8	27,3
$\frac{\text{Hum. ac.}}{\text{Ful. ac.}}$ ratio	0,20	0,22	1,70	1,13	0,18	1,0	1,17	—
E_4/E_6 of hum. ac.	5,0	6,3	3,5	3,4	5,0	4,8	4,4	—

Interesting data, coinciding with our materials, on the humus of the black clayey magnesian tropical soils under sparse savannah vegetation in Southern Senegal (Africa) are presented by DUCHAUFOUR and DOMMERGUES (1963). The authors consider that the principal reason of such a peculiar character of the humus is the alternative moistening and drying of the soil under savannah, favouring the condensation and polymerization of humic acids. Analogous are the S.V. ZONN's (1964) statements on the results of studying the main types of soil formation in mountain tropical areas of the South-Eastern Asia.

The BACHELIER's experimental work (1963) concerning the influence of the alternative moistening and drying on the humic acid polymerization, the SINGH's works (1954, 1956) on the catalitically acting montmorillonite surface in the blacksoils of India, completely correspond to the cited above views.

The materials characterizing the peculiarity of humus in ferrallite-margalitic and black tropical soils are of great interest as an example when physico-chemical properties and parent material distort zonal features of humus formation, determined by bioclimatic conditions.

Hence, with the undoubtable correctness of the V.V. DOKUCHAEV'S principle on the geographical principles of humus formation according to natural zones, no less true is the P.A. KOSTYCHEV's statement about the great importance, besides bioclimatic, of the other conditions of soil formation, particularly, of the parent material.

3. THE DECOMPOSITION OF ORGANIC MATTER IN DIFFERENT SOILS AND ITS IMPORTANCE IN NITROGEN SUPPLY OF PLANTS

The data on nitrogen resources in the organic part of the USSR soils are illustrated in Fig. 1. Maximum humus nitrogen content occurs in chernozems where it amounts to 7-10 t/ha in the 0-20 cm. layer, and 35 t/ha in the 1 meter layer. These

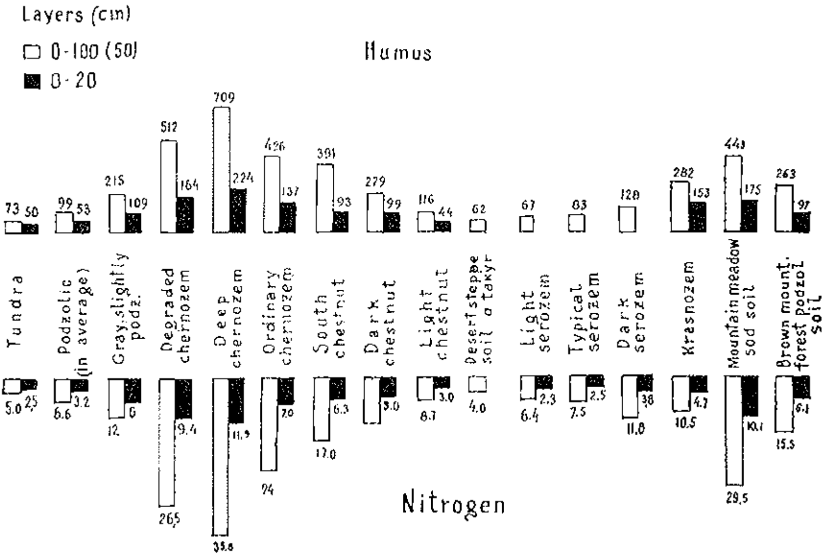

FIG. 1 — Humus and nitrogen reserves in the USSR soils (t/ha).

values gradually decrease both towards podzolic and dry steppe soils and become minimum in the brown semidesert soils and in light serozems (2-3 t/ha in the 0-20 cm. layer, 4-6 t/ha in the 1 m. layer).

The role of soil nitrogen in the supply of crops with nitrogen is confirmed by the following data. According to the approximate calculations by COLAR and GREENLAND (1963), the annual uptake of nitrogen by agricultural plants of the earth is about 100-110 million tons. But the world chemical industry produces only 14,5 million tons of nitrogen as fertilizers, which are unevenly distributed among the countries: the largest amounts of mineral nitrogen have the countries with small territories and dense population, the least — the countries with large territories. So, the amount of mineral fertilizer nitrogen (in Kg per 1 ha of tillage soil) was as follows in different countries in 1966 (¹).

Japan	Holland	GFR	Great Britain	France	USA	USSR
112	128	54	39,3	21,5	7,0	3,6

It is well known, that for the building of one centner (=100 kg) of grain, the plant as a whole requires about 3 kg of nitrogen (D.N. PRYANISHNIKOW, 1945); therefore in Japan and Holland the applied fertilizers can provide for high crop yields of 35-40 centner/ha. In G.F.R., France and Great Britain the applied fertilizers essentially improve nitrogen supply of plants. Insufficient is the application of fertilizers in such countries as the USA and USSR.

It follows from the data given above that with few exceptions (Japan, Holland) nitrogen supply is accomplished either partly (France, G.F.R., Great Britain) or mainly (USA, USSR) on the expense of soil nitrogen mobilization. Therefore, the decomposition of humus with the formation of mineral nitrogen assimilable by plants play a very important role in the total balance of this element in agriculture.

Experimental data show, that the process of mineralization occurs with different intensity in different soils, depending not only on humus reserves, but also on the intensity of microbiological activity. Let us take as an example the USSR data illustrating the intensity of humus decomposition in new-

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(¹) The figures are taken from the paper by E.N. MISHUSTIN and A.V. PETERBURGSKY, *Biological nitrogen in agriculture*. Collection of papers « Biological nitrogen and its role in agriculture », Izd. Nauka, 1967.

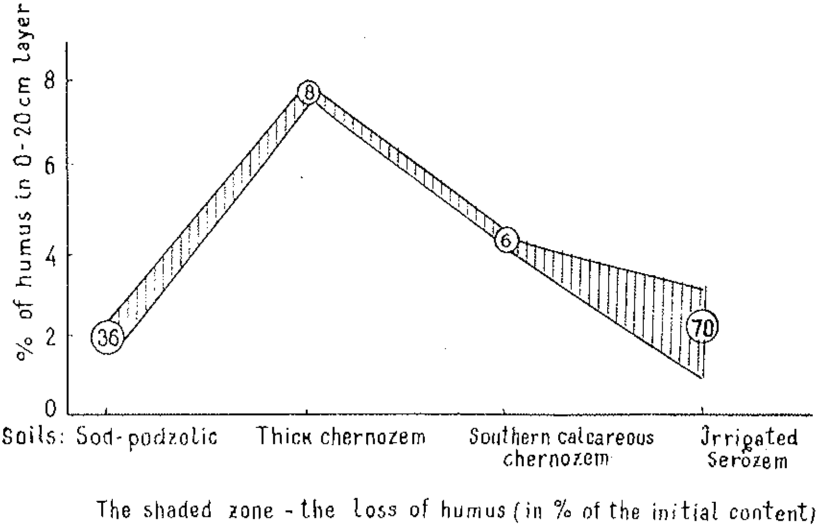

FIG. 2 — Decomposition of humus in ploughing-up the virgin soils for 12-13 years.

ploughed up virgin soils under various cultures without application of organic and mineral fertilizers during 12-13 years (Fig. 2).

During this period 70% of the initial humus decomposed in the irrigated Middle Asian serozem under cotton (that is under hydrothermal conditions favourable for microbiological activity) and about 40% of the initial humus content decomposed under small grain crops on a sod-podzolic soil of the central belt of the European part of the USSR (where under favourable moisture conditions, temperature becomes factor limiting biological activity).

Humus decomposition has a different character under small grain crops on chernozems and chestnut soils with moderate and particularly with insufficient moistening of the European part of the USSR and Kazakstan. During the same period (12-13 years) humus losses were here only 6-8% of the initial content. The intensive humus decomposition without replenishment of its reserves (by application of organic fertilizers and grass cultivation) is one of the main reasons of soil exhaustion. The return of nutritive elements (nitrogen, phosphorus and others) with plant residues, due to the activity of the free-living nitrogen-fixing micro-organisms and with precipitation does not compensate completely for their uptake with crop yields. This follows from the approximate nitrogen balance worked out by us for the small grain crops (Table 4). Its annual deficit reaches several kg/ha even when optimum values of nitrogen are in the income part of the balance.

TABLE 4 — *Approximate nitrogen balance under small grain crops.*

Uptake of nitrogen kg/ha by plant with grain yield 20-25 centner-ha.	Nitrogen entrance into soil, kg/ha				
	with seeds	with root and stubble residues	at the expence of free-living nitrogen fixing bacteria activity	with precipitations	Total
50-60	3	20	10	4	37

The negative action of the growing nutrient element deficit from year to year is especially soon perceptible on poor in humus soils (sod-podzolic, serozems), where the crop yields are low and do not satisfy the needs of population. The crop yields increase on the same soils after the application of mineral and organic fertilizers (Table 5).

TABLE 5 — *Mean crop yields (centner/ha) on old arable soils with and without fertilization.*

Fertilization	Timiryazev Agricultural Academy, sod-podzolic soil. Continuous winter rye, 1912-1960	Ak-Kavak Experimental Station, typical serozem. Continuous cotton, 1928-1953
Control . . .	7,3	15,6
NPK	12,2	29,9
Farm manure	—	25,3

Grass cultivation is of great importance on sod-podzolic soils and as well as on serozems. The perennial legume herbs (lucerne, clover) when well developed increase the content of nitrogen by 100-200 kg/ha in these soils, this being one of the reasons of the crop yield increments after the herbs.

The problem is solved quite differently on chernozems; here due to large humus reserves and the moderate rate of its decomposition it is possible to obtain sufficiently high yields of small grain crops (up to 20 centner/ha), provided the precipitation is sufficient to supply the plants with moisture (A.V. SOKOLOV et al., 1963). However, supplementary application of fertilizer nitrogen is necessary for higher crop yields on chernozems.

We finish our paper with the following statement. The soil is a « dépôt » of wealth, but its resources are not inexhaustible. The most important task of the farm people is, therefore, a rational utilization of these resources and the care for their conservation and restoration.

The carrying out of this task will meet the interests of the whole humanity.

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III

MATIERE ORGANIQUE ET PROPRIETES PHYSIQUES

THE EFFECT OF ORGANIC MATTER ON SOIL STRUCTURE

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The soil is the medium for plant growth. It provides the environment for the development and functioning of the plant's root system. Not only must the soil furnish the nutrients required for the metabolic processes involved in the growth of the plant but it must also provide favorable air-water regimes for the proper functioning of the plant. In too many instances, the nutrient uptake from the soil is limited by a lack or excess of water, a lack of sufficient oxygen or inadequate root proliferation due to high bulk densities that impede the growth of roots. In other words, poor soil structure becomes the limiting factor rather than the nutrient element status of the soil. One can say, therefore, that soil structure is a parameter of soil fertility.

Soil structure refers to the arrangement of primary and secondary particles into a certain structural pattern. The secondary particles are the aggregates within the soil. They may consist of primary particles that are bound together to form a granule or aggregate. Larger aggregates may consist of a group of smaller ones. The structural arrangement may consist of chiefly secondary particles, chiefly primary particles or a mixture of secondary and primary particles in which there tends to be a single-grained arrangement within the secondary units.

The extent of aggregation is related to the climate under which the soil has been formed. This is clearly shown in Figure 1. It is observed that the extent to which the silt and clay fractions are aggregated increases with rainfall from a minimum of about 15% in the desert soils to a maximum of about 50% in the chernozems or humid prairies. Then there is a decrease to approximately 25% in the podsol soils. This increase reflects an augmentation of the clay and organic matter content of the soil as a result of the higher rainfall. The decrease from the maximum coincides with eluviation of colloidal particles and the lower amount of organic matter in the surface layers of podsols as there is a change from grass to forest vegetation.

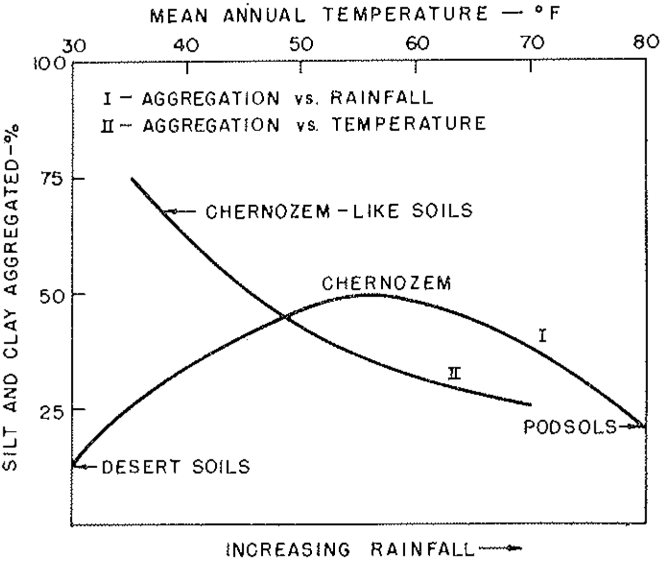

FIG. 1 — The effect of climate on soil aggregation

The decrease in aggregation with increasing temperature in the semi-arid, chernozem-like soils is a measure of the declining organic matter content of the soil. These curves indicate a rather close relationship between organic matter and aggregation. Experimental evidence has shown that both the percentage of clay as well as organic matter are correlated with aggregation. At high organic matter contents, the impact of clay is not so important. Organic matter seems to have its greatest effect on soils low in clay [3]. These interactions of clay and organic matter result in the formation of clay-organic complexes. GREENLAND [13] has reviewed the results of various investigators which showed that from 51.6 to 97.8% of the total soil carbon was in the form of these complexes.

Aggregation is only one criterion for characterizing soil structure. The pore space relations within a soil as related to the arrangement of particles are another important means of depicting structure, especially for their impact upon soil-air-water. One is interested not so much on the total porosity as in the distribution of the size of the pores, especially the larger ones that are known as the aeration porosity (sometimes called non-capillary porosity). These larger pores increase with soil aggregation and with the size of the aggregates. This relationship is well illustrated by the data of AGAPOV and MORGUNOV [1] in Figure 2. Non-capillary porosities below 10% are restrictive to adequate aeration. The optimum aeration is between 20 and 30%, corresponding to aggregates 2-3 mm in diameter.

What are the biological implications of structural changes in soils? The major impact of soil structure is associated with compaction, aeration and root development. As the percentage of organic matter decreases in a given soil, the bulk density increases with a significant decrease in aeration porosity. The combination of increased density and decreased aeration restricts root development, impairs normal absorption by the roots and impedes microbiological activity. Under these cir-

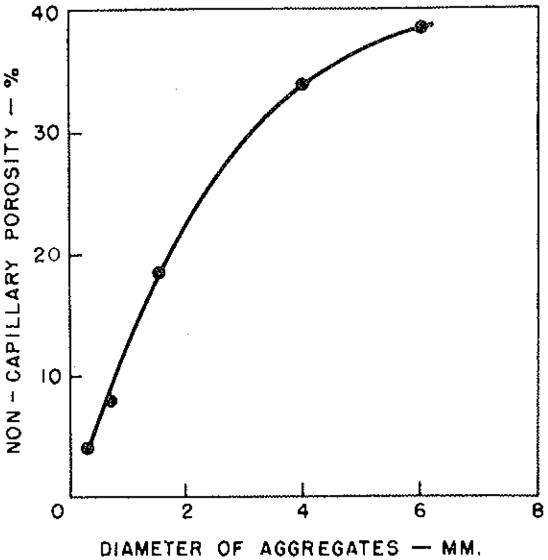

FIG. 2 — The relation of aeration porosity to aggregate size (after AGAPOV and MORGUNOV [1])

cumstances, the physical condition of the soil becomes limiting to plant growth rather than nutritional deficiencies. This is well illustrated in Figure 3, which shows the relation of beet yields to soil aeration on a heavy clay soil that had received differential organic treatments [4]. It is seen that yields increased rapidly as the percentage of aeration enlarged. A maximum was reached above 10% aeration porosity. The curve indicates that factors other than aeration became limiting above this percentage. The well-aerated plots showed nitrogen deficiencies. The percentage decrease in the loss in stand of young beets followed a similar pattern, with only small losses occurring at aeration porosities below 10%. This is an excellent example of the need to consider soil structure as a dominant factor in many soils that affects soil fertility.

There is a deterioration of soil structure when forest or grassland soils are cultivated to intertilled crops. Numerous researchers have shown that there is a corresponding decrease in soil aggregation as the organic matter disappears. There can be little doubt that this is a cause and effect relationship. Oxidation of organic matter with hydrogen peroxide produces the same decrease in the stability of the aggregates. Cultivation not only exposes the accumulated organic matter to greater microbial activity but also removes 1) the source of annual accretions to the organic matter cycles of the soil and 2) the structure-forming activities of earthworms that are always found in abundance in grassland sods. The loss of organic matter and subsequent decrease in aggregate stability occurs at a more rapid rate immediately following the beginning of

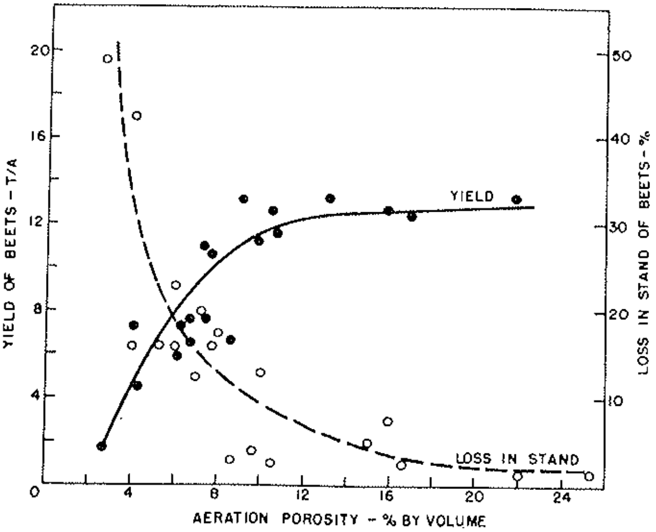

FIG. 3 — The relation of aeration porosity to growth of sugar beets

the cultivation period. This is clearly shown by the data of MARSHALL [18] in Figure 4. The curves depicting decreasing aggregation with time have similar slopes to that of diminishing organic matter content. Approximately 50% of the decreases over a 20-year period took place during the first year of cultivation.

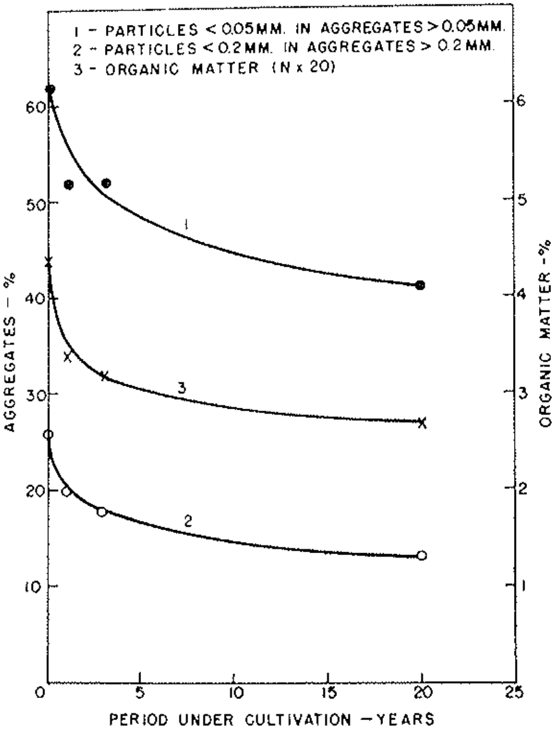

FIG. 4 — Effect of period of cultivation on soil aggregation (after MARSHALL [18])

The restoration of stable aggregation is a slow process and many years are necessary to bring about good stable granulation. Such restoration should rely on grass crops. Low [17] observed that it took 100 years of grass for the percentage of soil particles smaller than 2 mm that are aggregated into granules layer than 2 mm to increase from 12% in the cultivated soil to 73% under grass. He linked the improvement under grass with earthworm activities as well as with root effects. GREACEN [11] studied the relationship of aggregation with depth under virgin grassland, cultivated and different ages of pasture. His results are shown in Figure 5. There are

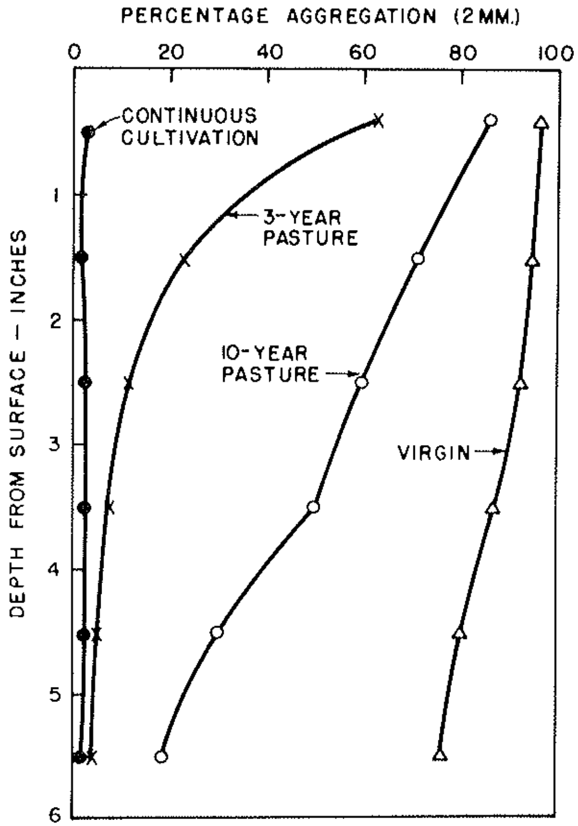

FIG. 5 — Soil structure profiles (after GREACEN [11])

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several points of significance in these graphs. The virgin sod shows 80 to 100% aggregation from the surface to six inches in depth. Continuous cultivation reduced aggregation to about 2½% at the same depths. Three years of pasture increased aggregation considerably in the upper two inches of soil, with the major effect being in the first inch. This is in the area of the concentration of roots. The soil under 10 years of pasture showed improved aggregation at all depths with the first inch closely approaching the stability of structure of the virgin area. These curves indicate that the root effects of grasses become deeper with the age of the sod as the root systems proliferate.

How does organic matter increase the stability of soil aggregation and porosity? Before this can be answered one needs to visualize what takes place when organic materials are added to the soil. This incorporation brings into the picture the activities of the soil microorganisms, fungi, bacteria, actinomycetes, yeasts. Organic material itself without biological transformation has little, if any, effect upon soil structure. Microorganisms without organic materials as sources of energy are ineffective in producing soil aggregation. Intense microbial activity takes place after the incorporation of organic materials to the soil. There is a large increase in the population of microorganisms. Fungi and actinomycetes produce mycelia. The metabolic processes of the microorganisms synthesize complex organic molecules. Decomposition products of the breakdown of organic materials are left in the soil. The sum total of these effects is the production of stable soil aggregates. This stability, therefore, can result from: 1) the mechanical binding action of the cells and filaments of the organisms, 2) the cementation effects of the products of microbial synthesis, or 3) the stabilizing action of the products of decomposition, acting individually or in combination.

Much research has been done to evaluate the aggregating effects of various soil microorganisms, studied both in pure and mixed cultures. Practically all of these investigations showed that the stabilization of aggregation depended upon the type of organism, the species within a given type, and the presence of 1) a source of energy and 2) available nitrogen for microbial metabolism. The results of several investigators are summarized in Table. 1. Fungi are ranked first in their stabilizing effects although MARTIN [19] found a strain of Bacillus subtilus that was equal to his best fungus, Cladosporium. WATSON and STOJANOVIC [28] also observed that certain gum-producing bacteria were equal to the fungi used for stabilizing aggregates, both being superior to the actinomycetes. The fungi and actinomycetes cause a mechanical binding of the aggregates by the mycelia that they produce. They also produce products that have a stabilizing influence. The bacteria produce gums that have a cementation action. MARTIN [19] estimated that about 50% of the stabilizing effect of fungi was due to mechanical binding and 50% to products of synthesis or decomposition. About 80% of the stabilizing influence of the bacteria was attributed to products of metabolism and only 20% to the cell bodies. SWABY [26] observed that the stabilizing effect of fungi on aggregation was directly related to the length of the mycelia. The impact of fungi and actinomycetes on soil aggregation is temporary and disappears as a result of bacterial decomposition of the mycelia. HARRIS et al. [15] found that stabilization of aggregates by a fungus only occurred in the presence of sucrose as an energy source even though there was little difference in fungal numbers between the sucrose-treated and non-sucrose soils. Fungi stabilized the larger aggregates but this did not occur until there was mycelia growth of the fungus. At early stages of incubation bacteria were more important than fungi in the initial stabilization of small aggregates. Under anaerobic conditions, bacteria produced aggregates that were stable for a longer period time than under an aerobic state. Fungi were not operative under anaerobic conditions and could not stabilize the structure. Moreover, since the anaerobic bacteria could not use the microbial products of sucrose metabolism as a source of energy, the cementation action of these products were not subject to microbial attack. They concluded that aggregate stabilization was more a function of microbial synthesis of soil-cementing agents than the physical presence of bacteria or fungi in the soil. It seems, therefore, that the products of microbial metabolism are the major cause for stabilizing soil aggregates except for the mechanical binding effects of fungi mycelia in the early stages of organic matter decomposition.

Table I — *The ranking of types of microorganisms with respect to the stabilization of soil aggregates.*

			Bacteria		
	Fungi	Actinomycetes	gum-producing	other	Yeasts
Peele and Beale [24]	I	—	2		—
Martin [19]	I	—	I	2	—
McCalla [20]	I	2	3	5	4
Swaby [26]	I	2	2	3	3
Müller [23]	I	—	2		—
Watson and Stojanovic [28]	I	2	I	3	—

What is the nature of the products of microbial synthesis? Numerous investigators have attributed the major role of soil aggregate stabilization to the cementation action of polysaccharides. (See Greenland [13] for a review). The polysaccharide theory is based upon several scientific observations.

1. When polysaccharides are added to the soil, there is an increase in the amount and stability of the aggregates.

2. There are many organisms in the soil that produce polysaccharides during the process of metabolizing energy sources.

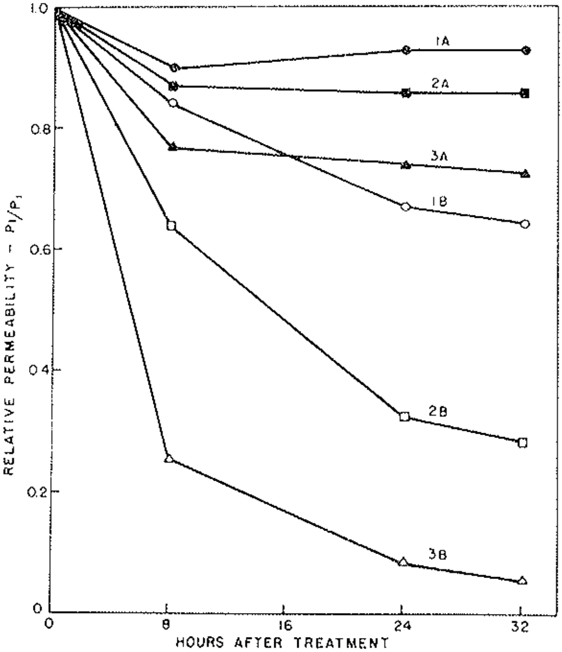
3. Polysaccharides can be extracted from soils. Estimates have been made to indicate that 5 to 20% of the soil organic matter consists of plant or microbial polysaccharides.

4. There is a statistical correlation between aggregation and the polysaccharide content of the soil.

5. When polysaccharides are removed from soil by chemical treatment, there is a decrease in aggregation.

These polysaccharides are a mixture of large, linear, flexible polymers. They have large numbers of OH groups in the chain. They vary in their content of amino, carboxyl, phenolic or other groups. They are subject to decomposition by bacterial action inasmuch as they can be used as a source of energy. This fact is well substantiated by the data of HARRIS and his associates [14] who observed that the addition of nitrogen to soils treated with polysaccharides and incubated reduced the stable aggregation after 20 weeks from 92% (no N added) to 35%. They can be considered as transitory products in the organic matter cycle dependent upon the ecological conditions that favor active microbial activity. The impact of polysaccharides on the stability of soil aggregation can be evaluated by chemical treatment with sodium periodate.

GEENLAND, LINDSTROM and QUIRK [12] investigated the effect of destroying the polysaccharides in soils on the stability of aggregates. They used a modified technique of DETTMAN and EMERSON [7] in which the original permeability (P_i) was measured with Na-saturated aggregates using 0.05 N NaCl. The change in permeability of the control ($NaCl + Na_2B_4O_7$) and the periodate treated soils ($NaIO_4 + Na_2B_4O_7$) at various times (P_t) was determined. The investigation compared plots with different rotational histories. The curves shown in Figure 6 present the results for 2-yr., 4-yr. and permanent pasture plots. It is seen that there was a slight decrease in stability of aggregation by treatment with sodium borate (Curves 1A, 2A, 3A). This decrease was the highest with the 2-yr. pasture. The large decreases in stability occurred with the periodate treatments, especially with the soils not under per-



A = After treatment with 0.02 N $NaCl + 0.2$ N $Na_2B_4O_7$
B = After treatment with 0.02 N $NaIO_4 + 0.2$ N $Na_2B_4O_7$
1 = Permanent pasture
2 = After 4 yrs. pasture in WWPPPP rotation
3 = After 2 yrs. pasture in WPPF rotation
(W = wheat; P = pasture; F = fallow)

FIG. 6 Changes in relative permeability of soils with time (after GREENLAND, LINDSTROM and QUIRK [12]).

manent pasture. In the rotation with only two years of pasture the stability of the aggregates was reduced by over 90% after 24-32 hours of leaching (Curves 3A, 3B). The aggregates from soils under continuous wheat were completely destroyed by periodate treatment after 8 hours of leaching. On the other hand, the stability of the aggregates from the permanent pasture was only reduced about 30% by the periodate treatment. The data indicate that whereas polysaccharides appeared to be the major cementation agents in cultivated soils other factors were contributing to the stability of the aggregates in old grasslands. MEHTA and his coworkers [21] could not destroy the aggregate stability of a brown earth forest soil with periodate which indicated that polysaccharides were not the stabilizing medium. The stability was destroyed, however, by oxidation with chlorine dioxide (CIO_2) which does not oxidize polysaccharides but does lignin and humic compounds. Stability also deteriorated upon soaking 7 days with sodium pyrophosphate, Na-EDTA and NaOH followed by wet sieving in water or by treating with N HF which caused partial destruction of the crystal. CLAPP and EMERSON [6] also observed that periodate treatment of Minnesota grassland crumbs did not destroy the stability of the aggregates. They reasoned that the organic polymers were probably coordinated with polyvalent cations and the edges of the clay crystals. Pretreatment with sodium pyrophosphate prior to periodate oxidation caused a destruction of the aggregates. Thus, the majority of the evidence confirms that polysaccharides contribute a major role in the stabilization of soil aggregates under a wide variety of conditions. However, there are situations such as forest soils and long-established grasslands where the stabilizing agent is not as transitory but more stable than polysaccharides.

Humic acids, which are fairly stable products of biological decomposition of organic materials, are generally extracted from soils with NaOH and precipitated with HCl. They are a mixture of high-molecular-weight polymers containing amino acid and phenolic groups. Electron micrographs by FLAIG and BEUTELSPACHER [9] have shown them to be spherical in shape.

SWABY [25] separated α-humic acid from the soil and found it superior to all other humic fractions in soil aggregation. Fulvic acid, that part of the extracted humus not precipitated by acid, had a poor binding action. The addition of $CaCl_2$ or HCl improved the structure due to greater fixation of α-humate within the aggregates. Microscopic examination showed that the humus was either present as films around the macroaggregates or as particles of precipitated humus. The humate film had to be spread over the soil before fixing with electrolytes in order to obtain cementing action. He postulated the possibility of polar bonding between the NH_2, COOH, and OH groups of the humus with negatively-charged clay. He treated the soil with different chemicals to obtain information on the nature of the groups on the organic colloids that are active in aggregate stabilization. Acid or alkaline hydrolysis destroyed the cementing substances in the organic materials suggesting that colloidal proteins or polysaccharides were important in the formation of aggregates.

Ether extraction had no effect, thereby eliminating gums, fats and waxes as active agents. Esterification had only a slight effect, indicating that the COOH groups of proteins or polyuronides were of only small importance in polar bonding. Deamination reduced aggregation, again suggesting the binding action of proteins or aminopolysaccharides. Acetylation lowered the cementation effects, indicating that phenolic or alcoholic OH groups were important. Oxidation decreased cementation, suggesting that lignin-like colloidal substances were important in aggregation. As a result of these chemical treatments, SWABY concluded that amino-polyuronides, polysaccharides, proteins and lignin-like colloidal material all have cementation action. There is the possibility that fats, resins and waxes may arrest slaking by making the aggregates waterproof and therefore increase their stability. However, it is the cementation action of the above-mentioned complex organic compounds that are of major importance.

What are the mechanism involved in the formation of the clay-organic complexes that are responsible for soil structure. In the organic matter phase, it has been shown that one is concerned with high molecular weight polymers of varying composition and shape. The polysaccharides, polyuronides, etc. consist of mixtures of linear, flexible polymers. Humic acid is a mixture of spherical polymers. In the clay mineral portion there are two main types that will be considered. One consists of clay minerals with mica-type lattices in which two silica sheets are held together by an alumina sheet. In this group there are minerals, such as the montmorillonite, that have expanding lattices. Then there are the illites in which the lattice does not expand. As a result of isomorphous substitutions in the Al and Si sheets, the surfaces have negative charges which are neutralized by exchangeable cations. There is a large surface area, particularly with the montmorillonites that have both external and internal surfaces. Another type of clay mineral is kaolinite that has one silica and one alumina sheet. The alumina sheet may not have a charge. There is a low cation exchange capacity. The broken bonds at the edges of the crystal become positively charged under acid conditions. In the case of the polysaccharides, there is strong adsorption on the surfaces of the mica-type lattice clays. With the expanding-lattice montmorillonites there is adsorption both on the external and internal surfaces. Those adsorbed on internal surfaces form inter-lamellar complexes. Polysaccharides with carboxyl groups do not form inter-lamellar complexes. They are absorbed on the edges of the clay crystals. This is particularly true with kaolinite-type clay minerals. The energy with which these large, linear and flexible molecules are adsorbed to the surface depends upon their flexibility which determines the number of points of contact that it can make with the surfaces. Van der Waals forces play an important role in the adsorption process. They become more significant as dehydration brings the surfaces close together. There can be a H-bond linkage between the polymer and the oxygen atoms of the crystal. This means that the adsorbed polymer replaces water on the surface of the clay mineral. The surfaces are now covered with hydrocarbon chains and are most difficult to rewet. Polymers can be coordinated with exchangeable cations to give similar effects. CLAY and EMERSON [6] suggested that the stable aggregation of Minnesota soils was due to two kinds of polymers. One was coordinated with exchangeable cations and the other was H-bonded.

Humic acids are not adsorbed by clay minerals through processes of physical adsorption. They are negatively charged and should be repelled by negativly charged surfaces and attracted to positively-charged sites. They do not form inter-lamellar complexes with expanding-lattice type clays. There is evidence to suggest that they are adsorbed on positively-charged sites. BEUTELSPACHER [5] observed in the electron micrographs that they were adsorbed only on the edges of kaolinite, which are positive. They can be coordinated with exchangeable divalent and trivalent cations, in which these cations become bridges between the clay surfaces and the humic acid (See GREENLAND [13]). BEUTELSPACHER [5] concluded that humic acid is not adsorbed on montmorillonite unless the surface has been activated by aluminum or iron oxides, which serve as bridges between the clay and the humus. FLAIG [10] and SWABY [25] have suggested that Ca and Fe cause the humic acid to be precipitated on the surfaces of the clay. Dehydration then causes the film to be more or less fixed on the surface. Several Russian investigators have emphasized the importance of iron-humus interactions in the formation of stable granulation (2, 8, 16, 27). TIULIN [27] has divided aggregates into two groups depending upon their being associated with divalent or trivalent cations. Hydrated iron oxide is considered to be a major factor in the binding action of humus to clay particles.

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In summarizing the mechanisms by which organic colloids stabilize soil structure, one can say that they change the properties of colloidal clay surfaces with respect to their interaction with water. They compete with water molecules for space on the surfaces, reduce wetting and swelling and increase the strength of the aggregate through cementation effects.

The cause of the stabilization of soil structure by organic matter with time can be fairly well summarized by the curves developed by MONNIER [22], as shown in Figure 7. The peak of the curve represents the aggregation brought about by the microbial bodies in the soil. The major impact during this period of intense biological activity apparently is a mechanical binding action by the mycelia of fungi and actinomycetes and to some extent to bacterial cells. This type of aggregate stability is only temporary since the mycelia and cells undergo

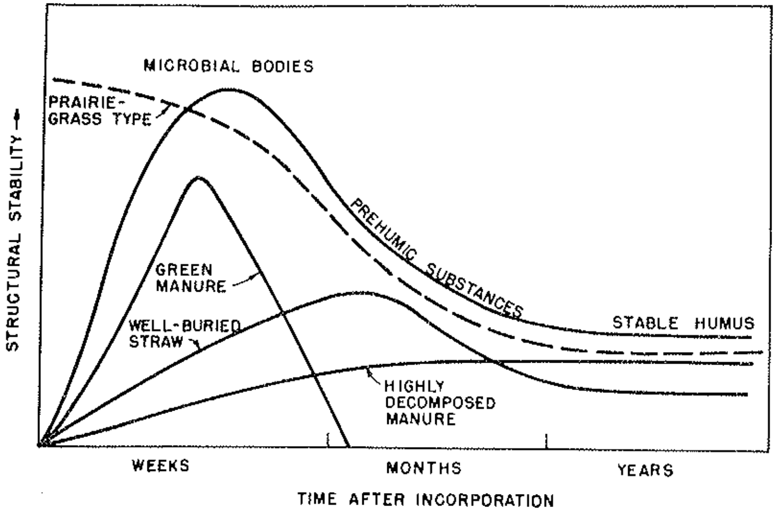

FIG. 7 — Stabilization of soil structure by organic matter (after MONNIER, 22)

bacterial decomposition as the intensity of the biological action declines. Stabilization of structure then enters the phase where the transitory products of microbial synthesis are responsible for aggregate stability. The specific activity of these organic substances in stabilizing structure is less but the aggregates formed are more resistant to further deterioration. These so-called prehumic substances are the polysaccharides and similar compounds which are subject to slow biological transformation. There is a decreased rate of decomposition which corresponds to a more durable effect on aggregate stability.

The final stage in the stabilization of structure is visualized as being dependent upon the stable humus that is formed. Stability is long lasting even though the intensity of aggregate formation is not as high as in the other stages.

It should be noted that green manure, which is readily decomposable and has a low C/N, showed a sharp peak during the intense action during its fermentation, but dropped to zero in a relatively short time. Undoubtedly, fungal mycelia played a dominant role during the early stages of decomposition. The well-buried straw did not undergo intense biological fermentation probably because of a higher C/C and a lower fungal activity. The highly-decomposed manure had already been subjected to biological activity and did not show an intensity peak. Stability of aggregation appears to be a function of the humic compounds produced.

The root effect of the prairie-type grass produced a high stability of structure before the sod was incorporated in the soil. There was no flush of biological activity. Stabilization of the aggregates formed resulted from the transitory products of microbial metabolism and the final stable humus that was produced.

The production of a stable soil structure has many practical aspects in the development of agricultural lands for crop production. In this era of population explosion and inadequate food production in the developing countries, tropical soils play a most critical role. It is difficult to maintain the proper organic matter cycle in these soils because of climatic and ecological conditions. One of the major problems yet to be solved is how to maintain a favorable soil structure under conditions of a food-producing agriculture. In other words, the parameter of soil structure is an unknown quantity in soil fertility of the tropics.

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DISCUSSION

Chairman: S. HENIN

HENIN

I appreciate very much the honour to lead the discussions this afternoon. Every minute I am more and more grateful to Prof. ALBAREDA who had the idea of this meeting which gives us the possibility in very comfortable conditions to discuss the many problems we are concerned with. I thank also the Papal Academy of Science for its kind invitation, the people in charge of the organization of this meeting, Prof. TAMAYO and Prof. HERNANDO, who have very kindly tried to satisfy all our wishes.

Now we will start the discussion of the two papers we have to listen to today, which are very important. Prof. BAVER, the well known soil physicist, presented a very exaustive view of our knowledge about the stability of the structure. I am sure that is one of the direct ways by which organic matter can act on the productivity of our soil.

PRIMAVESI

We have had the same experiences. Your paper is very interesting for us in Brazil, showing the same results and conclusions as our investigations.

FLAIG

I am very interested in your paper and I would like to ask you something. Some time ago we investigated also the excrements of earthworms, and found that this is a very stable aggregate, in which are some linear colloids. I would like to ask you how far the stabilisation of the aggregate depends upon the amount of earthworms in the soil?

Furthermore, I would like to mention that we made some investigations with polybasic acids and found at first an aggregation, then in high concentrations a dispersion and then again an aggregation. What is your experience in this case?

BAVER

Firstly, with respect to earthworms, I left them out of the paper purposely because of the time limit. The earthworm is a very important aspect of this whole structure situation. Though I have no data of my own I saw some data, including yours, on the impact of the casts of the earthworm, both inside and outside the earthworm, on aggregation. I have never seen such a brilliant example of the impact of the earthworm activity on the mixing of organic matter in soils as under sugar cane mulch in Hawaii. My personal opinion is that this is one phase of soil structure work that we soil physicists must give more attention to. In regard to your statement, I bave no experience at all and cannot answer it.

DHAR

Normally, humus is a negatively charged colloid, which can be aggregated by calcium ions. I wonder what experience you have in this matter.

Baver

If you take an extract of a humus and saturate some with hydrogen and some with calcium, you will find that the colloidal properties of the hydrogen humate and the calcium humate are almost identical; not in the presence of calcium salts, however. As soon as you add calcium salts, of course, you get flocculation. Apparently, with respect to the stability of structure, you have a different situation taking place in which the divalent calcium can coordinate with the humus in such a way that it becomes a bridge between the organic molecule and the clay particle. That is what Dr. Walter Russell suggested quite a few years ago to explain soil structure effects. There is no question that since humus is negatively charged it should be repelled by the soil. It has to be tied to the soil through an ion that is adsorbed by the soil. It cannot be tied through an ion that only has one valence and still be adsorbed by the soil.

Franz

I think we have to distinguish two different types of structure. One type is the structure of elements which is produced by shrinking of soil colloides, and the other is the structure with crumbs which are produced partly from colloidal organic matter and partly by biological processes. I think the aggregates you studied are firstly crumbs, is that not so?

Baver

I am referring here entirely to the organic matter effects on aggregation. You are exactly right Dr. Franz, because the clay particles themselves have a tremendous impact upon the formation structure, as Dr. Henin here can testify. This is another aspect of the situation that I did not want to bring into a short paper such as this.

FRANZ

I would like to remark that the production of crumbs is a process which must be distinguished between two different processes. One is the formation of relatively little primary aggregates which are formed by the flocculation of the colloids and the formation of aggregates by organic substances like linear colloids. The other is the formation of secondary aggregates which are much bigger. They are formed by biological processes like the fixation of aggregates by roots, mycelium etc. It is well known that the porosity of the soil depends to a large extent on the formation of these secondary aggregates. Prof. FLAIG spoke about the importance of earthworms on the formation of aggregates and that the number of earthworms in the soil is very important for this process. But not only the number of earthworms is important, also the composition of the population of species, because the different species of earthworms have a very different activity. There are some species which live on the surface and only work in the uppermost part of the soil and there are others which burrow very intensively and go into the deeper part of the soil, for instance Allolobophora caliginosa, which was introduced from Europe to Australia and New Zealand and is much more effective than the Australian worms. This earthworm makes many more aggregates than the Australian worm. So we cannot speak generally of the importance of a high population of earthworms for the soil. The imporance of the population depends to a high degree on their composition of species.

BAVER

I agree with everything you have said. You are exactly right with respect to your last statement concerning the species of earthworms, I also ran across that in the literature and it was quite striking.

[10] *Baver* - pag. 26

Swaby

I would like to emphasize what Prof. Franz has said because in New Zealand, earthworms from Europe were introduced only around some of the cities on imported plants, but in the country areas they did not spread very much and they had to be put there. When introduced in the pastures they made a tremendous difference. These earthworms fed and cast the faecal remains on the top of the soil and helped greatly to improve the structure of these pastures. While I am speaking I would like to take up another point. I am very well aware of the more stable types of structure you get when you use a film of a humate to glue particles of soil into crumbs, since I think that this is the really desirable structure that we want in many soils. It is difficult to say how to get this, because the only way I know how to get a colloidal humate really mobile to coat soil particles is to form either a sodium or a lithium type of humate. One wonders how you could ever get a lithium humate in the soil, but I think there are mechanisms whereby you could get a sodium humate, because in the gut of many animals that live in the soil, particularly some worms, there is a sodium bicarbonate phase of their digestion and I think as they ingest a great deal of soil as well as the organic matter that they get their energy from, that it is during this phase of digestion, particularly in the gizzard, that you get sodium humates formed and these smear out over the surface of the soil particles. When they are voided as cast material they probably then are in a fairly fluid form and there is no great stability, but as they react with calcium ions in the soil and dry, I think they then become very stable films. I wondered whether Prof. Baver had any ideas as to whether any other ions could be used in the soil to peptise humates and get them coating soil particles.

BAVER

The only experience I have had in this area has been a study of pure colloidal humus systems, in which we found that the magnesium humate behaved similarly to the sodium humate, as far as dispersity and its ability to hydrolyze in the soil was concerned. As a matter of fact, it occurred to us in Missouri at that particular time, that perhaps the reason for the formation of magnesium solonetz might be due to the fact that the magnesium humate is so much more mobile than the calcium humate. Besides the lithium and the sodium ions, magnesium is the only one that may favour dispersion. I would be a little scared about its dispersive effect on the basis of its divalency because then it could act as a bridge and might not function similarly as you would expect it in a purely colloidal suspension.

BRADFIELD

I have been interested in soil structure in the humid temperate region for most of my life, in how to develop it and how to maintain it. For the last few years I have been in the rice belt area where farmers bend every effort to destroy soil structure. My early ideas have had to be re-examined. In preparing a soil for planting rice, the custom in most of the rice belt of Asia, is first to flood it with water, let it soak for 2 or 3 days then plough it while it is wet. After it has soaked in water a little longer after ploughing, it is harrowed repeatedly to break down the structure as thoroughly as possible. After it has been thoroughly harrowed the rice plants are transplanted into the deflocculated mud and they grow there the rest of their life cycle. Now how does the rice plant grow in this deflocculated medium? Its roots require oxygen the same as other plants but it is provided with a different type of mechanism. The oxygen reaches the roots through channels in the rice plant itself. In this anaerobic soil we find a zone around the rice roots where oxygen is excreted and where the ferrous iron in solution in the mass of the puddled soil is flocculated by oxidation to the ferric form. The Chinese farmer has learned to take advantage of this situation. After the rice is harvested, this puddled soil, if it is heavy clay, will become very hard. It will develop cracks an inch or so wide and you will have a soil very hard on the surface when water is lost by surface evaporation and within four inches of the surface the soils will still be in a semi-fluid condition, always wet enough that you can make it into a ball because of the low water conductivity. Many Chinese farmers discovered, however, that if soy-beans were planted into the clump of the rice stubble they find a medium in which they can make a fair growth, if they are put between the clumps they will not make a satisfactory growth. I am sure that part of this effect is due to the iron oxides which have been formed around the rice roots, because iron even if introduced into pure bentonite will completely change its physical properties. I know of no treatment which will alter the physical properties of pure bentonite more than the introduction of ferrous iron between the plates and then precipitating it there with an alkaline solution. This effect is very important in soils which undergo periodic flood. The other interesting fact is that if this highly puddled soil is dryed out thoroughly — and I mean thoroughly — and this takes a long period, usually it does not occur until one or two months after the dry period has started and at relatively high temperatures; then if it is slacked down by thorough wetting, we get a beautiful structure and a structure which can be maintained through a period of cropping that lasts until we reach the rice crop again in the rotation. So this matter of soil structure which I used to think of as primarily engendered and protected by soil organic matter can be produced satisfactorily by other mechanisms.

BAVER

I would like to testify to two things that Dr. BRADFIELD has said. We grew rice in the alluvial soils along the Missouri river on a very heavy gumbo clay. The soil was not puddled before the production of rice but the thing that impressed me was that under these flooded conditions the soil was well aggregated in the vicinity of the root system of the rice plant. In respect to the iron situation, one of most spectacular experiences I have had has been observing flood fallowing in Guyana, in which they plough the soil and cover it with water. The anaerobic conditions reduce the iron. When they take off the water and the iron is oxidised, you get the most wonderful structure you ever saw.

JENNY

In California, the humid region begins at 30-40 inches with extensive forests. Up to 80 inches, as far as can be estimated, there is not much further increase in organic matter production in the forest. This is corroborated by the calculation of the actual evapotranspiration which measures in a way the potential production of organic matter. Yet, in the soil the organic matter content keeps on increasing with increasing rainfall. Some years ago we speculated on explaining these diverse trends and, as one partial explanation, concluded that with increasing rainfall the clays become more acid and therefore have more exchangeable aluminium on their surfaces and hence may fix increasing quantities of organic matter, a thought that is along the lines of what you have been saying.

BAVER

I am very interested in yonr comment, Dr. JENNY and I think you are right. I remember when I wrote my thesis for Dr. BRAD-

FIELD we found that the hydrogen system had as good a structure as the calcium system. Of course, that wasn't what the book said. I am of the opinion that the structure of the hydrogen system, in the light of new ideas on hydrogen clays, is that we have aluminium in the system. In the presence of a large amount of aluminium we could have aggregation as a result of the organic colloid being tied up with clay through the aluminium. In Hawaii, for example, we have 10% organic matter in the hydrol-humic latosols. I will have to agree with you on the basis of more recent observations rather than the comments we have made in the past.

CULTURE TECHNIQUES FROM THE STANDPOINT OF CONSERVATION AND IMPLEMENTATION OF ORGANIC MATTER IN THE SOIL, IN THE LIGHT OF MODERN RESEARCH

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The present trend of progressive industrialization of agriculture, essentially governed by immediate social and economic ends, results as a rule in an over-simplification of human action in respect of the vegetative substratum; such action becomes pared down to a standardized series of mechanical or chemical culture techniques, supposed to be useful for the plants cultivated, as if the soil were an inert support without any biological function of its own in the complex phenomenon of crops development. And so there is no difficulty in neglecting the relevant knowledge acquired by modern science, which in fact is itself indirectly responsible for the said mechanistic attitude, inasmuch as it tends as a rule to consider the organic world as wholly reducible to physical and chemical laws, although of a somewhat special nature (1). The practical conse-

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(1) In this connection, the observation of J.S. HALDANE, which we willingly report, is significant: « The fact that crude data of biology appear as physical and chemical data, has led to the widespread misunderstanding that biology can be nothing more than physical and chemical science, and to the still more widespread misunderstanding that, however mysterious a phenomenon of life may be, the only profitable way of investigating it is

quence of this is a growing undervaluation of what is the distinctive and fundamental characteristic of fertile soil (that is to say soil suitable for the vegetation of the higher plants, as against a «sterile » mineral detritus); a characteristic expressed by the presence of organic matter, indeed of variously humified organic matter. The presumed possibility of ignoring the existence of this characteristic hinges on the conviction that every requirement of plant life can be satisfied with artificial physical (mechanical) and chemical means.

It is not superfluous to specify that in reality things stand very differently, and this in order to clarify, in what sense and from what particular standpoints culture techniques today seem capable of correction or improvement in the interests of better regulating the metabolism of the humus in the soil, thereby enhancing the socalled agronomical or integral fertility. As is known, by this term is meant the complex of specific properties of the soil in highest degree encouraging its habitability in respect of the principal agrarian cultures, although of course appropriate distinctions have obviously to be made for certain aspects of the said properties, when reference is made to the main requirements of, in the first place, the more highly differentiated large groups of cultures (for example, arboreous and herbaceous plants), and then of the minor homogeneous groups (such as cereals, root-plants, herbages) and, finally, of the single species cultivated. This does not alter the fact that — apart from rare exceptions — the properties of fertile soils satisfy most cultures, and comprise: a determined settling-down of the soil particles, such as permits a favourable circulation of

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by assuming provisionally that it can be interpreted physically and chemically. This way, however, leads to no intelligible results, and mechanistic physiology is not only extraordinarily barren, but fails completely as a practical working creed, if we regard it as physiology, and not as mere bio-physics or bio-chemistry. It is only through specifically biological interpretation that biology can make progress as a science. The progress of abstract bio-physics or bio-chemistry does not represent that of biology ».

air and water, and a correlated action on the hypogeal thermal equilibrium; a sufficient concentration of nutritive elements; an availability — still inadequately defined — of substances of hormonal nature that affect the vegetative luxuriance of the plants and which derive, at least in part, from the activity of the soil micro-organisms; and the list could go on — since there is no doubt, that a multiplicity of factors, presumably only in part known, concur in producing integral fertility, such as pH value, optimum ionic ratios, the various categories of colloids, etc.

Now, the organic matter in the soil plays a polyvalent part and to a greater or lesser extent affects all the previously mentioned properties; so much is this so, that ever since the remotest antiquity, and that is to say several thousands of years ago, farmers had empirically discovered its « fertilizing » function and had enriched its content in the soil by means of dung and green manures, or also by simply allowing the soil to lie fallow. In fact, as regards the physical properties of the substratum, and especially the state of aggregation, there are by now clear the nexuses existing between the water stable glomerular structure (correctly held to be the best for herbaceous crops in general) and the humus endowment of the soil, although it has been found that only the group of humic acids exerts a lasting stabilizing action, while the fulvic acids are liable to a more rapid metaholism — which nevertheless also satisfies certain needs of the plants. On the other hand, it is in equal measure known that these products of secondary synthesis are for the most part due to the activity of heterotrophic micro-organisms living on the organic residues of the higher plants; it also seems likely — if not definitely ascertained — that the humic acids responsible for the stability of the structure are in the main elaborated by anaerobic bacteria (for example the ulmic or hematomelanic acids): as will be more fully stated later, this makes it necessary for culture techniques to concern themselves not only with the direct requirements of the plants cultivated, but to an equal extent with those of the micro-organic flora of the vegetative substratum.

As to the differentiated effects of organic matter — decomposed by various types of microbic flora — in respect of structurality, certain significant indications have been gained from pluriennial trials carried out under our control on sods of various forage species, in comparison with bare tilled soil: in both the classes of variants considered, the organic matter content grows over time to like extent, and is noticeably increased in the presence of mineral manures; but only in the case of forage cultures or of spontaneous grass cover does the humus produced secure an appreciable improvement of structurality, to the point of doubling the fraction of the aggregates > 4 mm and reducing to a third the leached fraction (<0.25 mm); in the tilled soil, on the contrary, the structurality tends distinctly to worsen over time. In the first case, in fact, it is the anaerobic micro-organisms that take part in the humfication, while in the second the increase of organic matter is almost entirely due to the aerobic microbic flora, favoured by the tilling. On the other hand, to increase the aggregation, the organic matter of the higher vegetables contributes even by direct inference, particularly through the mechanical pressure exerted by the roots, as can be deduced from the fact that in certain variants with forage species, in our trials, there was found a rather slight increase of humus, but a conspicuous increase of structurai aggregates, at the expense of the finest particles.

It seems excessive to dwell here on the nutritional chemical function of organic matter, since this has for a long time and with greater insistence been made clear, even if at the present time — with the possibility of using artificial fertilizers — it does not appear unconditionally the most important and the least easy to substitute of the properties of the organic matter itself. However, it is as well to recall that besides being a conspicuous source of nitrogen (¹), the organic matter introduces into the surface sheets of the soil all the nutritive elements available in the deeper sheets explored by the adult roots, including the micro-elements that can only with difficulty be introduced and dosed into common fertilizers, concentrating them in proportions close to optimum in the rhizo-sphere of the new plants in germination; so that — if the epigeic vegetation (and sometimes the roots themselves) were not removed with the harvests — the balance of mineral nutrients in the substratum would tend continuously to show a growing amount of assimilable substances, always provided it were not baulked by preponderant erosive processes. But a peculiar feature of the nutritive function under consideration, and one particularly worthy of note, is the participation of the organic matter, especially when decomposed, in the respiratory activity of the soil, as a result of which the micro-climate close to the soil becomes enriched in CO_2 — essential not only for better germination, but for the very life of the plants — and considered for both the limiting factor in the present era of our planet (O. VERONA). According to C. ANTONIANI and Coll., it is the fulvic acids that most greatly contribute to the generation of CO_2, inasmuch as they are the most decomposed humic substances, or those most given to transformations of a destructive kind, although the humic acids or other organic colloids are not therefore excluded from the « respiratory » process.

These colloids, besides having a nutritive function in the

(¹) Recent research by DELL'AGNOLA, MAGGIONI and FERRARI on the extract with NaF of humus fractionated with gel-filtration has, however, brought to light humus fractions not containing (soluble) N and having a molecular weight comprised between 4000 and 9000; the soluble nitrogen would appear to be prevalently contained in the fractions with lower molecular weight, and these would seem to correspond to the fulvic acids, whereas the humic acids (in which also the presence of nitrogen is constant) would appear to have a lower N-mobility degree, despite the qualitative affinity of the proteic fractions in the two classes of acids (C. PETRONICI, M.M. KONONOVA and J.W. ALEKSANDROVA).

previously mentioned direct ways, also indirectly contribute to nutrition, by regulating — thanks to their high absorbant power — the circulation of free nutritive elements which are sometimes (as in mineral fertilizers) present in excessive amounts, particularly in the neighbourhood of the tender shoots, and by then gradually yielding them to the plants during the vegetation; for the same reasons the humic acid increases the resistance of the plants to the acid reaction of the substratum (A. PETERBURGSKIJ). There remains less explored the hormonic and auxophytic function of the organic matter in the soil, to which — with good grounds — it seems necessary to attribute a significance of prime importance, since it creates in the substratum quite a specific environment, due to the development itself of vegetal life inside the inorganic world, and conditions this development in its successive stages (R. BLANCHET). The function in question is performed through biogenous organic compounds, which evidently exert a stimulant action on plant growth, similar to that of the so-called hormones; these compounds include aminoacids, polyphenols, micromolecular organic acids and other humic substances, as also the microbiological decomposition products of lignin; sometimes — as in the case of humic acid and of potassium humate — they are able to exceed the effect of the auxin (W. FLAIG, G. FREITAG, M. KONONOVA, J. RZEZABEK). This effect, as far as sodium humate is concerned, results in increase of the respiratory activity of the plant, as well as in the physico-chemical absorption of root- and micro-organic toxic excretions, the accumulation of which in the soil would slow up and perhaps prevent the vital processes (M. SCHMIDOVA, S. GUMINSKIJ). The respiratory activity of the roots (as also the percentage of sugar in the shoots) of rye is increased by substances having quinonic function (thymohydroquinone), which, in the bean, accelerate the production of dry matter by decreasing the proportional absorption of water (W. FLAIG). On the other hand the humates increase respiration and chlorophyll concentration (in *Begonia sempervirens*), while root development (in the tomato is increased above all by humic acid, whereas fulvic acid to a greater extent favours the height and weight of the epigeic part (SLADKIJ and TICHY). The presence of humates exerts a rhizogenetic action, connected with the absorption of N, both in herbaceous plants (NIKLEWSKI, CHAMINADE, BLANCHET) and in arboreous species (WILDE), and, in particular in respect of poplars and eucalyptus seed-beds, humic acid increases the weight and height of the part exposed to the air, as well as the content of mineral substance and N in the foliage, and of organic matter in the roots (GIULIMONDI). The humic and hematomelanic acids, by increasing the hydration of the living plasma, slow up plasmolysis, while the fulvic acids decrease the viscosity of the protoplasm and increase its mobility (V. RIPACEK); they also increase the number and size of the root cells (¹), whereas the humic and hematomelanic acids preferably influence the growth of the parenchymatic tissues; in any case, however, the action of all the previously mentioned acids is clearly differentiated according to the species cultivated, upon which it is exerted (Z. SLADKIJ).

It appears to be incontestable that the biogenous compounds mentioned above originate, even if only in part, from secondary syntheses actuated by heterotrophic micro-organisms, if to the latter there has to be attributed as a rule the formation itself of the humus. In this light aquires all its value the biological function of organic matter, as a substratum necessary for the reciprocally useful symbiosis between the higher and lower

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(¹) The stimulant action on the growth of the roots caused by the acids of the humus is confirmed by the findings of L.A. KHRISTEVA; this Author notes also that these acids exert on the physico-chemical state of the protoplasm an effect favourable to the absorption of nutritive substances, which fact could be correlated with the previously mentioned increase of hydration of the plasma, due precisely to the aforesaid acids, as well as to improvement of the fermentative mechanisms of the cells (increase of amylase), and to activation of the supply of O_2, especially in the early stages of life.

vegetal organisms, not neglecting the contribution made to such symbiosis by numerous soil representatives of the animal kingdom. And perhaps it is not out of place to think of a truly genetic function of the organic matter in the soil, and this not only in that form, in which every environment, however characterized, affects the natural selection and thus the evolution of living beings: indeed, even without wishing in this connection to accept the theses — which are nonetheless not without suggestiveness — of the neo-Lamarckians (P. WINTREBERT), the fact remains that not a few organic compounds have shown, that they are capable of acting directly on the hereditary genic structure (such as colchicine, ethylene immine, ethyl methansulphonate, etc.), and it would be entirely arbitrary to consider, that such compounds and other similar ones, as yet not determined, could not be found in the soil during some stage of the metabolism of the original organic matter. Indeed, a critical and experimental examination of the question (which here cannot obviously be gone into thoroughly) could probably lead to the perception of a certain correlation between the existence of the said compounds, the pluri-millennial use of organic matter in agriculture and the evolution of the cultivated plants from their savage progenitors, with an over high degree of certainty ascribed solely to the conscious or unconscious selection of man.

From all this it follows that the organic matter not only imparts to the soil the properties contemplated in the concept of integral fertility, but is capable of acting also outside such limits as immediate factor of certain physiological processes of the plants; and if reflection is given to the quantity and complexity of functions performed simultaneously by this factor, then the inevitable conclusion is, that to imitate it faithfully, the artificial means today available to the farmer are entirely inadequate, and that therefore, at least for the time being, the appropriate control of organic matter remains an irreplaceable pivot for the rational utilization of cultivated soil. Thus it has to be asked, what form should be given to this control, which aims to keep the organic matter in the soil in ideal conditions or, rather, from what points of view contemporary culture techniques do not seem to contribute to the aim in question and should consequently be rectified and integrated with more effective action. A general reply would be meaningless, since both the accumulation and the metabolism of the humus at different latitudes and altitudes are notoriously differentiated, just as they are in given orographic conditions, with the result that the measures taken in respect of the humiferous equilibrium of the soil have also to be distinct according to the requirements of each single case. This equilibrium — to put the matter very schematically indeed — is the more stable, the lower are the average temperatures, and minimum the seasonal temperature range, and the higher is kept the degree of humidity in the soil as the result of sufficient rainfall. Therefore, in the damp temperate regions the problem of humus does not in general give rise to great difficulties, and the relative culture techniques — always provided the cultivated soil is periodically supplied with organic matter — are essentially resolved through its mobilization, obtained automatically by means of preparatory and subsequent tilling operations (relatively deep and violent) when implanting the culture, as well as — in the case of badly drained soils — by means of measures for their drying. The humiferous equilibrium, on the contrary, becomes more and more precarious, as we go from the previously mentioned polyennial pedogenetic cycle belts (marked by the tendency to accumulate organic matter from one year to the next) to the annual pedogenetic cycle belts, in which the destruction of the humus produced during a season takes place in the same year, when there is lack of special protection of the cover of vegetal residues; here the metabolism of the organic matter is extremely rapid, particularly by reason of the great heat, even if the absolute quantity of organic matter produced annually may be extremely high as the result of very heavy rainfalls, as in the tropical and equatorial regions. In the hot sub-arid regions, on the other hand, the reserve of humus is moreover somewhat small, in view of the scarcity of vegetation through lack of water; and not very different conditions are found in those transition zones, where — in the presence of high temperatures — the rains, even if abundant, are nonetheless concentrated over a short period of time, with the rest of the year dominated by drought: the sub-tropical and typically mediterranean zones are cases in point.

All these belts of the world are those most greatly interested in the conservation and increase of humus in the soil. Now, as regards the dry zones, the first culture intervention will clearly consist in providing them — where possible — with irrigation, which is today one of the heaviest commitments of modern technics as applied to agriculture, based on the creation of reservoirs — sometimes enormous — of an extensive distribution of water (with use of sprinkling also), and even on the desalting of seawater. But where hydric resources of this kind are not available, it is impossible to do without adequate arrangements of the cultivated surface such as will retain a part of the rainfall, though removing the excess without causing erosive phenomena. However, it is not intended here to call close attention to these wide sections of culture technique, since they do not specifically concern the humus problem, but embrace a much wider subject-matter, and that is to say the hydric supply for the cultures, even if this directly and to a great extent also affects the increase of organic reserves in the soil. It would rather seem more opportune to dwell in the first place on the culture tecniques related to the tilling of the soil, since it is among other things precisely in these, that it is legitimate to see the spread of certain errors, traceable to an intense and indiscriminate mechanization of agriculture. It must first and essentially be pointed out that at least 80% of organic matter of any origin — residues of epigeic crops, living and dead roots, microbic microflora — are found concentrated in the first 15-20 cm of the active stratum of the soil, and sometimes at depths even

[11] *Haussmann* - pag. 10

shallower (cf. M.C. CIZEVSKIJ and V.S. KOSINSKIJ, C.R. CLEMENT and T.E. WILLIAMS, W.W. EMERSON, A.S. ALOV, etc.), and that therefore the metabolism of the humus in nature (to which the fertility of the substratum traces back) takes place in combined conditions of aerobiosis and anaerobiosis, both linked up with the thickness of the surface organic stratum. On the other hand, every type of tilling concurs in the rapid degradation of organic matter with increase of the oxidative processes, and also mechanically destroys to greater or lesser extent the stable glomerular structure, conditioned by the presence of humus: the first fact, even if it prejudices the conservation of the potential fertility, nonetheless serves to fructify the accumulated nutritive reserves; but the second is wholly negative as regards habitability of the substratum.

It follows from all the foregoing that in principle, and for the ends here considered, tilling should be as infrequent as possible and should employ implements that least pulverize the soil, as is confirmed by researches in the most varied environments (V.R. WILLIAMS, S. HÉNIN et al., H. RENEUVE, S.J. GOBILLOT, H. MOREL, J.B. PAGE and C.J. WILLARD, J.B. HESTER and F.A. SHELTON, L. KOLODNY and O.R. WEAL, L. CAVAZZA). Among the implements causing greatest damage are harrows, disks, milling-cutters, heavy rollers, motorized traction and transport, especially if used at high speed and on over-dry or over-wet earth, and especially if this earth already has a naturally labile structure or one deteriorated by previous technical errors. Now, it is not necessary to waste words on recalling that industrialized agriculture abuses the implements mentioned to an ever-growing extent and also the manner of using them, heedless of the seasons and of the state of humidity of the soil, tending to make use of powerful and massive machines which function rapidly and violently; account is taken of the number of working hours, even of cultures to be effected in succession in the same year, but not of the requirements of the soil, which are after all the same as those of high and constant crops.

Like tendencies exist in ploughing, where the availability of inanimate motive power seems to authorize the most radical deranging of the strata of the earth, either by bringing to the surface inert soil lacking organic life, or by insisting on opening up furrows at depths never till now attained: 70-80 centimetres and more. From what has been said regarding the distribution of organic matter in the soil, it is clear that — again generally speaking — any overturning of the stratum by means of ploughing should affect only the thickness enriched with humus, barely touching its disposition, so that the original organic matter present on the surface becomes placed underground in order to undergo a prevalently anaerobic humification (creator of structurality), while the already humified matter comes — as seed bed — into contact with the future culture, for gradual utilization on the part of the crop. An overturning that buries the organic stratum under a mineral substratum (also in the case of the introduction of dung or other manures) would render simply inoperative the polyvalent function of the humus, with all the imaginable negative consequences for fertility.

In reality, even overturning limited to the humiferous stratum does not always seem to be essential: in the sub-arid and inter-tropical belts in particular, agriculture has for millennia done without overturning implements, making use solely of the pick-plough and nonetheless frequently succeeding, as historical evidence shows, in favouring a growing increase of fertility. In all likelihood, this fact is due to the extreme superficiality of the active stratum in the previously mentioned zones, as well as to the considerably milder effect of the ancient implement on the disgregation of structure and on the degradation of humus, as compared with any modern overturning implement. Neither do there lack, among our contemporaries, supporters and practitioners of culture systems without overturning, both in the zones in question (PANTANELLI, DESSI DELPIERI, TITTA, who allows an overturning limited to the first 10 centimetres) and especially in the inter-tropical zones (J. PHILLIPS, H. MAR-

TIN-LEAKE), and even in the pluriennal cycle zones (A. DELUCQ, S.S. SOBOLEV, T.S. MALZEV). It is presumable that the overturning of the organic stratum is justified in all those cases, in which (especially on account of the impermeability of the underlying mineral matrix) the humiferous reserves are slow to decompose and can — if not removed from the deepest horizon — give rise to processes of peat formation, which have a distinctly adverse effect on the proper development of the plants cultivated; an even more decisive overturning, i.e. one which comprises strata that are almost or entirely without organic matter, can be required in highly clayey or compact soils, for the purpose of flocculation — temporary though it may be — of the mineral colloids by means of exposure to atmospheric agents, such as allows the sowing and taking root of the culture. However, the deepening of the over-turned strata should take place gradually, so as never to cause the presence of a wholly inert stratum on the surface, but rather to mix with this a part — slight though it may be — of the humus present in depth. Similar conclusions are reached by the most recent research work of A.S. ALOV in damp-temperate zones and on leached soils (such as the podzols, with mineral and colloidal accumulation in the illuvial horizon), in respect of which the Author predicts a deepening of the humiferous stratum by means of a moderate overturning (30-60 cm) comprising the previously mentioned horizon, and if necessary combined with re-mixing with the surface sheet.

The principles set out above have on several occasions been put to the test of experimentation, especially as regards the depth of the cultivations, there being still firmly held the current conviction that the deeper the cultivation, the better is its effect on the development of the roots, and thus of the plants. However, the data collected are not really favourable to this thesis, and an impressive series of observations indicate that only rarely does there exist a reason for taking the preparatory work beyond 20-25 cm. (DECOUX, LYSOGOROV, ACHROMEJKO, APSITZ, CZERATZKI, KENN and RUSSEL, BUESS, TULAJKOV, D. TALLELIS, DE CILLIS, CANDURA, LISA, CROCIONI and SASSO, DEL PELO PARDI); indeed, the closer one goes to the inter-tropical and equatorial zones, the less advisable it is to go deeper than 10-15 cm. (JACKS and WHYTE, ORAM, POLETAEFF, VALDEYRON, VEAUVY, VERGNAUD, GOUROU, RICHARD-MOLARD). Deep cultivation has often also been invoked for the purposes of preventing the formation of cultivation crusts, and of favouring the removal of the excess waters in the sub-soils; or else for the purpose of increasing in the soil, in the dry zones, the susceptibility to invasion by rain water: but the first of these purposes can be achieved without appreciably disturbing the organic stratum, and this by following up a surface ploughing with a horizontal subsoiler, of which today there are improved models with multiple organs — perforated, drill type, etc. (STEFANELLI). At first glance, the second purpose is seen as likely to take absolute precedence over every other consideration, since water becomes the limiting factor of vegetation; but in reality, careful experimentation has shown that only certain types of soil are — in fact up to a certain point only — favourably affected by deep cultivation, if necessary followed up by repeated more superficial cultivations (worked fallow, dry farming), for storing of the humidity. We cannot here go into the complex individual enumeration of cases, which also depend on the degree of rainfall, but we should note that the benefit is often contested (ORAM, PERRIN DE BRICHAMBAUT, BRYSSINE and GRILLOT, J. BENDER) or even denied (G. PASSERINI holds, that in the clayey substrata the colloidism — by very quickly causing the surface soil particles to swell by wetting — thereby prevents the further penetration of the water in depth), and is in any case linked up with multiple and radical difficulties, in large part deriving from the destruction of the humus (hydric and eolic erosion); consequently, even when the purpose is achieved, it remains very rare that such means obtain a real increase of the crops and a lasting conservation of fertility.

The foregoing thus shows, what favourable prospects for the accumulation of organic matter have been opened up with the introduction of the sod-seeding and minimum-tillage techniques, based on the use of total weeding with Diquat, Paraqüat, Aminotriazole or other herbicides, and on the successive direct sowing of the culture, at most preceded by cultivation — combined or not with a burning of the dead residual plants —, a surface cultivation with rotovator or a special type of rotary harrow, in conjunction with the sowing machine (¹): according to ALLEN, the said system reduces to minimum the alteration of the surface stratum of the soil and is thus capable of ensuring the best conditions for regulating the metabolism of the humus. Among other things, it has been learnt from the studies carried out by the National Research Council in Italy that, among the herbicides, the dipyridilics — in addition to their dessicating action on the plant tissues — have a positive influence on the structure of the soil, subsequent to the formation of very stable aggregates bonded by large organic cations. All this is particularly valuable for the planting of cultures that follow a meadow, since — as will be gone into later — it is precisely with the polyennial meadow that there is established in the soil the biotic regime most propitious for the formation of the organic compounds responsible for the potential fertility. The new praxis, in fact, is liable to decrease in the soil the rate of loss of the organic matter and humidity and to influence, lastly, the course of pedogenesis, besides modifying — with the continuous use of herbicides and the lack of tillage, or at least of ploughing — the entire ecological equilibrium between the annual cultures, the respective weeds and the pathogenous agents

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(¹) A piece of equipment of this kind, provided also with a manure distributor, is the SISIS Contravator/Lospreder, manufactured by Messrs. SISIS Equipment (Macclesfield) Ltd., of Macclesfield (Cheshire, Great Britain); another similar machine is the Howard Rotaseeder, manufactured by Messrs. Howard Rotovators Ltd., of West Horndon (Essex, Great Britain).

(entomological and cryptogamic). In the long run these effects may prove more valid than any immediate and slight disadvantages for some cultures — which among other things probably derive from an as yet imperfect application of the appropriate technical measures: allusion is made to the cases, in which the yield of the non-cultivated implantation is somewhat inferior to that of the cultivated one, as is the case of autumn wheat in the tests of A.E.M. HOOD, H.R. JAMESON and R. COTTERELL, and of R.A. ARNOTT and C.R. CLEMENT, for maize in the tests of A. CANTELE and L. GIARDINI, etc. As against such results, however, equal or superior ones are recorded in respect of implantations treated with herbicides: for maize by J.E. MOODY, G.U. SHEAR and J.N. JONES, for barley and kales (with the addition of 100-200 units of N) by HOOD et al., as well as by ARNOTT and CLEMENT (with or without addition of N); for sugar beets, CANTELE and GIARDINI have obtained the maximum weight per root by means of herbicide treatment combined with surface tillage. Finally, in the tests controlled by us of implantation of lays on degraded sods of alpine mountains (1000-1500 metres above sea-level), there was found to be a perfect taking root of the species sown, and in the 2nd year of vegetation — especially with the adoption of manuring — a quanti-qualitative productive result absolutely unattainable with other techniques; similar tests carried out by A. TRENTIN in a different mountain environment have confirmed our findings, with an excellent result for the mixture planted (particularly the graminaceous components) and an overall production at the 2nd year of about 4900 F.U., as against the 3000 of the non-treated control. These results will be easily understood, if it is recalled that sod seeding respects, in the substratum, the biotic regime most in accord with the polyennial herbages, the regime in fact of uncultivated soil, to which we shall shortly be reverting.

If it is foreseeable that with a better specified methodology (choice of the specific weeding agent for each culture, dosage and time of application of the herbicide, combined or not with tillage and its characteristics, etc.), the new techniques will end up by obtaining — at least at the outset — productions not inferior to those today given with the traditional systems; however, some reservations have for the moment to be made as to the consequences of systematic chemical weeding on the microflora and fauna of the soil; there is no doubt that contact with certain herbicides causes a more or less pronounced inhibition of the development of schizomicetes and actinomicetes and, according to the research work of S. CARINI, decreases the number of microbes (excluding, however, the proteolytics and the nitro-bacteria in the case of 2,4 D), although only in the extremely superficial stratum, while at a depth of 10 cms the microflora remains intact. The fact that such depression may be only temporary, and quickly disappears after the multiplication of the surviving micro-organisms, does not do away with the danger that given herbicides exert a more lasting and selective action also in respect of the useful flora and fauna of the soil, and therefore damage in the latter the metabolism of the humus and the preparation of fertility, with negative final effect on the size of the yields. In the working out of the definitive methodology of the system, a strict control of the phenomena mentioned is therefore necessary, especially with the introduction of new chemical preparations in current use. The same applies in general with respect to the by now very widespread use of the most widely varied chemical preparations, although with considerably different intentions: without forgetting the mineral fertilizers themselves, or the artificial correctives of soil reactions, reference should be made to the insecticides, fungicides and nematocides expressly prepared for suppressing numerous components of the vital community existing in the agricultural environment and forming part, in some way or other, of the living and dead organic matter, in the final analysis destined to enrich the humus of the soil: the advantages obtainable with the use of the said means should be measured against the possible damage, and in this last respect there should be no undervaluation even of the restrictive conditioning of the capacity for adaptation both of all the spontaneous flora and fauna and of the cultivated plants themselves.

The measures so far considered have the fundamental aim of imparting to certain culture techniques conservative functions in respect of the organic matter in the soil; it will be as well now to consider, what means are available to modern agriculture for increasing the content in humus, characteristic for the zone of operation, with particular attention being paid to the pedogenetic belts which most require such increase, marked as they are by the scarcity and instability of the organic compounds in the soil. The most immediate means would seem to be the manuring with dung and stable liquids, which — it follows from what has been said — should be principally understood as biological reinforcement of the substratum, there being relegated to second place its purely chemical and physico-mechanical or physico-chemical effects, and clear distinction thus being made from the use of mineral fertilisers; this latter use, reserved to the nutrition of the cultivated plants (and if necessary of the soil micro-organisms), is useful but not sufficient for the maintaining of the integral fertility, so that it cannot be held to be a substitute for organic manuring, as on the contrary there is the tendency in many cases to believe and to have believed by others, with certain benefit to the industries concerned. Moreover, it is helpful to recall that mineral fertilizers, depending on their composition and the soils in which they are used, not infrequently worsen the structurality of the soil (Cecconi, Salazar and Martelli, who quote a wide documentation in this respect) and thus act in a way, that is precisely the opposite of that of the humus, whose content in the substratum should therefore be particularly reinforced, where the previously mentioned danger exists. On the other hand, as a consequence of the growing specialization of the farms into determined productive sectors, agriculture without cattle is an ever more frequent fact, which makes it necessary to seek surrogates for animal excretions and for litter: among the most ancient of these is green manure, but it has a short-lived action and is also of a somewhat different nature from stable manure, being not yet humified organic matter. The composts of earth and plant residues are more suitable, though they have fallen into disuse through shortage of the labour required for their preparation; and some advantages can also be gained from fossilized organic matter, as is shown by the research work of BEUTELSPACHER and NIGRO with Italian lignites, which contain humic acids similar to those of vegetal soils but, in this case too, the economic aspect of the finding of like sources of humus for the purpose considered remains questionable (¹). Thus notable interest attaches to the artificial humic manures, today produced on industrial scale by city waste or by the organic residues of factories, with possible inoculation of bacterial cultures, which make its humification more active and complete: their effectiveness obviously depends on the process adopted for their manufacture, and regrettably many of the products on the market are in no way distinguishable from an inert material. But rationally obtained preparations show, if adopted with adequate criteria, that they possess excellent properties — so much so as to make it possible to obtain with, for example, 10-15 ql/hectare of such preparates integrated at the depth of 10 cm of the surface stratum by every culture implantation, results equivalent to those of 200 ql/hectare of farmyard manure of medium maturation, and sometimes even better results, as some of our pertinent trials have shown. The diffusion of the said manures in the annual pedogenetic cycle belt would appear to be particularly promising.

To the preparations inoculated with humifying bacterial cul-

(¹) At least for rich cultures, such as vegetables, it seems more convenient to make use of humic acids first extracted from lignites by industrial processes; this new technique has had appreciable success in the U.S.A.

tures are related the attempts to introduce directly into the soil autotrophic (chemotrophic) micro-organisms, aerobic or anaerobic, destined to activate the biotic regime, where it is weak or absent (degraded detritus), by means of the fixation of nitrogen and thus the proteic synthesis (A. CERUTI); and worthy of mention among the same kind of intervention are the bacterial strains selected for the nitric enrichment of the soil (Azotobacter, Bacillus radicicola), for the solubilization of tricalcic phosphate (J.J. SAMOJLOV et al., R.J. PIKOVSKAJA) or for the mobilization of the potassium, contained in the alumosilicates (V.G. ALEKSANDROV). These are in any case all complementary means for the organic reinforcement of the soil, which is in practice not easily obtained with only the previously mentioned organic manures, since — except in specialized orchard cultures — it is not as a rule feasible to make annual distribution of the said manures in respect of all the cultures of the farm; to this it should be added, that the effects of similar contributions of humus — with respect to integral fertility — appreciably differ, especially in point of degree of intensity, but also qualitatively, from those of the humified organic matter, forming spontaneously in the soil; for which reason there are good grounds for the conviction that without this latter type of humification, increased by appropriate measures as required, the soil subjected to agricultural exploitation is not capable of keeping indefinitely the necessary characteristics of habitability, nor of giving rise to constant and high yields, at least for the majority of agrarian cultures. In determined circumstances the organic manures can to a great extent make good the aforesaid absence, for a limited period of time, and in this sense are always extremely valuable; but a rational agriculture cannot as yet do without an enrichment of the soil with humus deriving directly from the biotic activity of vegetal life, and this is a point deserving special consideration within the framework of contemporary culture techniques, which often leave ever less space to the intervention of natural pedogenetic factors.

In a previous historical and geographical study we made it clear, how for the complete regeneration of fertility after a series of exploiting annual cultures, it is still necessary — as it was in the primordial era of agriculture — to allow the soil, periodically and at the right moment, an interval of rest, during which in the vegetative substratum, no longer disturbed by man, occurs a renewal of certain constructive biological processes, interrupted by continuous cultivations. It is likely that, with the introduction of sod seeding, this interval of rest will in future be to a great extent cut down, if not totally done away with; for the time being, however, with the traditional culture techniques, the obtaining of high and constant yields has shown itself to be conditioned by the alternating of periods of utilization for annual cultures, with periods of lying fallow, and this indeed at all latitude and ever since the most ancient times. Agriculture itself — and the civilizations to which it has given rise — have been able to survive and evolve only where the continued exploitation of the soil, with the resultant progressive (even if slow) diminution of the yields, has not proceeded to the « rest » — or abandonment of the fields — at a stage of degradation of the soil such, that every spontaneous reconstitution of the fertility becomes impossible; where, that is to say, in the rotation of the cultivations there was respected, in systematic manner and with appropriate frequency, the suspension of all tillage and the return of the substratum to the conditions of an uncultivated soil for a period of time, sufficient to graft there a lasting deposit of organic matter and to allow its slow humification — creator, among other things, of a stable glomerular structure.

In Europe, ever since the 16th-18th centuries, the rest period — which in the temperate belts gives rise to spontaneous grass cover — was gradually replaced by the artificial sowing of polyennial herbages, essentially leguminous, and was a decisive step not only for the economy of the farm (bound up with the development of animal production), but also for a rapid and efficient increase of the organic reserves of the soil, combined with the setting up in it of the biotic regime typical of the « rest », which we have defined as regime of uncultivated soil, as against that of tilled, cultivated or sown soil. As a matter of fact, this technique was known already to the Romans, who sometimes — in place of the rest — periodically sowed lucern in the soils given culture rotation; but this fell into disuse in the Middle Ages and was re-introduced, it seems, in an independent way, but with only modest initial good fortune, by the Arabs in Spain. Later, and especially in the Northern European micro-thermal regions (less favourable to the cultivation of pure leguminous species), there became widespread the practice of mixing clovers and grasses, which, from the standpoint of reconstitution of integral fertility, attain the maximum effects, thanks to the peculiar root system of the grosses (capable of greatly hardening the soil) and also to the influence of some of them on the activation of microbic life, specifically decisive both for humification and for nitrogen fixation. The relative documentation is by now so plentiful, as not to allow or require exhaustive quotations here; however, we wish to recall the works of A. WEHRLI, D. EBERT, C.R. CLEMENT, A.P. KURTESOV, M.J. GROHOVSKIJ, V.R. WILLIAMS, H. VETTER, and in particular the points made by PAVLYCENKO and WEAVER with regard to soil binding capacity, and those of HUBBEL and CHAPMAN on the part played by the micro-organisms living normally in the sward, points confirmed also by the research work of CHISCI and CARINI at the Experiment Station for Fodder Crops, Lodi, Italy, in which among other things there has been observed a surprising and not previously noticed abundance of aerobic bacteria fixers of nitrogen in the *Festuca rubra* sward, an abundance even greater than in the clover cultures, and an exceptional development of the proteolytics under the cultures of the genus *Agropyrum* (*A. intermedium, A. tricophorum, A. sibiricum*). It is also important to note that the effects of the meadow as regards the so colled « rest » are ap-

[11] *Haussmann* - pag. 22

preciably different from those obtainable with organic manures, both because of reaching higher yields (H.H. MANN and D.A. BOYD) and because of the greater percent. increase of stable aggregates; this happens even when the annual contribution of farmyard manure implies exceptionally high doses (100 t/hectare), with a corresponding increase of organic matter in the soil — more than 9 times higher as compared with the meadow (G. MONNIER). Nor are equivalent the effects of the meadow itself to those of the seasonal forage catch crops, whose nature of cultivated land cultures marks their biotic regime, among other things depressing the structurality of the soil (G. HAUSSMANN and S. CARINI), and increasing the aerobic microbic flora (S. CARINI).

The foregoing places the meadow (especially polyphytic) in the pedogenetic zones considered, as pivot of all rotation and as principal and not-suppressable means for the reinforcement of fertility, independently of every one of its functions for the purposes of herbage production, and thus of every immediate economic consideration. This statement confirms the inconsistency of the recurrent attempts — in modern agriculture, which is oriented towards the maximum simplification and specialization of culture arrangements — to exclude the meadow (and thus the « rest » period) from the rotations, with the pretext that any benefits it might bring, if anything only perceptible in the long term, can also be achieved with artificial means, which would allow even the continuous mono-culture of annual plants. In the light of the enormous masses of data which categorically deny claims of this kind (based usually only on a few years' observation), the problem of the inclusion of the meadow in rotation no longer concerns the usefulness (undeniable), but rather — for each pedogenetic belt, kind of soil, type of meadow, etc. — the duration of the meadow itself in relation to that of the remaining cultures in rotation. Indeed, the improvement of fertility brought by the meadow benefits the other cultures inasmuch as it is manifest in them as posthumous effect of the rest period, perceptible through the increase yield and the positive characteristics acquired by the soil; such effect obviously falls off over time, and postulates — before it disappears entirely — the return to the polyennial meadow, it being nonetheless borne in mind that the period between the two meadows can be lengthened by having recourse to organic manuring and to the other measures already mentioned, for the purpose of humus conservation. Now, the problem set out has not so far been sufficiently clarified by the experimentation in respect of the single ecological and agronomical environments, even if partial studies of the kind in question are not lacking (HÉNIN, PSTUSENKO, KONONOVA, KOBLET and WEHRLI, PAVLYCENKO, MONNIER, THERON and HAYLETT, CLEMENT, T.E. WILLIAMS, etc.). It has thus been shown that the longer the duration of the meadow, the longer is its posthumous effect also; that for this to have an appreciable consistency, the meadow should last at least 3 years; that with such meadows of brief duration the ratio between this and its posthumous effect (and thus the optimum period of annual cultures) is 1:1 - 2:1. In reality, in the empirical agriculture of the temperate zones, where manuring is a current practice, it is observed that the fertility of the soils (and the size of the yield) keeps fairly high, with only 30% of the rotated surface put to meadow (of brief duration), in rotations from 3 to 9 years. However, to examine this important problem thoroughly and to better specify the range of the posthumous effect in the various orderings and culture techniques, there has been in progress since 1962, at the Station for Herbage Cultures of Lusignan, and with the cooperation of other French Institutes, an impressive complex of joint research work, planned for a minimum period of twenty years, which aims to throw light on the various reflexes of the posthumous effect of the meadow rest period on fertility and on the production (P. JACQUARD). Similar and parallel research work, suitably adapted to the local ecological conditions, has been started by the Italian National Research Council at the

Faculty of Agriculture of Sassari, in respect of the typically mediterranean environment; this has also been done with the cooperation of other Institutes.

If from these investigations it finally proves possible to deduce reliable indications as to the ratios, most answering the needs of agriculture, between the biotic regime of the uncultivated soil (polyennial meadow) and that of the sown soil (annual cultures) in the regions in question, it is in any case legitimate to hold, on the basis of the notions already acquired, that while grassland, in its various forms, constitutes the ideal type of « rest » for the pluriennial pedogenetic cycle belt, its useful duration can be shorter as the tendency to accumulation of organic matter in the soil is greater (¹). The closer we get to the hot and hot-arid zones of the temperate belt, the longer should be the « rest » as compared with the sown period, inasmuch here the rhythm of the accumulation of humus slows up (and also in part changes its characteristics), while the organic degradation is notably speeded up during the culture periods. At the same time, although the artificial meadow always succeeds in performing its fertilizing function, its useful effects are now attenuated by the fact that the scarce rainfalls allow it only a very slight or even negligible development, little or nothing superior to that of the spontaneous vegetation on non-cultivated land. The consequent burden on the economy of the farm (which is denied the utilization of the herbage produced, or else this is made non-remunerative) therefore makes it necessary, in the zones with rainfall lower than 400 mm, to renounce the

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(¹) EVEN in Sweden, though, trials still in progress show the best success of long rotations with 50% of « rest » (3 years of ley + 1 of fallow, in a 8 year rotation), in comparison with shorter rotations (4-5 years) with only 2 years of ley; the monoculture of cereals, however alternated between them or with fallow, and above all the continuous succession of a single art (wheat, barley or oats) lowers always in the course of years the yields, sometimes by 40-50% as compared with more diversified rotations, especially if better balanced by meadows or leys. (L.S. AGERBERG).

polyennial meadow and to have recourse to the simple « rest » (non-culture or sown long duration grassland), which will be all the longer, the more expressed are the characteristics of aridity and of annual pedogenetic cycle. However, it is incontestable that in the hot sub-arid zones also, and particularly in the mediterranean zones, the organic matter — although present, even in the untilled soils, only in a small proportion — exerts its full fertility-protective action inasmuch as it gives rise to a notably stable soft humus (mull) with distinct prevalence (as compared with the fulvic acids) of the humic acids, which cause a pronounced increase of structurality in the soil under forest, grazing swards or « macchia » (bush) formation (PALLOTTA, CECCONI and RADAELLI), as compared with sown lands (1).

Coming now to the sub-tropical and tropical belt (with periodic rains), the herbage cultures re-acquire their importance, but the growing intensity of the thermal factor considerably restricts their benefit, very quickly destroying the organic matter deposited in the soil and the soil's structure (PEREIRA, CHENERY and MILL), so as to make it necessary to reduce the sown crops, in the zone of the wet savannah, to 1-2 years, as against 6-10 or more years of rest. (J. THERON). This destruction is further favoured by the violence of the rainfalls, to which is due the immediate leaching of the solubilized components of the substratum or also the direct removal of any deposit through sheet erosion. Therefore the meadows — which here, for the reasons given above, reach the climax of an almost definitive equilibrium after only two years — can be only very mildly exploited for herbage, if the pre-eminent effect of ferti-

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(1) In the said conditions there are also found (PETRONICI) grey humic substances, even more stable than the humic acids (brown) and evidently due to inactive humus or humus degraded by flocculation and irreversible dehydration. Similar processes are responsible, among other things, for the formation of clay-humic complexes, in which a part of the organic matter becomes strongly immobilized (ESCHENA).

lization is to be obtained, while in the case of green manuring the said effect is minimum, inasmuch as it is almost totally cancelled out by the pertinent tillage of the soil, especially in the savannah zones. The aforesaid phenomena find their fullest expression in the equatorial belt, making precarious any other remedy but total rest, with return to natural spontaneous vegetation, and that is to say arboreal, indeed forestal vegetation, if necessary integrated with special plantations for a very long period of time (sometimes 20-50 years), after only 2-3 years of sown cultures (R. CHAMPSOLOIX, R.L. PENDLETON, J. PHILLIPS): in this way a switch is made to itinerant or shifting agriculture, intermittent or occasional, adopted ever since prehistory by the local population and too often badly treated by European colonizers who — judging it to be backward and irrational — saw fit to replace it with techniques in use in their own countries of origin, with irreparable damage to the fertility of the soils put to culture. Here, then, in the annual pedogenetic cycle regions, absolute rest becomes the essential condition for every agricultural use of the soil; the respective durations of the first and the second are inverted, as compared with what happens in the temperate zones, with notable prevalence of the rest; all the other known measures for increasing the humus appear complementary, even if in any case to be recommended; the biotic regime of uncultivated soil is instituted not with the meadow, but with the forest.

The outline that has been traced is evidently highly simplified and in reality has multiple variants, especially in relation to the altitude of the zones concerned, inasmuch as the rules valid for the succession of the latitudinal belts are repeated (even if with some not negligible provisions) also in the altimetric succession. There exist nowever typically inter-tropical cultures, such as irrigated rice, which sometimes — on account of their particular physiological characteristics — tolerate practically continuous growing, being only slightly sensitive to some of the fertility factors imputable to the presence of organic matter in the soil; on the other hand, the irrigation of the zones subject to drought may allow means of cropping not unlike that carried out in the temperate regions, except that it is always necessary to keep the inverse ratio between sown soil and soil at rest, this latter represented by herbage or even arboreal cultures. It is, finally, superfluous to add that the experimentation in the belts in question is considerably less advanced than in the temperate regions, so that further details are to be expected in future, in respect of the scheme set ont, as more systematic studies are developped in connection with agriculture. But it is as well to bear in mind that agriculture itself in those regions — the essential ecological and pedogenetic characteristics of which remain those here outlined — will only with difficulty ever be able to assume the development and importance that it has reached in the temperate zones, marked by the polyennial accumulation of humus in the soil; it is these temperate zones, thanks to the part that organic matter plays in them, that are due to become the principal food source of the world, with highly serious repercussions on the resultant burdens of the peoples owning the relative lands, for the struggle against hunger in the world.

To draw conclusions from this panoramic review of the culture techniques suitable for improving the functions of the organic matter in the soil, it seems possible to express the conviction that the most effective of them, indeed the only essential one (until such time as we have greater experience of sod seeding), is the systematic and appropriately frequent alternation between sown periods and rest periods, however expressed — non-cultivation, polyennial meadow or forest; or, in other words, the alternating of the biotic regime of the tilled soil and that of the untilled soil. The latter represents the phase of the farming cycle, in which the substratum takes on certain favourable characteristics of the virgin soil; following on the settling down, the density of the vegetation and the consequent prevalence of anaerobiosis in the substratum, and with the contribution of a soil flora-fauna diversified and specific to such cenosis, there is increase in the deposit of less labile humus, which improves the structure of the soil and creates a stable reserve of potential fertility. In nature, like conditions appear, at absolute optimum, under the coverage of a grassland sod, in the pluriennial pedogenetic cycle belt and in the prairie vegetal associations, and are obtained in agriculture with the planting of meadows, if possible polyphytic and of more or less duration; in the annual pedogenetic cycle belt such conditions are considerably less well fulfilled, in view of the intensity of the thermal factor, and only in the presence of a sufficient humidity can they be induced, and to only a modest extent, with a spontaneous or artificial forestal coverage, inasmuch as the shade thus obtained (and not attainable with a herbàceous vegetation), by attenuating the light and heat, allows a somewhat persistent accumulation of organic matter.

The biotic regime of tilled soil differs essentially from the precedent one on account of the fact, that to the soil there is imparted, by means of annual tillage, a greater degree of softness, due to fractures between the clods: the aeration of the substratum is increased and the metabolism of the humus is accelerated, so that there is modification of the dynamic characteristics of the soil (pH value, structure, content in organic matter and in mobile nutritive elements), but the more static characteristics (profile, mechanical composition or texture, total content in nutritive elements) can also be adversely affected. The complex of these consequences determines, with a selective action of the hypogeal environment, an impoverishment of species of soil organisms, among which there come to prevail those suited to the aerobic conditions, engaged in the catabolic processes of the organic matter; there is, in general, attenuation of the action of the biological factors (among which the microbic synergism and the aggregating action of the roots), while there is increase in the action of atmospheric agents (thermal change, action of water and frost, incidence of wind, etc.), and this despite the fact, that the cultivated plants themselves introduce into the soil a not negligible amount of organic matter with their roots, stubble and other residues. The final effect becomes an immediate increase of actual fertility, made available to the cultivated plants, which fertility is however constitutionally instable and decreasing, and ceases the more rapidly, the more intense is the degradation of the active humus.

The farming cycle, then, cannot hinge solely on this last phase, in which the crops are destined to diminish over time, and must of necessity contemplate the integration by the biotic regime of the uncultivated soil, which should be actuated before the substratum — excessively exploited by the annual cultures — becomes biologically inactive and reduced to mineral detritus. All culture techniques connected with the regime of the tilled soil should be so oriented, as to utilize for as long as possible the benefits acquired in the phase of the biotic regime of the uncultivated soil, and that is to say so, as to slow down as much as possible the previously described degradation processes. If this alternation of biotic regimes is observed with the most appropriate measures in each case (especially as regards frequency and duration of the single periods, as well as the type of vegetation in the rest periods), then agriculture itself — as human action on the life of the soil — takes on a decisively constructive pedogenetic role and finds itself in a position to direct the evolution of the soil towards those equilibria, that will ensure for an indefinite length of time the alimentary resources for ever more demanding mankind.

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DISCUSSION

Chairman: S. HENIN

HENIN

Prof. HAUSSMANN has a wide knowledge of the problem of applied soil science. He wrote two years ago a very good book in which he tried to explain a historical problem considering the agricultural techniques. He is also director of the main station for grass production in his country. I think his paper is very important because it brings us to the heart of our problem.

PRIMAVESI

You write about humic acids elaborated by anaerobic bacteria. The question in this case is if bacteria can also live under aerobic conditions?

HAUSSMANN

Some aerobic bacteria can live under anaerobic conditions and we have found that it is possible to find in the same species of bacteria colonies which can live sometimes in anaerobic conditions and sometimes in aerobic conditions. Some of the micro-organisms are — there is no doubt — completely aerobic, but some groups of bacteria can have both types of existence and development.

PRIMAVESI

We verify that in an absolutely anaerobic ambient no humus is formed. According to our experiences the grumes are not only formed by acids, but also by bacteria. The second question: peat formation on the surface justifies turning over? In our conditions, a stratum of peaty organic matter on the surface does not improve very much by ploughing. What it needs is lime, mineral fertilization and mesolife. The mesolife is animated by liming. What is your experience in this case? Deep ploughing: Don't you think that the effects are not so much related to humus as the micro-life? It is really difficult to separate the two factors. Don't you think that the activity of humus is partially conditioned by micro-life?

HAUSMANN

I have no direct experience of equatorial or tropical situations, I rely only on references, so I could not really answer your question. But I do not think your case contradicts what is the general observation. I mean that humic acids can improve the situation as well as bacteria, because bacteria participate in producing these acids.

Now about the peat sheets or surface undecomposed organic matter, of course it should not be ploughed in the underground, before it is at least partly decomposed, to give some improvement to the soil. It is the same problem as in the cold humid climate with a high humic content in the soil: the problem is to mobilize this organic matter. So the approach is probably the same in both cases, only that when you destroy the organic matter, in tropical soil it is very difficult to reconstruct this organic matter. On the other hand, in cold climates, it is rather easy. That is the difference.

[11] *Haussmann* - pag. 38

FRANZ

What do you mean by meadow?

HAUSSMANN

Meadow is a long duration sward of forage culture meant generally for cutting, not for grazing. Lay is a grazing land, meadow is a sod for cut. Now, some observations tell us that meadows are somewhat better for soil improvement than grazing land, but substantially they are equivalent and you can destine grassland either for grazing or cutting, it is not important.

FRANZ

I am largely in accord with Prof. HAUSSMANN and would like to say that our experiences correspond widely with those explained in his report. In permanent meadows, I think that this term is correct, we have never had difficulties with organic substances. We have always, in the case that the soils have enough nutrients, so many roots that the production of humus by roots produces a content of humus which reaches five or six per cent. The same is the case in good pastures, but when we plough the land the content of humus is much lower and then there is the problem of how we can obtain a humus content of a sufficiently high degree. The experiences in Central Europe indicate that alfalfa and alfalfa with grass have a very great importance for humus economy of the soil. One year of alfalfa produces such a big quanlity of roots that the difference between the yield of roots of cereals and alfalfa is so big that it corresponds to the third part of fertilizing with 150 centners (15 tons) of farmyard. Soils with alfalfa which have a rotation of two or three years can help a lot to conserve a high humus content in the soil.

HAUSSMANN

I think you are quite right, but I should precise that for structure improvement a mixture of alfalfa with some grasses could do better; in fact, grasses are generally more useful than clovers, because of a finer root system.

BRAMAO

I very much appreciated your lecture, Dr. HAUSSMANN. I think that many of the points you made in your paper will be discussed further during the last session.

I would like only to make a comment here concerning the productivity and fertility of tropical and equatorial lands. I think you said that these lands were of a very low productivity and therefore for the production of food in the world we have to rely mainly on the temperate zones. I think, I cannot share your opinion in this instance. Firstly because in the tropical and equatorial zones there are so many different kinds of soils and environments. There are very wet environments and very dry environments. There are very leached soils and saline soils. There are deep soils and shallow soils. You have soils with a very low content of plant nutrients and soils rich in plant nutrients. So I think I cannot agree with your generalization.

I think there are many promising possibilities in the tropical and equatorial zones. I have had the opportunity of living and travelling quite extensively in these zones. As soon as people can invest and have markets for their products, productions are likely to rise, as in Hawaii, in some farmlands of Brazil, etc. It is true that in some of the equatorial and tropical lands there are bad soils, « problem soils », which we do not know how to use. But often soils do not really offer great problems and can be developed with good results.

HAUSSMANN

I am very glad to hear what you say, because it gives us some more hopes about the future of these countries. I also put in my paper that probably the highlands in the tropics and in the equatorial zones are, in some aspects, similar to temperate zones. So I just made some distinction between the different situations. I had to generalize the main lines, perhaps excessively, and I am quite aware of it: all the generalizations, although necessary for certain cases, are connected with risks either for the tropics, or for the temperate zones. In equatorial zones, the altitude can be a very favourable factor for a high yield production, as is confirmed effectively by some important examples. What I wanted to stress is that the main factors of growth in equatorial and tropical zones, compared with temperate ones, are less favourable in general, not in specific or exceptional cases. You see, in temperate zones we have more concentration of favourable factors than in the tropics: that is the conclusion of the whole speech. Not that something good cannot be achieved also in the tropics; it is a question of appraisal, not of calculations.

BRAMAO

I would like to go a little further and say that there are large reserves which are practically untapped and that most of the agriculture outside Europe and North America is still traditional and soils are producing only a fraction of their capabilities. So there are still vast possibilities for raising food production the world over. I think people who have travelled widely and seen the developing countries do realize that the majority of the land of the world is not yet under the era of technological agriculture.

ALEXANDER

Although certain herbicides may cause an inhibition, often minor, of the development of bacteria and actinomycetes, there are many papers which show that herbicides have no agronomically important effect on microbial processes. Are the biologically formed organic compounds generated in soils essential for plant growth? What percentage of the yield can be attributed to inorganic nutrients and what percentage to exogenously generated growth factors? If only a small percent can be attributed to the growth factors, then the issue of microbially formed plant hormones is of academic but not practical concern. Quantitative evaluation of the significance of unknown growth factors is thus essential.

HAUSSMANN

About your comment on the herbicides, I think our observations have given some data which demonstrate that there is some negative action. It is not of a very long duration, but for some time it is observable. Of course, for the moment, there is no immediate danger from the herbicides going into commerce, but a severe control on these compounds should be maintained. As to the evaluation of the growth factors, it has been a problem of much research and it was not very easy to state what is really the part to be attributed to the mineral nutrients contained in organic matter, and what is the value of these growth substances. We have many specific researches on these questions, but the numbers found are very different from soil to soil. It is a real problem for all of us today to express in numbers the value of the organic physiologically active products, and I hope to hear something about this item from the specialists of this matter, because we have to take from them the hints and suggestions for what we have to do in practice. We have to apply to cultures the principles which are found in the scientific research; we can control them only on a large scale in normal cultivations, and in this case the evaluation of the single effects varies very much with the soil type and the climate conditions and so on. The problem will probably be solved in the course of time with trial and experience. A certain specific effect of organic matter could not seemingly be denied, given the existent experience, even if still insufficiently precised in numbers, and we are trying now to evaluate the duration of this effect and its importance.

HERNANDO

I should like to ask three questions. One is in relation to the organic matter that you say is more convenient to overturn in the soil. Also, at the same time you are talking about the overturning being 10 centimeters. Our experience is that it is right when it is straw or another not very composted organic matter and also that instead of saying 10 centimeters deep it would be much better to say « not completely overturned ». It is convenient to leave some parts on the surface, but in some soils it is possible to do it with 10 centimeters deep of cultivation, in some with 20, and in others still only with 5 cms.

HAUSSMANN

I can agree completely.

HERNANDO

You talk about the organic residue of town-refuse and you think it is convenient, or may be good, to inoculate with bacterial culture. Our experience is that it is of no use. In fact we never have the possibility to find a real answer for this inoculation. We found that whether we used inoculation or not we always arrived at the same type of transformation. You say also that in relation to the use of town-refuse it is convenient to apply between 1 and 1.5 tons per ha, for instance, and the effect is almost the same as with 20 tons of farm manure. According to our experience the results are very variable: sometimes you can get results like that, and in other cases the result is completely different. You can get better answers with farm manure than with fermented city wastes. In this connection I shall show something in my paper.

HAUSSMANN

I think I was rather careful to state my opinion on the matter, because, of course, the effect of city wastages depends on the way of the preparation and of the fermentation of these wastages. If the preparation is not good, there is no effect at all; in practice, we have observed from zero to very high effects, because the commercial products are not standardized, the processes being different from one town to another. Our personal experience with these products is that the so-called inoculated wastages have a better action, I mean a very effective result. Of course we cannot swear that these effects depend on the bacteria inoculated: to control this, we should consider the different processes and check every step of the industrial procedure. But if we rely on the field trials, one could conclude that the city wastages, when they are inoculated, seem to be reasonably effective.

HERNANDO

I can add more to this. I was talking about the city wastage prepared in the same factory with the same method. I can add that normally during manufacture of the composted city refuse the temperature increases very quickly up to 65°C or more. With this temperature, only the termophylla flora can live. Maybe the microbiologists can help on this. If you inoculated first some other type of flora, you get no effect at all, because the conditions in the medium are no good to types of living flora other than the termophylla.

FLAIG

According to your paper, you said that in some cases it would be useful if organic substances did not decompose so rapidly under special climatic conditions. If one would use a more humified material, which is more humified than it can be under normal humification processes in soils, for instance young brown-coals, such as lignite, would you believe that one would have better effects in such climates where normal humic compounds are decomposed so rapidly?

HAUSSMANN

I think so, even if I have no personal experience with lignites.

FLAIG

You believe that in cold climates the normal humic substances have more effect than in hot climates?

HAUSSMANN

Yes.

GENERAL DISCUSSION OF PAPERS PRESENTED ON 23 APRIL 1968

Chairman: S. HENIN

BAVER

I want to make two comments. With respect to Dr. ALEXANDER's comments on herbicides, I think the sugar industry in Hawaii is the heaviest user of herbicides per hectare in America, and they have been at it for a long time. We made special studies in regard to the impact of these herbicides, varying all the way from the chlorinated hydrocarbons to the triazines and others and we could find no effect upon the microbiology of the soil.

Now I am changing the subject considerably. I also want to emphasize one point you make: that is on the question of sod culture. In north-western Ohio, where we grew corn (maize) as one of our Number One crops, the farmers have always used these heavy rotations on the soil, in order to get good tilth. With the advent of herbicides to control weeds and with the use of herbicides and no tillage they have been growing continuous corn for a number of years here and the farmers will tell you that the tilth of the land is as good as when they were using rotations. That confirms what you had to say.

FRANZ

You have told us that you have no good results with soils which are ploughed very deeply. I agree with you though only in those cases where you have soils that were never ploughed more deeply. In case you are not deeply ploughing a soil which before was ploughed deeply, then the zone looses its structure, and this is very bad for the evolution of the roots, for the erosion of soil, for the penetration of roots, etc. In my opinion, the production of a good soil structure is a process which needs a certain time for evolution. A very good structure cannot be produced in a few years but it can be destroyed in a very short time, so that it is very dangerous to plough soil deeply and to plough only shallowly afterwards.

HAUSSMANN

That is the experience in Italy. When we introduced large mechanization here after the last war, the farmers began to plough the heavy clays at 1 metre or 80 cm. It was completely upsetting the biological life in the soil and, as this work was done once in four, five or six years, then the successive cultures were ploughed only 30-40 cm., and the phenomenon of which you have spoken was completely verified.

FRANZ

There are the same experiences with sugar-beet. The fields were ploughed 40 or 50 cm. deep 30-40 years ago, and now with the tractors they are ploughed to 25 and 28 cm. Under the recently ploughed horizon of these soils you can find always a horizon which is very bad in structure.

HERNANDO

I should like to ask Prof. DHAR a question. When we tried to put your method in practice in Central Spain, we found that when we left straw on the surface during summertime (normally we have no rain until the end of September) we did not find any change in the aspect and composition of the straw. It remains just as when it was left after the harvest. Can you say something about the method to get a good effect with that?

DHAR

Unless there is water, nitrogen fixation is not possible. It is well known that water molecule breaks up into H and OH utilizing the energy of oxidation ($H_2O + 112$ K. Cal. $= H + OH$). The atomic hydrogen formed combines with nitrogen and forms ammonia. So it is well known that under dry, completely dry conditions, no chemical change or microbiological change is possible with cellulosic material. In our country we have no composting when there is no rain or we have to add water to start the chemical changes and the biological changes. Along with what I have been emphasizing therefore composting the straw alone is not very suitable material. The straw should be strengthened by phosphates.

HERNANDO

The theory is good but practically we cannot use it except in irrigated land.

DHAR

If you cannot get the result, you have to improve your conditions. Without water, nothing is possible.

HERNANDO

I should like to comment on Dr. BAVER's paper. You present the yield of beets, sugar beets I suppose, in relation to soil aggregation, and you get quite a good correlation between the yield and the soil aggregation. We tried to make a similar study between the yield in sugar beets and the soil structure and found that in our conditions it was not possible to get a good correlation. In other cases, however, we got a very good correlation if we considered as a whole the heating of the soil, the transpiration, the precipitation and the structure of the soil. Then we got something like a balance of energy in the soil. In this case we got a good relationship, independent of the conditions of precipitations and the remaining climatic conditions of the special area.

BAVER

The soil I was talking about is a very heavy clay soil. The soil is so compact that under conditions of poor structure, the root would start growing and actually push itself out of the ground. We could see the top of the beet above the ground getting sunburned: the beets were short and stubby and developed side roots, and it was not until we improved the structure of those soils that we started getting a tapered beet and increased the yields. We had been obtaining only 3½ tons of beet per acre and that is a very low yield. With this improvement in the structure, yields went up to 13 and 14 tons of beet per acre. Thus, it was on a different kind of soil than the one on which you were working on. I found the same situation with bananas down in the Ulua River Valley in Honduras where the two areas of bananas were giving different results. One was growing good bananas, the other was producing poor ones with nutrient deficiencies. The difference between the bananas in the two areas was entirely a function of the aeration porosity within the root zone.

SWABY

I find it very interesting to come to Europe and hear many people advocating the use of compost and dung, whereas in Australia we use neither, partly because our animals are not housed like yours. With our milder climate they live out in all weathers, and so the dung is really scattered all over the fields by the animals. We certainly never make compost because it is much too costly, and I wonder whether the costs of making compost in Europe aren't really excessive and the values you get from it are worthwhile. I personally would like to see the labour charge for making compost put into artificial fertilisers and use these instead of compost. Now where is my argument wrong? Can you tell me what is the great value of your compost? Are we missing something good?

HAUSSMANN

Well, as a matter of fact Lombardy, where I stay, is using composts for some hundred years as a normal practice. When just because of the cost of such work we began to abandon this practice and utilise only mineral fertilisers, we have noticed that our principal forage — the ladino clover — has really gone back as yield and this not because of lack of uutrients, of course, but just (as we can explain it) because of a very complex action on the compost. There is a biological action which probably is linked with the microbes and earth-worms and so on, and there is also a physical action of the compost as it is used: it is distributed on the sward during autumn or winter and it protects the plants from freezing, ladino being rather sensitive to cold. And so the absence of these two favorable factors is followed by a lower production or at least by a lowering of quantity of clovers in the sward, inducing the farmer to appreciate very much the use of compost. On the other hand we have elaborated also a method of doing the compost mechanically, which is quite possible with bulldozers and other similar means.

So practically it doesn't cost too much and doesn't compel us to abandon this practise for the moment. However, we couldn't consider equivalent the use of compost and mineral fertilisers, that's the practical result of our experience.

FRANZ

I would like to ask our American colleague about the last experiences with straw mulching and subtilling straw in the soils, firstly in the dry regions. I think that this is a very important matter but in Europe we don't use it just now, but I would be very interested to hear what is tbe result of this method in the United States.

BAVER

If I could hear the question again from the beginning, I didn't get the first part of the effect of straw mulching.

In the Mid-Western dry-land farming area, the use of straw mulch is a well-established practice for moisture conservation and wind erosion control. Actually, it takes a very small amount of mulch to conserve moisture. As I have been away for some years and have just returned to Ohio, I have been impressed with the movement of mulchtillage, so to speak, from the dry-land farming area of the Western plains into the more humid part of the corn belt. I think it is a growing practice as far as tillage is concerned. We have to consider minimum tillage. We can plant in the destroyed sod or we can plant in the residue of the previous small grain crops.

BRADFIELD

I agree with Professor SWABY about the making of compost. In many countries the amount of labour required is, I feel, entirely too high and the gains are too low to justify the large investment in labour. I think that we need to find ways of using the crop residues that cannot be used as animal feed, or cannot be put to other economic use, for the improvement of soils but by other less laborious methods. I think in many cases residues can be left on the ground and used as mulches, in other cases they can be handled in such a way that they can be easily incorporated. There are many things that we can do which will give us positive gains from the organic matter without converting it into compost. The only place that I feel compost making is justified is in the preparation of potting soils for use in greenhouses etc.

HERNANDO

Prof. FRANZ says that only in America the mulching method is used for the straw, but it is not generally so. I should like to say that in Spain we do also mulching straw. There are farmers who get poor results with it. We have no rainfalls in the summer. In harvesting we leave the straw cut into small pieces on the soil, spread out for the combine. Immediately after the harvest we make a very shallow cultivation that slightly removes the stubble in the soil, and we leave it until the end of September. Then after the first rain it is possible to cultivate the soil for seeding, but we recommend to grow a leguminous crop in the following year so as to get better results of the straw than with cereals.

HAUSSMANN

I want to say that in Italy we have had an experience quite similar to the Spanish one. We have controlled the effect of the straw and we have noticed that there is no immediate increase of yield, but there is a rapid positive effect on structure. The structure is surely improved, so probably it will affect in the long run also the crops.

HERNANDO

We found that during the first two or three years there was no clear effect on the yields, but things got better after; the yields increased and in the twelfth year it was nearly double the yield than the control.

ALEXANDER

One often gets the feeling that natural products are necessarily good and synthetic chemicals are necessarily bad. I might comment on the recent Canadian and US experience in regard to the problems associated with the addition of crop residues, particularly the generation is soil by micro-organisms of highly potent plant toxins, which not only have a direct effect on plant growth, but also predispose plants to pathogens. This seems to be a serious problem in some areas, so I would like to repeat that natural products may occasionally not be beneficial.

SWABY

Mr. Chairman, I wonder if I could perhaps amplify a little of what Prof. ALEXANDER has spoken because in Australia we practice stubble mulching to a very large extent on our cereal areas. It is done a little differently from what it is in the United States and Canada however, because instead of under-cutting the straw after harvesting and leaving it to lie on the ground horizontally in a mulch, we knock it down with sheep. They graze the heads of wheat that may still be there unharvested and they eat a certain amount of the straw, but largely they knock it down and there it lies as stubble mulch. Now we thought that this was going to be a very good erosion control and in fact it is, and it also improves intake of water, but occasionally, about one year in three or four, we find this mulch a great nuisance, and one of the troubles is that it usurps nitrogen if you do not get adequate rotting period before you plant your seed. But even more subtle is this problem that Prof. ALEXANDER has mentioned, that is occasionally you get toxic effects from this straw. These are largely due to microbial products, but we have also found, and McCALLA from Nebraska supports us in this finding, that the straws themselves contain phytotoxic substances before any microbial breakdown has taken place. It almost seems as if nature has an inbuilt system for preventing the germination of a seed until adequate rains come to wash out these water soluble toxic materials. When they are washed out they decompose and then the straw is no longer toxic.

NORMAN

I think I want to go back to the question Prof. SWABY presented earlier. Whether composting is worthwhile is still not completely answered. I think we see in the United States at least, considerable change in practice in managing crop residues, but some of the reasons for the changing practices are not because one practice was better than another but for reasons that relate to minimising labour, and for reasons that relate to the improvement of farm equipment and the availability of tractors of greater power and higher speed. So there is a sort of vast compromise that has developed in the Mid-West now, of leaving the residues pretty much on the surface or with minimal incorporation, doing far less cultivation than used to be the case, and controlling weeds with herbicides. Over a period of years this is extraordinarily effective in reducing the kind of infestation which the farmer had to deal with previously. And then the higher fertilisation rates and the wider use of nitrogen fertiliser particularly, has meant that the amounts of residues per acre are much greater than used to be the case. However, the residues themselves are decomposed under this system, which has been arrived at by a series of compromises for a variety of reasons which seem to me to be ending up in a rather wise way of meeting the crop residue problem.

FLAIG

I believe one should not speak generally about toxic substances which occur during humidification in the soils because toxity depends upon the concentration, and some substances which can be toxic in higher concentration, are not toxic and have no effect on plant metabolism in lower concentrations. One should speak about physiologically active substances.

HENIN

Avez-vous encore une question? Bon! Comme il reste quelques minutes permettez moi de faire une remarque.

Je suis un peu inquiet de l'orientation de notre discussion, car le but de notre colloque est d'aboutir à des conclusions concernant l'utilisation des matières organiques. Une des difficultés est que dans les pays ayant une agriculture traditionelle certains techniciens ont des convictions, presque une religion de la matière organique. Généralement on trouve à l'origine une observation exacte mais extrapolée. Il me semble que c'est parfois le cas même dans nos discussions. Cela tient évidemment au petit nombre de références dont nous disposons. Mais la généralisation suppose une analyse. Ce n'est pas du tout la même chose d'enfouir la matière organique en couche, entre les raies de labour, ce que l'on fait pour éviter le développement des mauvaises herbes, ou de la mélanger au sol. Les effets sont souvent mauvais dans le premier cas et bons en particulier sur la structure dans le second. Ce fait répond à un souci du Prof. SWABY, expliquer comment la matière organique peut migrer dans le sol, je pense que la distribution se fait par un mélange et la fixation par évolution de la matière organique en contact de la matière minérale.

Peut-être ces remarques pourront nous aider à tirer nos conclusions.

Je tiens à remercier encore tous les orateurs.

IV

TRANSFORMATIONS OCCASIONNEES PAR DIFFERENTS AGENTS DANS LA MATIERE ORGANIQUE DU SOL

MICROBES, ORGANIC MATTER AND SOIL FERTILITY

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THE MICROBES

Microbes, representing numerous morphological and physiological types, are found in every particle of earth, in composts, and in a variety of other natural substrates. They are present in great abundance in our sewage disposal systems, in the air above and around us, in the water we drink and in the rivers, lakes, and seas we bathe in. They are also found in human and animal bodies and in the wastes of human lives and of human economy. Most of them are harmless saprophytes and are of great importance to our existence on this planet. Others are harmful, either through their destructive action upon the materials essential to human economy or through their parasitic effect upon man, his domesticated animals, and his crops. Man has learned to take advantage of the saprophytic microbes and to combat the injurious ones.

The role of microbes in the transformation of organic matter is highly significant in connection with these various activities. Two totally different considerations are usually emphasized in the study of these activities, notably: *a*) the liberation of plant and animal nutrients, and *b*) the effect upon soil fertility. In most instances, studies have been carried out with the microbiological population of the soil as a whole. The chemical products liberated in the decomposition processes were analyzed and conclusions drawn concerning microbial activities. This was true, for example, of the liberation of ammonia in the soil, the formation and accumulation of nitrate, fixation of atmospheric nitrogen, formation of CO_2 and absorption of oxygen. This may be considered as the analytical approach to soil microbes. On the other hand, individual organisms were isolated from the soil, grown in pure cultures, and the resulting activities integrated or interpolated in terms of soil reactions and, therefore, of potential soil fertility. This may be considered as the synthetic approach. Each of these approaches has certain advantages and disadvantages. Each tells only part of the story as to the actual part played by soil-inhabiting microbes in the liberation of nutrients in available forms from complex organic materials and in making the soil fertile.

Not only does the microscopic population of the soil take an active part in the decomposition of plant and animal residues on and below the soil surface and in the transformation of the various constituent organic and inorganic substances, but also in the formation and transformation of the black residual mass of organic matter, known as humus in the soil. These processes as well lead to the liberation of the various nutrient elements stored up in the humus, making them available for new plant growth. Of considerable importance are those processes which involve the transformation of the essential nutritive elements nitrogen and carbon, phosphorus and sulfur. The various cycles of these elements have been elucidated. The element nitrogen has been investigated, beginning with the breakdown of proteins and other complex organic materials, leading to the formation of amino acids and ammonia, nitrate and other organic and inorganic forms. The transformation of sulfur was studied in its changes to sulfate, the reduction of the latter to sulfide, the oxidation of elementary sulfur, and a variety of other reactions. The transformation of carbon, phosphorus, and iron also involves, directly or indirectly, the activities of various saprophytic groups of microbes.

The microbes inhabiting the soil and other natural substrates do not live in watertight compartments or in pure cultures. True, conditions are found in nature where the growth of one kind of organism is favored over that of others, resulting thereby in a colonization effect. This was well recognized by the early soil microbiologists, especially as regards the constancy of certain bacterial species. JACOB G. LIPMAN stated that « there are species of bacteria so common in cultivated soils as to constitute a definite bacterial flora. This flora may vary with climatic conditions, the composition of the soil, and the methods of tillage and cropping. However, it shows fairly constant characteristics ». E.J. RUSSELL and his collaborators (1923) also recognized the fact that « there is a close relationship with vegetation, the soil population being dependent almost entirely on the growing plant for energy material, while the plant is equally dependent on the activities of the soil population for removing the residues of previous generations of plants and for the continued production in the soil of simple materials, such as nitrates, which are necessary to its growth. »

Some of the processes carried out by microbes in the soil are not due to the activities of single species, but are rather a result of collaboration of a number of different groups. It is often difficult to establish the role of a particular organism in a given reaction. The decomposition of cellulose, one of the major waste products of plant life, can be brought about by a variety of bacteria, by many fungi and numerous actinomycetes, and even by certain protozoa and other invertebrates. The same is true, even to a greater extent, of the decomposition of proteins and of hemicelluloses, which are readily utilized by a great number of microbes. Various other organic compounds that make up the waste products of plant and animal life, as well as various hydrocarbons and synthetic substances, are also attacked by certain bacteria and actinomycetes. Some of these transformations are carried out in chain-like reactions, where one organism utilizes the products of another, one reaction leading to another and the activities of one microbe depend entirely upon those of another. This is true, for example, of the decomposition of proteins to amino acids and to ammonia, followed by the oxidation of the ammonia to nitrite, and of the latter to nitrate, finally leading to the utilization of some of these products for microbial nutrition and plant growth.

Taken individually and by themselves, each of the processes of decomposition, oxidation and reduction fails to elucidate the complexity of the soil population, with its numerous activities and interrelationships. Microbes may not only assist one another in obtaining essential nutrients, but they may also bring about a variety of other reactious, which are either stimulating or injurious to one another. Some produce vitamins and other substances which promote the growth of other microbes or higher forms of life; some give rise to substances that are injurious to other microbes, notably the antibiotics and various lytic agents.

The numerous interrelationships in a complex microbiological population may be summarized briefly as follows: *a*) associations and antagonisms among microbes in the utilization of essential nutrients; *b*) competition for available space; *c*) selective effect of environmental conditions upon various groups of microbes; *d*) relationships among microbial cells belonging to the same species, as well as among microbes belonging to different species; *e*) relationships between young, growing and reproducing cells, and older or resting cells; *f*) relationships between varieties of microbes that are naturally immune or resistant to certain antimicrobial agents or that have gained such properties and those that are sensitive to such agents; *g*) relationships between microbes that can find protection in the tissues and organs of higher forms of life, notably the symbiotic organisms (root-nodule bacteria or mycorrhiza fungi) and those that are injurious to the higher living systems (various plant and animal pathogens); *h*) relationships among micro-organisms possessing the capacity to attack other living organisms (parasites) and saprophytic micro-organisms; finally *i*) relationships between organisms that obtain their nutrients from simple inorganic elements and compounds and utilize CO_2 as a source of carbon and chemosynthetic or photosynthetic sources of energy (autotrophic forms), and those that obtain their nutrition from dead organic residues (saprophytes).

All these relationships occur among microbes inhabiting the soil, which comprise the soil population. They depend entirely upon the nature of soil, plant vegetation, and the various environmental factors, notably temperature, moisture, aeration and reaction. A given set of conditions will lead to the establishment of a certain population of microbes; other conditions will result in a somewhat different population, either qualitatively or quantitatively. It has often been argued that desirable microbes must be introduced into the soil if they are lacking there. It is not often recognized, however, that the mere introduction of microbes will not necessarily lead to their establishment in a given soil unless conditions are also changed to favor their survival.

When fresh soil is brought to the laboratory, there is a change in the relative abundance of the various groups of microbes. There is a rise in the total numbers of bacteria and of certain other organisms; this is accompanied by an increase in concentration of essential plant nutrients that are responsible for the improvement in soil fertility. The aeration of the soil, the processes of drying and moistening, are sufficient to account for at least some of these changes. This appears to replicate in a minor way the changes that take place in natural soils with the changes in season, from winter to spring and from summer to fall.

Although frequent reports are found in the literature concerning the ability of numerous forms of life to utilize atmospheric nitrogen directly, without the aid of microbes, the weight of evidence points to the fact that this capacity is limited to only certain special groups of microbes. Leguminous plants, with which certain bacteria form root nodule associations, are largely concerned with this process. Although it has not yet been fully established which member of the symbiotic partnership, the bacteria or the plant, is primarily responsible for the fixation process, the results are phenomenal. Other groups of microbes, notably certain algae and certain free living bacteria are also capable of fixing atmospheric nitrogen, but the importance of this process in the overall accumulation of fixed nitrogen in nature is still debatable.

When a wheat seed germinates and produces rootlets, the nutrients required for their continuous growth are obtained largely from the soil; such nutrients are made available largely through the activities of the microbes inhabiting the soil; the green leaves of the growing seedling draw for the synthesis of their cell substance upon the carbon dioxide of the atmosphere, this gas being liberated chiefly through the activities of the microbes acting upon the soil organic matter. During the various stages of growth of the plant, it is attacked by a number of microbes acting as parasites; some, especially certain fungi, attack the roots; others attack the leaves and the seed. Certain microbes living in the soil, if properly encouraged, have the capacity to combat some of these infectious organisms. When the wheat plant matures and is finally harvested, the grains are stored away, whereas the stubble and frequently the straw and chaff as well, are allowed to be decomposed by microbes either in the soil or in a compost or in a manure pile. The harvested grain, as well, may become subject to microbial attack if its moisture content is too high, at or above 15%, thus causing damage to the grain in storage. If the moisture is still higher (30%), the destruction will be even greater. This may result in a loss in the germinating power of the grain or in its complete spoilage. Frequently poisonous products may be formed, especially when the endosperm of the grain is attacked by microbes.

Large numbers of microbes are constantly added to the soil. They include forms injurious to human health, such as the typhoid, tuberculosis and other bacteria present in human excreta. Plant pathogens are also constantly added to the soil with plant residues and animal excreta. Microbes that are beneficial to human economy, such as those essential in decomposition processes and in nitrogen-fixation, notably the legume bacteria, may also be added. The survival of these microbes in the soil presents very special problems. Their relation to those that are already found in the soil or the indigenous (autochtonous and heterochtonous) microbial population involves interaction between different microbes, between microbes and root systems of plants, resulting finally in the particular state of soil fertility, thus involving also the role of microbes in soil formation and soil deterioration.

The earlier microbiologists were largely concerned with the nutrition of various groups of microbes and with the mechanism of transformation of the chemical constituents of the substrate in which these organisms lived. When enzymatic reactions were studied at all, they were largely limited to the transformation of proteins, starches, and lipids. More attention was later paid to the biosynthetic mechanisms involving particularly the oxidative and reductive enzymes, to the various metabolic pathways, to the function of specific metabolites, and to the composition of the cell as a whole. Problems of oxidation and reduction, the mechanisms of different fermentations, the cycles of elements and compounds involved in biosynthesis, the biogenesis of specific metabolic products, such as acids and alcohols, antibiotics and vitamins, enzymes and hormones, received particular consideration. More recently, the introduction of tracer elements in the study of the nutrition of microbes, of chromatographic columns for the analysis of microbial products, and the use of other modern equipment (such as countercurrent distribution, ultra centrifuges, etc.), has greatly facilitated the study of the problems important to our understanding of the metabolic reaction of micro-organisms.

Some investigators believed that the metabolism of all micro-organisms is governed by certain fundamental principles, which are only slightly modified under specific conditions. Others, however, have insisted that each of the numerous species of micro-organisms, comprising thousands of strains and varieties, possesses its own peculiar type of metabolism, as demonstrated by differences in the qualitative and quantitative yields of some of the products resulting from its growth and nutrition.

A.J. KLUYVER attempted to synthesize the information on the great diversity of metabolic processes carried out by micro-organisms. He interpreted the biochemical information as representing a series of step reactions, each chemically intelligible and each mediated by a specific enzyme. The transfer of atoms or larger units from one molecule to another leads to numerous reactions involving transhydrogenation, transphosphorylation, transamination, transmethylation, transacetylation and transglucosidation. KLUYVER emphasized the fundamental unity in the biochemical reactions in all living systems. He also drew attention, however, to the existence among the micro-organisms of cases of biochemical specialization and processes which he characterized as exaggerated examples of reactions that are occasionally encountered as quantitatively minor side reactions.

In speaking of *microbes as a whole,* VAN NIEL emphasized the fact that growth factors for yeasts and bacteria are similar to vitamins required by higher animals, thus leading to the use of microbes for the assay of vitamins and amino acids, and for the detection and identification of as yet unknown growth factors. When it was established that several of these participate in biochemical processes as coenzymes or building blocks for coenzyme synthesis, the usefulness of microbes increased still further, due to their rapid rate of growth and the possibility of controlling the material by the use of pure cultures in chemically defined media. As VAN NIEL said, « The microbes thus became the material *par excellence* for studies of special nutritional problems and of enzymes systems. »

HUMUS FORMATION AND TRANSFORMATION

The formation of microbial proteins may illustrate better than any other process the transformation brought about by micro-organisms in the formation of humus in nature. The micro-organisms play various parts in this process: 1) they bring about the decomposition of fresh plant and animal residues; 2) they contribute in their synthesized cell substance of the humus itself; 3) they are responsible for the further decomposition of the various constituents of the humus. The presence of microbial cell material in the humus or in its disintegration products has been established. In certain types of humus, as in composts or in forest soils, microbial cell substance contributes far larger amounts than has been generally recognized.

SHMOOK suggested that proteins are present in the soil largely in the form of bacterial and protozoan cells. The function of microbial cell substance as a source of humus has also been demonstrated by TRUSSOV and others. SCHREINER and SHOREY suggested that the various chemical substances they found in soil humus are characteristic constituents and may be looked upon as having been synthesized by micro-organisms. According to DONATH and LISSNER, cellulose decomposition by bacteria is accompanied by the formation of a variety of bacterial products; the pectin-like slime produced by these organisms was said to play an important role in the formation of humus.

Several processes of decomposition of plant residues in forest soils, leading to the formation of different types of humus, were recognized by FALCK:

1. The complete destruction of the organic matter by fungi, whereby the yearly addition of plant residues is balanced by the amount of decomposition taking place, without any increase in the total amount of humus; this is accompanied by extensive synthesis of fungus protoplasm, which serves as excellent fertilizer for the forest trees. The cellulose tends to disappear completely, the lignins being more resistant. In some cases, however, as in the process of corrosion of woody material, by Basidiomycetes, the lignins and cellulose alike are completely decomposed; this process predominates in acid humus soils.

2. Decomposition of the plant residues is begun by fungi and continued by lower invertebrates and bacteria. The fungus mycelium, as well as the partly decomposed plant residues, is particularly attacked by larvae of various insects and worms, with the result that a dark mass of humus is produced. This humus is broken down further by bacteria, in the presence of bases; this action results in the liberation of carbon as CO_2 and of nitrogen as ammonia. A mull type of soil is thus formed.

3. In the absence of abundant fungus development a forest humus layer, frequently referred to as « surface peat » is formed. The similarity between the carbon-nitrogen ratio in soil humus and in the protoplasm of micro-organisms, especially fungi, was emphasized by WAKSMAN (1938). He suggested that this is due to the fact that microbial protoplasm makes up a large part of the humus. The decomposition of cellulose added to the soil is controlled by the amount of available nitrogen. The fungi and bacteria decomposing the cellulose synthesize microbial cell substance in direct proportion to the

amount of cellulose decomposed. The ratio between the cellulose decomposed and the available nitrogen required for synthetic purposes is about 30 to 1; i.e., for every 30 parts of cellulose consumed by fungi and bacteria, 1 part of nitrogen is changed from an inorganic form into microbial protoplasm.

When plant and animal residues are added to the soil or are placed in composts under favorable conditions, they immediately become subject to attack by micro-organisms, provided sufficient moisture is present. The rate and nature of the decomposition processes depend on the oxygen supply, temperature and reaction. Some of the plant constituents, such as the starches, sugars, proteins and amino acids, are rapidly attacked. The production of intermediary compounds, such as alcohols and organic acids, takes place largely under anaerobic conditions; under aerobic conditions, the materials are decomposed chiefly to carbon dioxide, ammonia (in the case of the nitrogenous substances), phosphorus compounds and various other compounds. Considerable synthesis of microbial cell substance accompanies these transformations. The production of intermediary dark colored substances, largely formed from the newly synthesized microbial cells, takes place. The plant materials are not decomposed as a whole, however, various chemical constituents being attacked at different rates. Some of the microbes are able to decompose a considerable variety of the plant constituents, whereas others attack only few and will frequently act only upon complexes of a specific chemical structure.

Of the various plant constituents, the lignins are most resistant to decomposition by microorganisms. Their accumulation can be measured by the reduction in the methoxyl content of the residual material. The resistance of the lignins to decomposition is particularly evident under anaerobic conditions, when the activities of practically all fungi and actinomycetes, some of which are capable of attacking lignin, are excluded. Under aerobic conditions the lignins undergo considerable decomposition, although not to the same degree as the cellulose and hemicelluloses; lignins of different plants vary considerably in this respect. The nature of the organisms capable of bringing about the decomposition of the lignins, especially in field soils, is still imperfectly understood.

We may thus conclude that during the decomposition of plant and animal residues in soils and in composts, some organic constituents are attacked readily by micro-organisms, whereas others are more resistant to decomposition. Accompanying these processes, micro-organisms synthesize new organic complexes in the form of microbial cell substance. The nature and the rapidity of the processes of decomposition are modified by the environmental conditions, which influence the type of active microbes, as well as the mechanism of decomposition and the nature of products formed. The mass of decomposing plant residues, together with the newly synthesized cell substance, forms a dark mass of material which is commonly referred to as humus. This humus has no definite chemical composition, but changes constantly as a result of the continuous processes of decomposition. Some of the humus constituents are readily soluble in alkalies and in organic solvents, giving rise to the so-called « humic acids ».

The humus of mineral soils, of lowmoor peats and of forest peats is characterized by a high content of lignin and protein and a low content of cellulose and hemicelluloses. The humus of highmoor peats, originating largely from sphagnum mosses, is low in protein and in ash, high in hemicelluloses and cellulose, and is high in fats and waxes. The humus of sedimentary peats is characterized by a high ash content, a low cellulose content, a high protein content, and a low fat and wax content. Coals, ranging from lignites of recent origin to anthracites of older origin, are characterized by the fossilization of humus, through the stage of peat formations in prehistoric times. The forest floor is characterized by a type of humus which represents recent stages of decomposition of tree residues; this humus can be clearly separated into zonal layer of distinct chemical composition. One may thus speak of humus, not as a single complex or even group of complexes, but as of a state of organic matter, varying in composition depending on the conditions of formation.

SUMMARY

The microbiological population of the soil plays a dominant role in the formation and transformation of the organic matter, in the liberation of plant nutrients in available forms, in the amount and nature of the resulting humus, and finally in the fertility of the soil.

The microbes do not live in the soil in water tight compartments or as pure cultures (with very few exceptions, as in the case of legume bacteria, which are protected from association with other soil microbes by the plant roots), but in complex populations. The various groups of microbes, comprising bacteria, fungi, actinomycetes, protozoa, and other microscopic plant and animal forms exert a variety of influences upon one another. Some assist the growth of others, while some cause injury to others; some produce chemical substances capable of encouraging the growth of other microbes, while some exert antagonistic effects and produce substances (antibiotics) which inhibit the growth of and even destroy other microbes.

The varied activities of the microbial population of the soil, the nature and concentration of the organic matter are, in addition to the nature of the soil, environment, vegetation, methods of soil treatment and systems of cropping, the most important factors that control soil fertility.

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DISCUSSION

Chairman: A. G. NORMAN

NORMAN

Thank you Dr. WAKSMAN for that very interesting account of soil organisms which we all found stimulating, enriched as it was by somewhat unusual scientific illustrations. We have time now to discuss this question. I would just like to start, with the remark which may be of an anticlimax however, to say that as far as I am concerned any definition of soil that does not include the soil population is not a complete definition.

WAKSMAN

Dr. NORMAN, may I be permitted as a senior citizen to ask you whether you might not be willing to come up here as every chairman has done, so that we can hear you better. I really can't hear a word through all these heads and I am very anxious to hear what you say.

NORMAN

For Dr. WAKSMAN's benefit, I'll repeat my comments perhaps a little more graciously than I did last time. I was thanking you for what was a very illuminating discussion of the soil population.

At the same time it was a highly entertaining and personal one, illustrated as it was by the various stories that pointed out the principles to which you wished to draw our attention. I went on to say that it was perhaps something of an anticlimax to remark that any definition of soil that did not include the soil population was not a complete definition. Incidentally, it is a very interesting and entertaining mental exercise to try and write a good definition of soil.

I believe that Dr. JENNY has sometimes addressed himself to the question of what is the definition of soil. Certainly the fact that it is the environment of a diverse population is a very important characteristic. And it is in my opinion a population which is highly competitive, competitive for energy material, for nutrients and the survivors in which are simply those whose biochemical processes are sufficiently flexible or dovetail into those of the other organisms so that they may be successful in this competitive environment.

SWABY

Dr. WAKSMAN, I'm very glad that you mentioned the difficulties of establishing organisms in soils and I'm very well aware of this hardship, but there are occasional success stories and you have mentioned some yourself. We, for instance, have very few thiobacilli in some of our soils and yet you can introduce these provided you put in a sulphur compound. It does'nt always have to be elemental sulphur, even sulphate will do this. One other that I must mention is, that in our country many of our soft woods are introduced from America — the pines — and we did not bring with them the proper mycorrhizal fungi. Instead our naturally occuring ones, which were on our eucalypts, often had to make do, but they are by no means so successful. They are not very good scavengers for phosphorus, for nitrogen and for other organic nutrients. And so BOWEN and THEODOROU have been very successful in introducing more efficient mycorrhizal fungi. Now of course you could say that we could have predicted these successes because we added a specific food or a specific host and I would agree with you. We have had another partial success in which we put a benign organism like Azotobacter on a seed coat, and though this bacterium dies out in a space of about 5 weeks after the seed is sown in the soil, it has an effect upon the seed because it does temporarily reside there and produces some effect which leads the plant to develop its flowering primordia earlier than those which were uninoculated. As a consequence Rovira can get cereals ripened something like a fortnight earlier, and this means a lot to us in our drought-prone continent. In looking into the way that this occurs, it seems as if it is partly due to gibberellin-like hormones produced by the Azotobacter but when we use natural gibberellins they don't have the same effect, so we have not got the correct explanation for it yet. I was going to say that not every seed in a commercial sample benefits by this inoculation. If your seed is good quality and all the seeds germinate in one day, say, you have no benefit at all from Azotobacter inoculation. It's only when you have a variety of seeds that have either been damaged in harvesting, or for some other reason have become pinched, that you get this benefit. Seeds that take two or three days to germinate, benefit mostly from the Azotobacter inoculation. This has led Rothamsted researchers to hypothesize that perhaps these somewhat sickly seeds are protected from root pathogens by Azotobacter. Well, it may be so, we don't know. This I think shows that in some instances if you choose the right environment, such as the surface of a root of a young seedling where lots of substances are leaking out, you can actually establish for a short time at least benign organisms that have no great aggressive power in colonizing the soil.

Waksman

I am delighted that Prof. Swaby has brought up this point, and I would be willing to bet first of all that gibberillic acid is not the only growth-promoting substance produced by micro-organisms. I would be willing to bet further that a good chemist would take Azotobacter and try to isolate certain growth-promoting compounds as my friends in Japan have done with gibberillic acid. The question is whether the effect is due to a growth-promoting substance. There is always the possibility that Azotobacter having a supply of available carbohydrates may actually fix some nitrogen which would be available to the germinating seed. That possibility is not eliminated and I think it should not be very difficult to establish whether nitrogen fixation by Azotobacter takes place, although there is always the possibility that Azotobacter provides some special sort of stimulation to the seed, but whatever the fact is, it is certainly an extremely important question. Incidentally, why did not somebody write a book on growth-promoting substances produced by the soil micro-organisms from the point of view of soil fertility. We know that to be the case of animal nutrition, as in the case of vitamin B_{12}; the tremendous progress could not have been made in the isolation of this vitamin without a knowledge of the need by a certain bacterium of vitamin B_{12}; these bacteria have been used in developing a testing procedure, and I am sure such testing procedures could be easily developed for the relation of Azotobacters to germination of seed.

PRIMAVESI

In the humus formation, the microbial action is decisive. We may conclude of your excellent paper that microbial products and subproducts, not composed, form the principal part of humus. If microbial activity is more diversified and more active such subproducts do not accumulate and humus does not form.

But the effect of « humus » on soil fertility, we may have even, if it never accumulates, because its non-existence in tropical crop soils does not indicate its non-formation.

Your excellent contribution confirms in an exceptional way our experiences in laboratory and in the field.

NORMAN

I think that Prof. WAKSMAN did not quite get your question. Prof. PRIMAVESI is separating the effects of microbial products from the effects of humus and saying that under tropical conditions the latter does not accumulate.

WAKSMAN

As I said, decomposition of the organic residues depends of course on the soil population, but the nature of this population depends upon the nature of the plant and animal residues, the nature of the soil, the environment; therefore, under different conditions you may have a different type of decomposition, a different amount of the material, will be rapidly decomposed. Certainly tropical conditions and warm and temperate conditions would favour different accumulations of organic matter but there are also other factors involved. One would have to study all these factors. It is rather difficult to analyse such results without a knowledge of actual conditions.

FRANZ

Prof. WAKSMAN, you have in a very impressive form shown that the organisms in the soil form a biocenosis which is in collaboration. Every species is in contact with the others. In natural soils this is the case always and we find this biocenosis which correspond to the natural conditions of the soil and of the locality. But in cultivated soils this is not always the case because man is changing the natural conditions by fertilizers, by irrigating soil, by ploughing, by planting different monocultures etc. Not all the organisms which were present in the natural soil can exist in the new artificial conditions so that some of them die and the biocenosis becomes always poorer in species by every changement of environment. This is the case also, I think, with the bacteria and the fungi, and this is the case on a large scale with the animals. So the biocenosis of the cultivated soils is often very poor in species and the different biological processes cannot be realized in the same form as in natural soils. It seems to me to be a very big danger that man is changing natural conditions ever more frequently in a very rapid form. One year he does this and another year he does another thing, so that the micro-organisms which need a certain time to immigrate in a given soil, cannot immigrate newly, since they disappeared. It is a very important question to apply methods of use of soil which guarantee a certain continuity in ecologic conditions. New techniques of agriculture and also of forest use does not always correspond to this ecologic necessity.

WAKSMAN

I am glad that Prof. FRANZ brought out this fact, which is an important contributing element. I hope that you will permit me on Friday to analyze it in the general discussion. I've made certain observations of the various papers that I would like to summarize before you. Man modifies the soil constantly by cultivation, by cropping and by fertilization and I would prefer to answer this question on Friday in more detail, if you would permit me.

NORMAN

I would like to be permitted to comment on Prof. FRANZ's discussion. We all would agree with him that an abrupt change in land use from a natural condition to agricultural use certainly results in a great modification in the microbial ecology. It may be poorer in number of species, it certainly may be poorer in respect to the small animals and insects, but I am not really convinced that the population of cultivated land is necessarily any less efficient in the utilization of the energy material, because of the highly adaptive nature of the soil population. The organisms that persist are the ones that can make use efficiently of what is there.

FRANZ

If we make agricultural use of soils which correspond to ecological conditions, then an artificial biocenosis appears in such soils which is complete enough to guarantee a good evolution of biochemical processes. But it can be also that man produces an environment which is very bad, and then we have a very poor population, and then we have all the difficulties with structure, with bad humus decomposition, with fixation of mineral fertilizers etc.

BRADFIELD

I am not a micro-biologist, but I have a great curiosity about what happens to the flora and fauna of the soil that I am using in some of my experiments in the Philippines. I have felt that these changes in environment of a rather extreme nature may have some beneficial effects, especially on certain plant pathogens. If we grow rice in a soil that is saturated in water for a period of three to four months and then dry it out and grow a crop of corn or sweet potatoes or soy-beans, we are going from an anaerobic system to an aerobic system. Now is this good or is this bad? We have no evidence from crop yields, that it is bad. Can we prevent the build-up of certain pathogenic organisms? I think there is some evidence in the case of nematodes, for example, that if the soil is flooded periodically certain of the nematodes can be kept under control. Does anyone see any possible long-term objections to such a system, or is there from the micro-biological point of view possibly some advantages in these extreme changes in environment?

WAKSMAN

I would like to tell you another story. It was in the late 20's and as you know we have in the United States large areas of peat bogs. One of the most important of these is in the Everglades, Florida; I believe some 5 million acres. A well known company (a large paper pulp manufacturer) bought up a large area of the bog. They were planning to prepare it for the growth of a certain crop. Meanwhile, they planted potatoes for an early crop to provide the northern markets. They planted about a thousand acres and had an excellent crop of potatoes. The second year they planted twenty thousand or so acres but they did not harvest one good potato, because in one year the scab organism became well established in those peat soils and practically ruined the whole potato crop. It just happens that that type of peat is an ideal medium for the growth of streptomyces scabies; soil organic matter and a nearly neutral reaction form an excellent medium for this scab-producing organism. Therefore the only way that they could grow potatoes is to use sulphur, in order to acidify the soil. My old teacher Dr. BYRON H. HALSTED found in 1895 that the use of sulphur will suppress the development of potato scab. He did not know anything about the scab organism, he did not know anything about sulphur bacteria, but he knew that sulphur has such an effect upon the development of scab on potatos in New Jersey. It is possible that a similar set of conditions favours the development of certain other organisms. Once you change the conditions, I am sure that such organisms may become established — you may have to use a soil disinfectant to get rid of some of the nematodes and some of the plant pathogenic fungi. Man continuously modifies the microbial population, and has to learn how to control it, taking advantage of the good microbes and destroying the bad ones.

BIOLOGICAL CYCLES OF CHEMICAL ELEMENTS AND SOIL FORMATION

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Soils are the product of action of living organisms on the lithosphere. The most general and most significant result of biogenic transformation of rocks into soils is the formation of more or less permanent film of humus horizon covering the surface of the continents and of shelfs.

This film could be especially distinguished as « humosphere » equal to the other spheres constructing the Earth as a planet. Insignificant in a thickness this sphere is the most active part of soil cover of the globe, determining the level and potentialities of soil fertility.

Accumulation of specific organic matter and formation of humosphere in the upper part of the earth-crust, is the definite phasis of complication of the history of universal cycle of carbon and nitrogen of Earth planet (Fig. 1). Formation of humus and humosphere started with photosynthesis of plants of continents and continued by animals, insects and micro-organisms. It is very important in this connection to estimate the quantity and the compound of living organic matter (biomass) on dry land. The biomass of dry land is formed as a result of photosynthesis and is utilized in consecutive order by living

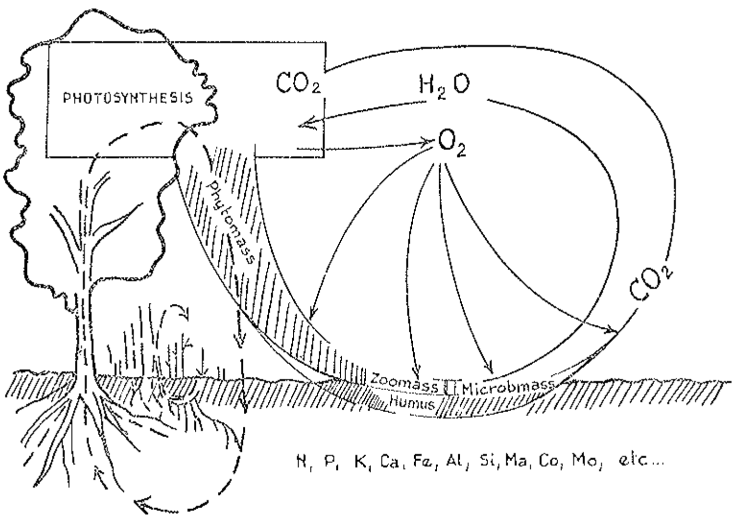

FIG. 1 — Biogenic cycles and soil formation.

animals, insects, micro-organisms and by man. The maximal annual production of phyto-organic matter takes place in the forests of humid tropics as well as in the forests of valleys and deltas of rivers of tropics and subtropics. Considerable amount of organic matter is annually formed in grassland landscapes of savannas, steppes and meadows. Arid steppes, tundras and deserts are characterized by very low annual productivity of phyto-organic matter (Table 1).

The annual photosynthesis on the whole of dry land of Earth comprise $1.5\text{-}5.5,10^{10}$ tons of phyto-organic matter (H.W. MATTSON, A.A. NICHIPOROVICH). This formes approximately 10% of phytomass of all Earth including phytomass of the World Ocean. The total annual photosynthesis of phyto-organic matter of the whole of Planet including the Ocean is of the order of 10^{11} tons.

TABLE I — *Productivity of vegetation of different landscapes. (Qu/he)* (¹). (L.E. RODIN and N.I. BASILEVITCH).

Landscapes	Phytomass	Annual increase	Annual fall off
Tropical valley and delta forests	15-17,000	3,000 (?)	500 (?)
Humid tropical forests . . .	5,000 (?)	325 (?)	250 (?)
Subtropical forests	4,100 (?)	245 (?)	210 (?)
Oak forests	4,000	90	65
Beech forests	3,700	130	90
Fir forest of southern taiga	to 3,000	85	55
Pine forests of southern taiga	to 2,800	61	47
Savannas (of Ghana) . . .	660	120	115
Savannas (India)	268	73	70
Meadow steppes	250	150	140
Arid steppes	100	42	40
Arctic tundra	50	10.55	10
Takyrs of deserts	1	1	1

The fate of vegetable matter formed as a result of photosynthesis, depends on type of plants as well as on geographical conditions of territory. Herbaceous vegetation of meadow steppes and savannas, fully or almost fully is getting dead annually, and in form of litter participate in the beginning of formation of soil humus. Annual fall off of vegetation of forests, particularly of coniferous and tropical forests, produces

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(¹) Qu/he means metric quintals (100 kg) per hectare.

a much lesser amount of organic matter (60% to 80% of annual increase). Considerable part of annual production of forests (of wood vegetation namely 20% to 40%) is utilized for creation of trunks, roots and branches, existing many years. Huge part of not yet fully estimated annual increase of phytobiomass would be utilized directly by animals in plants life time.

In the total the living biomass of dry land of the Earth is represented by phytomass of living plants and fall off (including roots), by zoomass of living animals and insects inhabiting soil (on the surface and inside), microbiomass of bacteria and fungi living in soils, and finally by remnants of died off organisms and of products of their metabolism.

V.I. VERNADSKY (1923, 1926 etc.) outstanding Soviet scientist was the first who calculated the quantity of living matter of Earth planet (quantity of biomass). He got the following order of figures of the biomass: living matter of the planet, 10^{17}-10^{18} tons; living matter of forest, 10^{11}-10^{12} tons; living matter of herbaceous vegetation, 10^{10}-10^{11} tons. The total amount of biomass of the dry land of Earth according to VERNADSKY is of the order of n. 10^{12} tons.

Many years later after V.I. VERNADSKY (1966, 1967) we recalculated the biomass of the main natural zones and landscapes of the Soviet Union and of the total dry land of planet as well. (Table 2). In accordance with our calculation the amount of biomass of whole planet is of the order of 3.10^{12} tons and not more than 1.10^{13} tons. Zoobiomass of dryland comprises approximately only 5% of vegetable biomass and could be measured by the order of $1\text{-}2.10^{11}$ tons. The main part of zoobiomass consists on invertebrata organisms inhabiting soil (90-99%). Particularly big is the component of invertebrata in zoobiomass of most fertile chernozem soils, meadow soils and highly cultivated soils of ancient agricultural utilization (99.8% of zoobiomass). The total weight of soil micro-

TABLE 2 — *Phyto - and zoobiomass of typical biogeocenosis.*

Zones or sub-zones	Biogeocenosis in natural zones	Higher plants		Algae		Micro-organisms		The total phytobio-mass	The total zoobio-mass
		T/he	Per cent from phytobio-mass	T/he	Per cent from phytobio-mass	T/he	Per cent from phytobio-mass	T/he	T/he
Tundra	Moss-lichen tundra	28/2.5 (1)	99.1	0.05	0.2	0.2	0.7	28.25	0.0115
Southern Taiga	Forests	357.9/8.5	99.8	0.5	0.14	0.2	0.06	358.60	0.3617
	Cultural landscapes	12	90.0	1.0	7.0	0.9	3.0	13.90	1.6800
	Flood planes	32	90.0	3.0	8.0	1.2	2.0	36.20	0.6650
	Reclamated flood-planes	31.25	87.0	1.0	3.0	3.6	10.0	35.85	6.4000
Broad-leaved forests	Forests	503/11.1	99.5	1.0	0.3	0.9	0.2	504.90	0.9025
	Cultural landscapes	20	91.0	1.0	4.5	1.0	4.5	22.00	5.0400
Forest-steppes	Meadow - chernozem steppes	23.7	93.0	1.0	3.9	0.9	3.1	25.60	1.4430
	Cultural landscapes	30.0	92.9	1.0	3.1	1.3	4.0	32.30	3.0200
Deserts	Deserts of middle Asia	4.3	81.0	0.5	9.5	0.5	9.5	5.30	0.2200
	Irrigated landscapes	15.0	84.7	1.5	8.4	1.2	6.9	17.70	1.8300

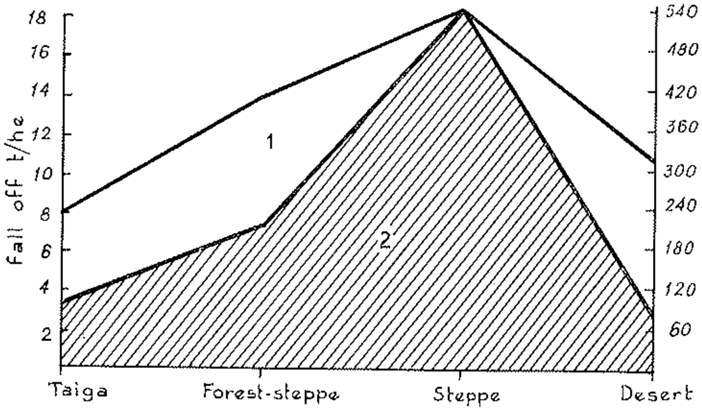
(1) In determinator — the annual increment of biomass.

organisms seems to be not more than of the order of n. 10^9 tons.

In accordance with V.I. VERNADSKY and our data, in total biomass of dry land of Earth absolutely predominate the biomass of forests. Nevertheless the leading role in biological activity of soils as well as in formation of humus and fertility of soils, belongs not to the forest vegetation, but to the herbaceous vegetation of Earth. Herbaceous vegetation has rapidly passing life cycles, and possesses a powerful system of roots producing enormous amount of organic matter annually. All this leads to formation in soils the high percentage of humus and adequate high level of soil fertility. Just the active and quickly cycling biomass of herbaceous vegetation and the associated invertebrata animals, leads together with micro-organisms, to the synthesis in the soil of considerable amount of humus. This is typical for fertile chernozems, prairie soils, brunizems, meadow and valley black colored soils. The above said could be very clearly illustrated with the data of I.V. TJURIN and V.V. PONOMAREVA (Table 3, Fig. 2).

TABLE 3 — *The total stock of humus in soils compared with the annual fall off of vegetation.*

Soils	Organic matter t/he		Coefficient of humification
	Fall off	Humus	
Podzolic soils	7.9	100	12.6
Gray forest-steppe soils . .	13.8	215	15.8
Leached chernozems . . .	18.0	550	30.6
Serozems	10.1	67	6.6



1. Annual fall off. - 2. Humus content.

FIG. 2 — Annual value of vegetation fall off compared with the humus stock.

The correlation between humus content in soils and amount and character of accumulation of phytobiomass is evident. The forest is a powerful destructor of soilforming rocks and a strongest factor of soil formation during the previous geological epochs. This was shown by a French soil scientist H. ERHART (1965). But starting from tertiary time herbaceous vegetation became dominant in many areas of continental plains. After wide spreading of herbaceous vegetation in tertiary time the so called sod process of soil formation started. This very process is typical for meadows, prairies, pampas, steppes, savannas and fields occupied by cereals. Under the cover of this plants black coloured reach of humus fertile soils are usually formed; chernozems, meadow soils, brunizems etc. If one accept that the total biomass of dry land of continents is of order of 10^{12}-10^{13} tons, and if the annual synthesis of phytomass on dry land is of order of 1.5-$5.5 \cdot 10^{9}$ tons, the average duration of whole cycle of carbon involved consequently in phytobiomass, then in formation of zoomass and finally in synthesis of humus (comprising the whole oxidation and mineralization of humus) - could be of the order of 200-600 years, and no more than 1,000 years. Apparently the main mass of organic matter, including the soil humus, exists in average no longer than several hundred years. Some parts of this organic matter could be deviated of soil forming process and could be involved into formation of sedimentary rocks, of sapropel, peat etc. Following to this conclusion we could say that the formation of humosphere of the dryland of continents is the pedogenic part of the more general planetarian cycle of carbon, involved into photosynthesis, in food chains, in soil formation and finally in mineralization up to carbon dioxide (Fig. 1).

Annual synthesis of vegetable biomass is accompanied not only by process of transformation of carbon, hydrogen and oxygen into organic matter, but by transformation and by absorption of considerable amounts of mineral compounds as well. In average the ash content of vegetation is approximately 5-9% with amplitude of the order of 1% to 45% of dry weight. If the average content of ash and nitrogen is 10%, then the annual mobilization of different mineral compounds by means of photosynthesis could be of the order of 10^8-10^9 tons. The fate of mineral compounds including nitrogen involved annually into photosynthesis of phytobiomass, is quite different from that of carbon, oxygen and hydrogen. In the process of destruction of organic matter, all mineral components will be finally induced into soil horizons together with humus. It would be so called biological accumulation of chemical elements in upper horizons of soil. The process of biological accumulation of important elements during the soil formation was discovered by VERNADSKY, GOLDSCHMIDT, WILLIAMS, POLYNOV. This phenomenon is the second aspect of process of transformation of rocks by means of organisms into soils. Therefore the higher is the humus content of upper soil horizons, the (as a rule) higher will be the content of nitrogen, of phosphorus, of sulphur, of kalium, of calcium and of some other elements being of high biological importance. This generalization includes not only macroelements but the trace-elements as well (copper, cobalt, zinc, molibden and others). The higher is the content of humus in herbaceous soils, the higher will be the content of trace-elements (Fig. 3). During the soil formation into biological cycling would be involved compounds of silica, of iron, of manganese, of aluminium as well. Involvement of these elements into biological cycling by means of phytosynthesis, is of paramount importance, in spite that the absolute content of silica, aluminium, iron and manganese in plant tissue is not very high. However the geological duration of soil forming process resulted by involvement into biological cycling through vegetation, a very considerable amounts of silica and sesquioxides, participating

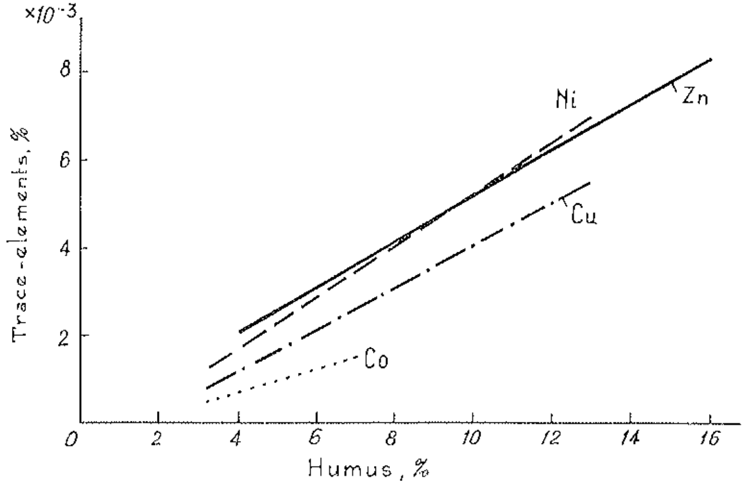


FIG. 3 — Connection between humus and trace-elements contents in soils.

subsequently in the synthesis of secondary clay minerals. One could consider as proved, that the definite part of soil fine earth and secondary clay minerals had been formed as a result of biological cycling of mineral compounds in the system soil forming rock - organisms - soil. The described thesis could be illustrated by Figures 4, 5 showing the content of sesquioxides, silica and other components in the ash of herbaceous vegetation of USSR. It is known that the capacity of soils to absorb and to keep the important for plants mineral components (in form fixed, but available for the plants) is connected with humus and secondary minerals of soils. If soil lost the upper horizons rich on humus, secondary clay-minerals, and macro- and microelements as well, its fertility would be lower or totally lost.

The amount of mineral compounds involved into biological cycling is very different in different associations of plants. (Figg. 6, 7). Herbaceous vegetation of steppes and meadows mobilizes annually into biological cycle as much as 1,000-2,000 kg/he of ash elements. Coniferous forest involves annually into biological cycling only 70-200 kg per hectare of mineral matters. The vegetation of semideserts and deserts could involve very little into biological circulation. Keeping reasonable alteration and rotation of cultural plants on our fields, we could control the direction and chemical character of biological cycling of mineral components of soils. From the point of view of fertility, the most powerful factor of biological cycling and accumulation of important mineral components in soil, among the other form of vegetation has the herbaceous vegetation. Just because of this the cultured herbaceous vegetation, particularly clover and alfalfa must be a regular element of any rotation of plants in the field. The culture of grasses in rotation, as well as organic manuring of soils, is very important as a way of enrichment of soils by carbonic acid for photosynthesis, by physiologically active compounds and by source of energy for soil organisms and soil forming process.

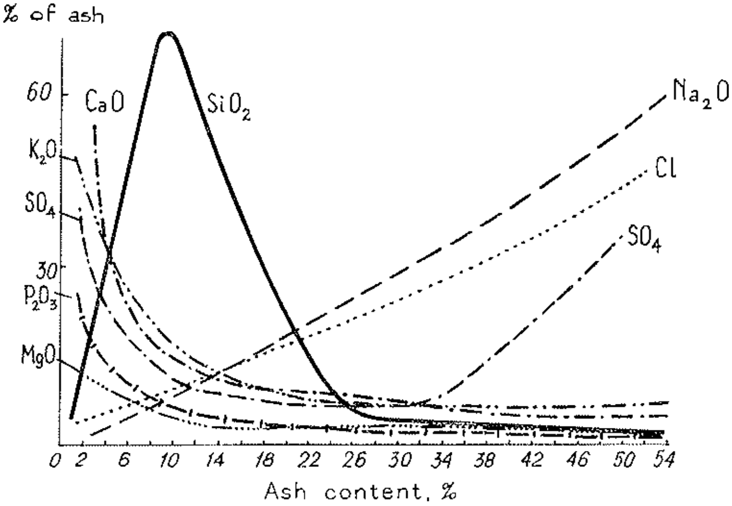


FIG. 4 — Changes of mineral components in ash of herbs.

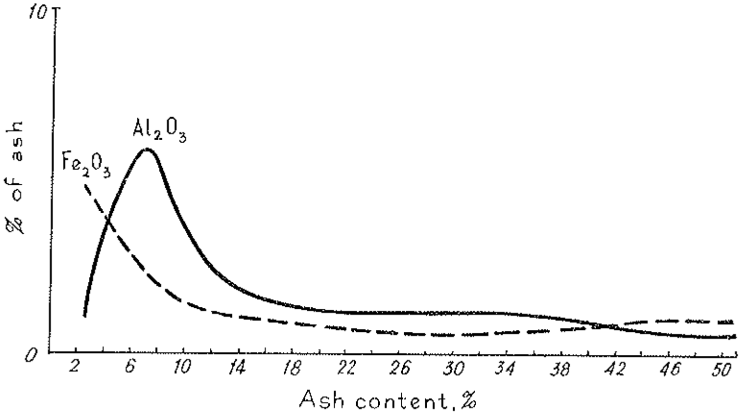


FIG. 5 — Order of content of Al and Fe in ash of herbs.

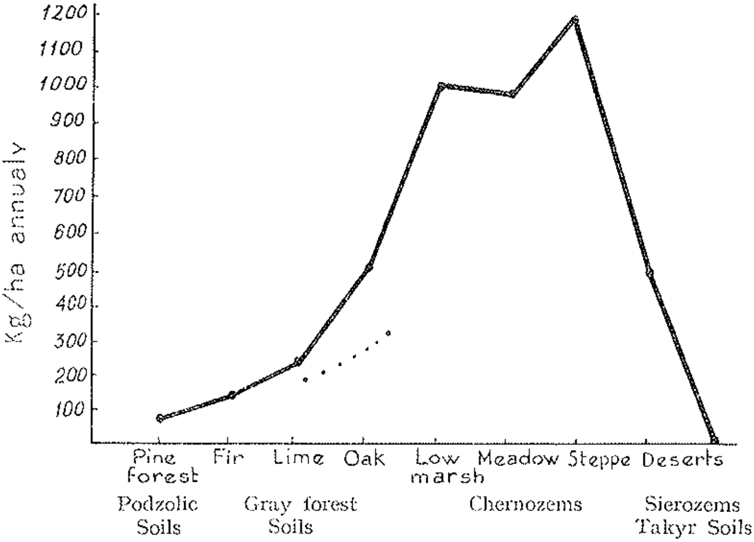
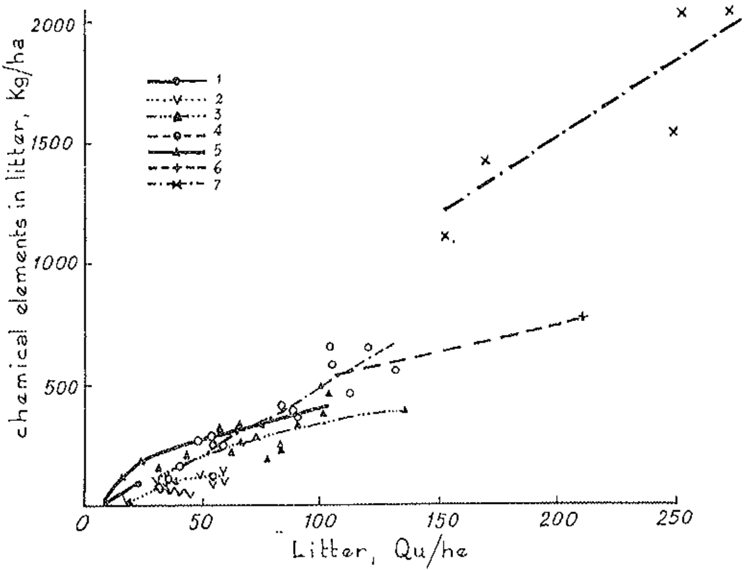


FIG. 6 — Annual biogenic cycles of mineral components



1. Tundra - 2. Coniferous forests - 3. Hardwood forests of temperate zone - 4. Steppes and steppe-meadows - 5. Deserts and dry savannas - 6. Subtropical hardwood forests - 7. Humid tropical forests.

FIG. 7 — Litter and chemical elements in Plants (N. BASILEVICH, L. RODIN).

The living biomass and soil humus as well, are the means of concentration of solar energy and apparatus of redistribution of this energy and of its provision for the chain of consecutive mechanical work and chemical reaction, comprising the substance of soil formation (Table 4).

TABLE 4 — *Energy accumulated in vegetable matter.*
(Calories per cm² annually V.R. VOLOBUEV)

Tundra and deserts	5 - 60
Chernozem-steppes	150 - 360
Humid subtropics	600 - 1,500
Humid tropics	1,500 - 3,500

Without this energy the existence of soil organisms and micro-organisms would be impossible as well as the soil formation itself.

Making evaluation of the role of living matter and particularly of phytobiomass in formation of soils, one must not forget the magnificent transforming influence of living matter on whole life of Earth planet. The lithosphere, atmosphere and hydrosphere of Earth are not only considerably influenced by living matter, but much more, they are fully transformed by integral effect of activities of living organisms in course of history of existence of life on Earth planet. The first plants penetrated on dryland in the Devon era, that means 300-500 millions of years ago. Starting from this period the deepest changes affected the physical-geographical environments of the Earth. Just from this time started the history of soil forming process as biogenic process of dry land of the continents. How magnificent is the transforming influence of life on conditions of Earth planet shows the table:

TABLE 5 — *Biogeochemical agents of soil formation.*

Biomass of dry land	10^{12} - 10^{13} tons
Annual photosynthesis of organic matter .	n $.10^{10}$ tons
Annual cycling of ash components and nitrogen with fall off	n $.10^{9}$ tons
Annual chemical discharge of rivers . . .	3 $.10^{9}$ tons
Annual discharge of silt by rivers	1.6 $.10^{10}$ tons

One could see that summary annual discharge of rivers is amounting of the order of 3.10^9 tons. This is very near to the order of size of annual turnover of ash components of vegetation - 10^9 tons. A summary discharge of silt of rivers has the same order of magnitude as the size of the annually synthesysed phytobiomass.

The modern geochemistry and pedology correctly consider that the chemical compound of hydrosphere, atmosphere, of pedosphere and of sedimentary rocks as well has been created in course of multimillion years duration of interaction of plants, animals and microbes with unorganic components of primordial earth crust.

Exactly in this, one could see the remarkable phenomenon differentiating Earth Planet from other Planets of solar system, and possible of Galactic. On previously dead Earth, endless evolution of matter has created the life. And life has created the biosphere and its child the soils, possessing the fertility and feeding the humanity if correctly and peacefully utilized.

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DEGRADATION OF NATURAL AND SYNTHETIC ORGANIC COMPOUNDS IN SOIL

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This brief review will concentrate on the decomposition, or lack thereof, of specific categories of natural and synthetic organic compounds. There is a large literature dealing with the decomposition of humus and the decay of crop residues that are applied to soil, but I shall be more concerned with specific natural and synthetic organic compounds, especially those which are of particular interest at the present time because their presence in soil contributes to or is the cause of actual or potential problems in agriculture, public health or plant and animal pathology.

Organic matter is commonly considered to have a beneficial influence on soil fertility. However, carbonaceous materials or individual organic compounds may also be associated with or the direct cause of soil infertility. A number of questions immediately arise in the mind of the scientist who wishes to examine the influence of organic compounds or natural products in soil. For example, is soil fertility being reduced as man attempts to get greater crop yields and higher quality farm products by the use of synthetic chemicals? Are problems being created because of the persistence in soil of synthetic chemicals, which are clearly needed in order to feed the ever-growing population of the earth? Why have these problems arisen, if they do indeed exist, and what can be done about them? What are the pedological, microbiological or biochemical reasons for the prolonged persistence in soil of those surface structures or cell constituents of pathogenic microorganisms which serve to prevent the destruction and loss of viability of the fungi, bacteria, actinomycetes and protozoa causing disease of plants, animals and humans. As man puts ever greater demands upon the soil in order to provide food for himself and his neighbors, the need for answers to these and related questions dealing with the degradation and resistance of natural and synthetic organic compounds becomes continually more acute. Moreover, as we gain further knowledge about the severity and extent of malnutrition and as we contemplate the awesome daily increase in the number of humans occupying this land-limited globe, we will probably be forced to increase our reliance on exotic chemicals, molecules not heretofore encountered by the soil microbial community, compounds for which there may be no enzymatic mechanism of degradation. The need for answers is manifestly apparent.

As scientists, even as agriculturalists, we must not shun the responsibilities to our fellow members of *Homo sapiens* by hiding behind the guise of basic research. Fundamental research is unquestionably essential not only to satisfy man's intellectual curiosity but also to provide a basis for developing answers to future applied problems, but we are currently involved in an orgy of scientific irrelevancies in a continuing era of malnutrition, a litany in praise of man's lack of feeling for man. A balance must be sought between needs of the future and the crying demands of the present, between the love affair between scientist and journal and the responsibility that should not need restatement between scientists and society.

BIODEGRADABILITY: CATEGORIES OF COMPOUNDS

Organic compounds which are added to or are generated within the soil may be arbitrarily divided into two categories, one containing the readily degradable compounds, the second containing the more resistant or recalcitrant chemicals. In the readily degradable category are found the monomers which serve as building blocks for the polymers that are the basis of cell structure; that is, the various sugars, simple aromatic structures, amino acids and nucleotides which are the building blocks of the polysaccharides, lignins, proteins and nucleic acids. Almost invariably, these compounds are rapidly degraded in nature. Among the readily degradable synthetic compounds, a number of pesticides could be cited; for example, organophosphate insecticides such as parathion and herbicides such as dalapon and 2,4-D. Among the resistant natural materials, humus unquestionably stands out. In addition, lignin and fungal melanins, which like humus fractions are polyaromatic, are highly resistant to biodegradation in soil. Surprisingly, although many of the polymers found in animal and plant tissues are readily susceptible to microbial degradation, complexes of these polymers are often resistant. Such complexing may account for the protection of cellulose by lignin (FULLER and NORMAN, 1943), for the protection of other polysaccharides by microbially-produced melanin-like polyaromatics (KUO and ALEXANDER, 1967) and for the protection of proteins by plant tannins (BASARABA and STARKEY, 1966). Marked resistance of synthetic chemicals to microbial destruction is a property of a number of chlorinated hydrocarbon pesticides; thus, several chlorinated insecticides have been reported to persist in soil for periods in excess of ten years, and extrapolations from their observed rates of disappearance suggest that some may remain in soil for many decades. Pesticide persistence data have already been reviewed by the author (ALEXANDER, 1965*a*;

ALEXANDER, 1965*b*). The marked durability of organic materials should not come as a surprise to soil scientists who are familiar with the longevity of certain of the humus fractions. In a recent paper, as one illustration, CAMPBELL et al. (1967) used carbon dating techniques to show the fulvic and humic acid fractions to have ages of 470 and 1235 years, respectively.

ECOLOGICAL FACTORS

A number of microbiological principles are relevant to a consideration of the durability of organic materials and to attempts to establish the biochemical bases for the longevity of certain molecular types in soil. For a microorganism to proliferate in the subterranean environment, it must be provided with all of its essential nutrients in a form which can be utilized. These nutrients include a source of energy, carbon, a suitable electron acceptor, other required elements and up to 15 or more growth factors. The absence of any substance essential for the growth of an individual species is sufficient cause for elimination following its introduction by deliberate or natural means. Non-exacting species may grow in a nutritionally simple environment, while fastidious types will be restricted to ecosystems containing all of the requisite nutrients. With time, however, colonization by microorganisms of an initially simple environment leads to its enrichment with the growth factors necessary for even the most fastidious of soil microbial types.

For an organism to grow in soil, temperature, pH, oxygen tension, osmotic pressure or toxin concentration must not exceed the species tolerance for these factors. Species with a certain range of tolerances will not thrive and often are excluded from localities in which the condition or level of the ecological determinant exceeds that of the organism. The inability of a microorganism to become established in a soil containing the requisite nutrients and in which the competitive pressure is weak may frequently result from the unsuitability of one of these factors. A detailed discussion of the environmental factors affecting the rate of microbial degradation of natural or biologically formed molecules in soil is to be found in several textbooks.

COMPARATIVE BIOCHEMISTRY AND BIODEGRADATION

After the era when many of the elementary principles of soil microbiology were elucidated, a new specter appeared on the scene, the specter of the organic chemist. As a consequence of the ingenuity and skill of the chemist, together with the agricultural scientists concerned with pest control, an ever increasing number and variety of synthetic organic compounds began to be introduced into the soils of both developed and developing countries. Many of these chemicals are short-lived and disappear readily as a result of biological, chemical or photochemical processes or by volatilization. Others remain unchanged for long periods of time, often entering into ground waters or surface waters where there likewise may be little microbiological, chemical or photochemical destruction of the polluting chemical. Because of their persistence in soil or in water, these pesticides may be responsible for several undesirable effects. For example, decreases in yield or quality has been noted in crops grown in pesticide-containing fields. Milk derived from cattle fed with forage treated with pesticides has been banned from the market in anticipation of a potential hazard to the consumer. These and related problems arising from the presence in soil of resistant pesticides occur frequently because of the widespread use of such chemicals and because often only minute concentrations are necessary to exert an undesirable influence.

Soil microbiologists and biochemists interested in long-lived chemicals are, to some extent, plagued by a doctrine elaborated many years ago by KLUYVER and DONKER, a concept which revolutionized much of microbiology and biochemistry. This concept, usually now designated as the doctrine of comparative biochemistry, is an integral part of the thinking and a common basis for experimental study in microbial biochemistry. Comparative biochemistry stresses the metabolic unity in the biological world, a unity associated with the existence of certain anabolic and catabolic processes common to all organisms. Comparative biochemistry is little more than a metabolic parallel and possibly an essential corollary of any doctrine of continuous evolution.

Many examples of both the utility and validity of comparative biochemistry can be cited. Thus, the mechanisms of carbohydrate breakdown are common in the muscles of higher vertebrates, in higher and lower plants, and also in the simplest of bacteria, and the similarities are apparent in organisms which evolved early in geological time and also in those which evolved more recently. The mechanisms of decomposition of proteins, amino acids, nucleic acids and aromatic compounds are likewise quite similar in the simple and in the complex organisms. Indeed, a vast amount of biochemical research of the past few years, to a large extent, presupposes the validity of extending the results of studies with model organisms, commonly microorganisms, to allow for an understanding of the metabolism of plants and animals. Frequently, when the issue is put to the test, exceptions are noted, but these exceptions are variables on the underlying themes of comparative biochemistry. In regard to catabolic pathways, therefore, it appears that there is one or but a few degradative themes in nature, although there may be a significant number of variations upon these few themes.

Yet, despite the fact that the chemistry of plant, animal and microbial cells and the major pathways of degradation are remarkably similar, there must exist major biochemical differences, individual physiological idiosyncrasies and peculiarities which are frequently overlooked in the search for common constituents and pathways. These biochemical variations undoubtedly account for the occurrence of unique cell components and sparsely distributed enzymes which catalyze the destruction of peculiar molecules, such as the pesticides.

Given the unquestionable validity and utility of the concept of comparative biochemistry, it is not difficult to design compounds sufficiently far from the mainstream of catabolic pathways which have evolved during the course of time that these chemicals are not metabolized. The likelihood of a microbial mutant arising which can metabolize the foreign material seems to be remote. It is always rather difficult to prove why something which does not occur does not indeed occur, but I believe that the universality of certain degradative pathways makes more reasonable the view that nonbiogradable materials do exist, compounds like those currently being added to soil as man endeavors to increase the production of food and feed crops.

EFFECTS OF RAPID DECOMPOSITION

The rapid decay of certain organic materials may have a profound significance; associated with the microbial destruction of biologically formed carbonaceous substances is a demand by the microflora for nitrogen and other nutrient elements. These elements are incorporated into higher plants. The addition to soil of readily available organic materials also results in a marked demand for electron acceptors; often this need is reflected by the rapid reduction of nitrate to yield nitrogenous gases which are unavailable to plants, namely nitrous oxide and molecular nitrogen, and of sulfate to the phytotoxic sulfide. Anaerobic decomposition may result in the biosynthesis of organic acids and alcohols that may be phytotoxic to economically important plants. Readily degradable crop residues and related organic materials may also serve to stimulate a microflora which antagonizes certain soil-borne plant pathogens. Although it is not clear whether the suppression of the pathogen results from competition, toxin production, predation, or parasitism, such types of biological control clearly are induced by the addition to soil of readily available materials. Some evidence exists for a highly selective biological control of certain fungal plant pathogens brought about by soil amendment with polysaccharides which are similar, if not identical, to those present in the cell walls of the pathogen. Thus, the glucose polymer known as laminarin and chitin selectively enhance a segment of the microbial community which in turn brings about the destruction of selected pathogen species and the microbiological control of the disease caused by the pathogenic fungus (MITCHELL and ALEXANDER, 1961).

ESTABLISHING METABOLIC SEQUENCES IN SOIL

Enormous progress has been made in recent years in establishing how microorganisms degrade natural compounds in unnatural conditions, that is, in laboratory media or in enzyme preparations. Examination of any of a variety of textbooks or monographs will reveal the extent of our knowledge of how sugars, organic acids, amino acids, polysaccharides, proteins and nucleic acids are destroyed in highly artificial circumstances. Little comparable progress has been made in studies of microorganisms or in any natural habitat. One might justifiably question wether this information can be applied to an understanding of what occurs in soil or whether it is important to know what is produced in nature, provided that the added material is destroyed and there are no accumulations of phytotoxins. It has been widely held that carbonaceous substances acted upon microbiologically would be destroyed completely so that there would be no untoward effects because of the appearance in aerated soils of low-molecular-weight products of microbial metabolism. It is now clear that this belief is invalid; e.g., many studies show that microbial decomposition of crop residues even in well aerated soils may lead to the formation of phytotoxins or compounds which may predispose plants to infection by pathogenic fungi. Similarly, a pesticide may be transformed to yield new phytotoxins, insecticides or fungicides-compounds not noted or sought in laboratories monitoring the disappearance of the parent material that was originally used. Many examples of such conversions have been described. It is my belief, however, that the soil microbiologist's interest in tracing pathways should be centered upon those intermediates which may appear free in soil rather than those which are restricted to the confines of the microbial cell.

A host of difficulties appear upon the initiation of a study of pathways of degradation in the highly complex soil environment. The chemical complexity of the environment is enough to frighten away most invitroologists not to mention many soil scientists. In many instances, the metabolism of the compounds of interest has not been investigated before even in the laboratory so that useful biochemical precedents do not exist. Frequently, the chemical of interest is added to soil in extremely minute amounts, as with the herbicides. Needless to say, it is not a simple task to establish metabolic pathways when the compound is applied in minute quantities to a highly complex environment containing a wide spectrum of microorganisms capable of catalyzing many different types of transformation.

Neither time nor space allows for an adequate description of some of the pathways which have been established either in artificial or in natural conditions. KEARNEY et al. (1967) recently reviewed the current status of information on the decomposition of herbicides. Unfortunately, the fate of many of the agriculturally important pesticides has not been investigated, and little is known about how these molecules are cleaved. Yet, even on the basis of limited data, it is clear that the initial enzymatic reaction effects a detoxication of certain biodegradable pesticides and that subsequent intermediates pose no hazard to crop development. On the other hand, a number of other pesticides that reach the soil are not themselves toxic but rather are converted to inhibitory products. These toxic products may persist for short or long periods and may affect species similar or dissimilar to the target organism. Such a conversion of a nontoxic to a toxic material is known as activation. Other toxic chemicals are metabolized to yield new toxicants; some of the microbiologically generated toxicants have been identified, but the identity of others has yet to be established.

An activation is evident in the conversion by members of the soil community of 4-(2,4-dichlorophenoxy)butyric acid, which itself is essentially nonphytotoxic, to 2,4-dichlorophenoxyacetic acid, a highly phytotoxic herbicide (GUTENMANN et al., 1964). 2,4-D, by contrast, is converted to the corresponding phenol which, for plants at least, represents a detoxication (Loos et al., 1967).

One might raise the question whether biodegradation of soil pollutants is really necessary. Cannot nonbiological degradation or sorption phenomena be relied upon to remove the toxicant? Although activity is often diminished or abolished by the sorption of pesticides to soil colloids, the danger of a potential hazard still remains. The pesticide may slowly be released from its bound state, and it then may become a soil or, after migration of the soil particles to a body of water, a water pollutant. Further, chemical degradations rarely are total in nature, so that despite the fact that the original molecule may have been modified, the products remaining after chemical degradation still may be hazardous. Biological degradation, therefore, appears to have certain unique virtues.

RESISTANT COMPOUNDS

Turning to the persistent organic materials, it is unnecessary to comment in detail upon the fact that the durability of natural products, whether added to the soil or generated therein, contributes to the formation and persistence of humus and the retention of plant nutrients. Frequently, the resistant natural product has a beneficial effect on soil fertility—maintaining a suitable soil structure for plant growth, preventing the leaching of nutrients, etc. A slowly degradable pesticide can also be considered beneficial in soil as it serves to control the population of the agriculturally important pest. In like fashion, a slowly available nitrogenous fertilizer, i.e., one slowly acted upon microbiologically, may have a pronounced beneficial effect by contrast with the readily available fertilizer. But the coin of persistence has a bad as well as a good side. The long-life of certain conidia, bacterial endospores, fungal sclerotia, protozoan cysts, and of other microbial propagules contributes to the maintenance of high population levels of pathogenic organisms which affect plants, animals or man. Persistence of viable forms of the pathogens can be attributed to the presence in these organisms of cell walls or surface structures that resist enzymatic destruction.

Nitrogenous constituents of soil organic matter are frequently quite resistant to microbial mineralization. It has been estimated that only shout 2 to 4% of the organic nitrogen is mineralized annually in temperate soils (ALEXANDER, 1961); that is, more than 90% of the nitrogen of the soil organic fraction is not converted to the inorganic form. It is rather surprising that, despite years of study of nitrogen transformations and chemistry, there still is no widely accepted explanation for the resistance of humus-nitrogen to microbial mineralization.

Other speakers at this study week are dealing with the chemistry of humus, and I shall not display my ignorance to such an august body of soil scientists. Yet, I might hazard the statement that we are still not sure why humus fractions are so slowly mineralized. Organic soils, like the humus of mineral soils, have been formed because of the inability of microorganisms to develop or metabolize rapidly in the environmental conditions present at the time when the organic deposits were being formed. Sheerly because of the microbial ineptitude, vast areas of highly productive organic soils are available to provide a basis for the food supply for large numbers of people. Results with the carbon dating technique show that organic soils or organic fractions derived from mineral soils may have ages in excess of 34,000 years (ALEXANDER, 1965*b*).

A number of hypotheses have been advanced to account for the resistance of the organic fraction. A common feature to many of these hypotheses is the suggestion that aromatic units or polyaromatics are associated with or responsible for the refractory nature of humus. Many lines of evidence point to the longevity of polyaromatics; e.g., lignin or melanins. We have frequently attempted to isolate microorganisms capable of degrading fungal walls containing a polyaromatic of the melanin type or to obtain microorganisms active in the hydrolysis of a synthetic melanin, but in no instance was such an organism obtained. BURGES (1960) cites several interesting instances of resistance to biodegradation: the presence of large masses of relict mycelium in mor humus and of considerable amounts of mycelium material encrusted with humic acid in a podzol.

PERSISTENT PESTICIDES

Although persistence is often an undesirable trait in a pesticide, it is simple to show how the long life of a pest-control agent is of value in agriculture or in non-agricultural pursuits.

Pest control tends to be of longer duration with such chemicals, minimizing the cost and reducing the labor. Persistent pesticides may pose no environmental dangers if the compound is not magnified in the food chain to reach concentrations that may detrimentally affect man, fish or wildlife. It would be highly desirable to possess persistent pesticides with no toxicity for any organism other than the target species, but unfortunately the existing pesticides are not too specific; should they be transported from or with the soil to another locale or should a susceptible plant be grown in a rotation in a soil containing a persistent herbicide, unwanted effects may appear. Many instances are known in which the presence in soil of a persistent pesticide reduced markedly the yield of one crop in a rotation; the chemicals typically were applied to eliminate weeds growing in fields planted to a crop unaffected by the herbicide, but they persisted and were toxic to the next crop species in the rotation. Regulatory agencies charged with maintaining the quality of foods face a somewhat different problem associated with persistent chemicals, in this instance, with the chlorinated hydrocarbon insecticides. Although many of these chemicals are not permitted in food products, they are present in fields cropped to plant species which are eaten by cattle. Frequently, the compound was used one or more seasons before the crop was grown, but the microbial flora of the soil has not eliminated the chemical, and it is taken up by the crop, is consumed by the animals and may enter the dairy product in which it is not permitted to be present. In addition to food or feed products being condemned because of their content of persistent pesticides, such long-lived synthetic molecules may be a matter of public health concern inasmuch as the chemical moves from soil into lakes, rivers and streams, entering the water consumed by humans.

Certain metabolic modifications of persistent pesticides are brought about by the soil microflora. Thus, DDT, aldrin, and other chlorinated hydrocarbon insecticides are converted to new products. However, the degradation is far from complete or the transformation occurs at an extremely slow rate, and the chemical remains a public health, an agricultural or an aquatic problem for long periods.

PERSISTENT PATHOGENS

Much information has been acquired on the behavior of alien microorganisms which are either deliberately or inadvertently introduced into the soil. The incorporation of diseased plant tissues or the burial of animal or human bodies infected with pathogenic organisms constitutes a means of deliberate introduction. Commonly, the alien microorganisms fail to develop significantly and often the population is completely decimated because the organisms are unable to form structures resistant to the antagonistic activities of the terrestrial community. Many of the plant, animal and human pathogens, however, do form resistant bodies, often but not invariably in response to unfavorable conditions. These resistant structures are frequently the forms by which the species maintains itself until the resumption of conditions favorable for its growth or until it comes in contact with a suitable host. Thus, sclerotia of many phytopathogenic fungi, endospores of *Bacillus anthracis*, protozoan cysts and the chlamydospores of certain fungal pathogens are the persistent structures formed by these organisms and account for their longevity in soil despite the presence of many microorganisms antagonistic to the pathogen. Each of these resistant structures exhibits a type of latent life, but not only are they able to maintain the capacity for active life but they also have structural components which prevent the destruction of the resting body by soil inhabitants. Yet, despite the tremendous importance of soil-borne pathogens, our knowledge of the chemical constituents responsible for the longevity of these bodies is very meager.

Part of our work has been directed at understanding why some microorganisms are so persistent in nature, while related species are readily eliminated by their parasitic neighbors. In the early investigations, it was noted that certain species of fungi have hyphae which are quite readily destroyed by lytic microorganisms. From soils enriched with susceptible hyphae, strains of *Streptomyces, Bacillus* and *Pseudomonas* capable of destroying the filaments were obtained. Enzymes were prepared from the lytic microorganisms, and their decomposition of filaments was demonstrated. The walls of the hyphae were then shown to contain chitin and β-1,3-glucan, substances which are digested by the chitinase and β-1,3-glucanase elaborated by the lytic soil inhabitants (MITCHELL and ALEXANDER, 1963; SKUJINS, POTGIETER and ALEXANDER, 1965; POTGIETER and ALEXANDER, 1966).

Inasmuch as cell walls of the susceptible fungi contained chitin and the β-1,3-glucan, components which conferred rigidity to the hypha and which, when destroyed, would allow for cell death, it was assumed that fungal structures which were persistent in soil would not contain such polysaccharides. However, some of the resistant hyphae and resting bodies contained either chitin, a glucan, or both. Consequently, it was apparent that another chemical substance resisted decomposition in soil and protected the pathogen. It was then observed that the resistance of the filaments of certain fungi, for example, *Rhizoctonia solani,* was correlated with the presence of a melanin-like component in the cell wall. To demonstrate the significance of the melanin, a melanin-less mutant of one resistant fungus was investigated, and it was shown to be susceptible to degradation by the chitinase-glucanase enzyme mixture produced by the lytic species. Moreover, resistant bodies which contained melanins in their surfaces could be made susceptible by removal of the polyaromatic which protects the susceptible, underlying polysaccharides (POTGIETER and ALEXANDER, 1966;

BLOOMFIELD and ALEXANDER, 1967; KUO and ALEXANDER, 1967). Melanin itself is very slowly decomposed in soil.

Melanins are not the only fungal constituents which resist enzymatic attack. Certain fungi possess surface components which are not rapidly degraded yet they contain little or no melanin; for example, hyphae of species of *Zygorhynchus* and *Mortierella* and spores of other fungal genera. Clearly, investigations of the basis for such resistance can be of considerable value and may allow for a direct approach to the biological control of soil-borne plant pathogenic fungi.

SUMMARY

By way of conclusion, I wish to emphasize that soil microbiological and biochemical problems of the types mentioned herein are daily becoming more acute as the demand for food increases with the ever increasing population. Not only is the uncontrolled expansion of the human population responsible for the increasing requirement for food but also the necessity of improving the nutritional status of many individuals in the developing countries. Without question, prevention of the thousands of deaths that occur each day, particularly among children, due to diseases associated with malnutrition will require ever greater emphasis on chemicals in agriculture. Some of these chemicals are the classical fertilizers. The crop losses attributable to insects, weeds and plant pathogens are so great and the existing techniques for bioenvironmental control are still so primitive that man will have to rely for a long time on synthetic pesticidal chemicals. However, despite the tremendous urgency of alleviating malnutrition, it is essential to protect the health of humans, domesticated animals, and wildlife, both the present and future populations. It would be biologically criminal and ecologically suicidal to assist deliberately in the demise of any cherished or economically valuable species. We must not, moreover, induce infertility in soil in attempts to have higher crop production and better quality foods and feeds. Thus, to increase the productivity of the limited land area of the earth and to minimize the potential of soil or water pollution arising from chemicals applied to or reaching soil, much more information is necessary on the behavior and the reasons for the behavior of synthetic and natural organic compounds in soil. In this way, it may be possible to meet, but only in part, the dramatic upsurge in demand for food because of the unfortunate and uncontrolled increase in the human population, to improve the nutritional status of the earth's human residents and, at the same time, to minimize or eliminate the hazards, potential or real, associated with soil pollution by synthetic chemicals and natural products.

It is a pleasure to acknowledge the invitation by the Pontifical Academy of Sciences. In all humility, however, I wish to stress to that distinguished body that I — as a scientist and an agriculturalist but also as an individual concerned with the well being of my fellow man — feel that concern solely with soil fertility is inadequate, insufficient und misleading. If we are to maintain *Homo sapiens* on this planet, we as scientists must also be concerned with human fertility. Let us not be ostriches with our heads in the ground seeking solely for ways of improving the land's productivity while man's own productivity moves in the direction of outstripping his ability to feed himself, his neighbors and his children.

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DISCUSSION

Chairman: A. G. NORMAN

HENIN

J'ai été très intéressé par cet exposé. On peut remarquer d'ailleurs que les actions toxiques peuvent être observées avec les matières minérales, par exemple le cuivre devient nocif dans les sols légers cultivés en vigne, du fait de l'emploi répété de la bouillie bordelaise.

En agriculture traditionellement on s'efforçait d'éviter les maladies grâce aux rotations. Le temps qui devait s'écouler avant qu'une culture ne revienne sur le même champ, correspondait approximativement à la perte d'agressivité des germes pathogènes.

La question est: pensez vous que la présence de matières organiques dans le sol, ou l'apport de matières organiques, grâce au développement d'une flore variée peut contribuer à la disparition des germes pathogènes?

ALEXANDER

Biological control is extremely effective for a number of diseases. Rotation, fallowing and return of crop residues are simply mechanisms of biological control. There are a number of instances where the deliberate addition of organic materials to soil induces biological control of soil-borne desease organisms. Alternatively, in many instances, the incorporation of organic material makes a disease problem far worse. So organic matter can be considered as a mixed blessing.

SWABY

Prof. ALEXANDER, I was delighted with the way you dealt with this subject and I wondered if you would permit me to ask you questions about two ways that we are trying to deal with recalcitrant molecules in the soil in Australia. We use some of these very persistent chemical weedicides, and one that we have chosen to work on is Picloram, made by the Dow Chemical Company. They are very worried about it also, because they are working very hard with a much bigger team than I have. The fact is that we cannot get legumes to grow after we have applied as little as 1 oz. per acre to kill weeds, until after a fallow of 3 or 4 years. What we have been trying to do is to alter some of the groups in their molecule so as to make this molecule a little bit more attractive to decomposition. So far we have not been successful and I think for a very good reason and that is that we do not exactly know which groups are the ones that are causing this persistence. We have a fairly good idea that it is concerned partly with the carboxyl group and partly with the amino group and may be not only the chlorine groups. Then comes a problem, what are you going to put in place of say a carboxyl side group. You could think of such things as long chain alcohol groups which possibly would degrade back to a CH_3 group, and this may then alter the molecule entirely. So this is the problem of getting chemical companies to put what we might call delectable groups into their products, to make them more attractive to micro-organisms. The second thing that we have been trying to do is to make use of the fact that sometimes we can find organisms in the soil, after a long period of enrichment that will actually attack these micro-organisms. We then isolate them, and in some cases it is not a question of one organism, but sometimes of several organisms to get a chain reaction going. We are trying to put these back, along with the weedicide, so that they will have a sort of in-built redundancy mechanism that might degrade them in a reasonable time. Would you like to comment on these ideas?

ALEXANDER

In regard to the first point, there are very few generalisations, even fewer principles. The compound you are referring to is a nitrogen heterocycle, and we have no information on the effect of the substitution on the rate of decomposition of such compounds. In some of the benzoic acids, which represent another category of herbicides, we know which substituents allow for greater degradation rates, and which substitutents hinder degradation, but this information is probably not applicable to your problem. In regard to the second point you raised, I am pessimistic about the success of inoculation. If one adds a large amount of an organic compound to soil, inoculation might be successful, if the requisite microflora was sparse. However, as you pointed out, only ounces are added per acre, and it is difficult to visualize an inoculated organism finding the chemical.

SWABY

We would put the organisms on with the chemical.

ALEXANDER

Then I would worry about weed control, if the population was highly active.

SWABY

But it does not break it down so rapidly.

ALEXANDER

Such inoculation might be useful, but there is little actual data in this aspect of which I am aware.

BAVER

I was wondering whether, in relation to this resistance to degradation, you have found any relationship to the ability of the soil to absorb these compounds. Because we found in Hawaii, for example, that terrific differences exist in the effect of the herbicides related to the absorption of the organic matter complex.

ALEXANDER

We have not looked for any such relationship. A number of other laboratories have demonstrated a correlation between adsorption of pesticides and their persistence. I might add that there are a number of ways by which the resistance of normally biodegradable compounds can be increased; for example converting the pesticides into insoluble derivatives.

BAVER

Dr. ALEXANDER, you told us that you made determination of 2,4-D in soil and also some plant experiments. Have you ever observed a change in yield of plants in a positive or negative sense?

ALEXANDER

We did not observe an increase in plant growth as a result of 2,4-D decomposition. Several laboratories in Europe have observed such an increase, however. Whether the stimulation is the result of a low concentration of 2,4-D stimulating plants or the result of the appearance of some intermediate in 2,4-D decomposition, I am not able to say.

BROADBENT

Dr. ALEXANDER, first of all I would like to comment that I am happy to see at least one other member of this group with an anthropomorphic approach to the subject. In connection with your discussion of recalcitrant molecules, I would like to ask for your views on the relative rate of breakdown on some of these more resistant molecules in relation to that of some of the materials encountered in soil organic matter which have lives of perhaps several thousand years, as indicated in your written paper.

ALEXANDER

We have advantage in the pesticide field in following specific and discrete organic molecules. Where data exist, the chlorinated hydro carbon pesticides seem to be degraded more rapidly than discrete humic fractions. Alternatively, if the percentage of the total organic fraction of soil decomposing each year is considered, DDT may be more slowly degraded than the total organic fraction.

NORMAN

I am not quite sure whether I am pleased or pained at the colorful language of our biochemists in this field. I really liked « biodegradeable » - it is a descriptive term. I get a bit more concerned about « recalcitrant organic compound » and now when I hear about « delectable groups » then I think I have finally reached the end of the road. What we are really talking about is a more positive kind of thing, these terms are negative statements. What we are interested in is whether there is present or not, in the population, organisms with enzymic capabilities of resolving certain chemical structures. The appearance of organisms that can resolve some of these peculiar structures is I think a very interesting phenomenon. Whether it is an adaptive system, and how persistent this character is in the flora, will present some problems for years to come. Thank you, Dr. ALEXANDER.

MICROBIAL TRANSFORMATION OF SOIL POLYSACCHARIDES

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A. INTRODUCTION

Soil polysaccharides include a diverse and complicated group of polymers, derived for the most part from the cell walls of higher plants and of micro-organisms:

1. *From higher plants,* chiefly as vegetation being returned to the earth at season's end. Essentially linear, homo-polymers, the most abundant of which is cellulose; including also xylans, mannans, galactans, pectic substances, etc.

2. *From micro-organisms* growing on the above glycans, and on other micro-organisms; in part, linear homo-polymers *such* as chitin and β-1→3 glucans, but mostly *branched polymers*: homo-glycans, hetero-glycans, glycopeptides.

The polymeric constituents of cell walls are polyesters, polypeptides and polysaccharides. The esters may be polymers of hydroxy acid, or, more often, polymers made up of alternating units of phosphate and a sugar alcohol. The alcohol, in turn, may be substituted with a sugar unit and/or alanine. (These polyesters resemble the nucleic acids, the latter having a sugar rather than sugar alcohol in the backbone). In general, the esters can be hydrolyzed with alkali, and there is little information on enzyme hydrolysis of these. Polysaccharides are the most abundant components of the walls. They vary in complexity from those containing a single sugar and a single linkage type to those containing several sugars, or modified sugars, with several types of linkages (Table 1).

The nature of soil polysaccharides is usually determined by acid hydrolysis of soil extracts. Glucose is the most abundant component, but the less familiar sugars — mannose, galactose, fucose, rhamnose, hexosamines — make up an appreciable part of the total (Table 2). Ribose, when present, is probably derived from nucleic acids; o-methyl sugars from various bacteria [10].

TABLE 1 — *Factors affecting complexity of polysaccharides.*

Kind of sugar: glucose, galactose, mannose, fucose, xylose, arabinose, rhamnose.

Modification of sugar moiety:

Oxidation to form uronic acids, or aldonic acids

Reduction in the form of deoxy sugars

Substitution: esters such as O-acetyl and O-malonyl
ethers such as found in muramic acid; O-methyl
amino-sugars
peptide, and lipid complexes.

Linkage type: α or β; 1→6; 1→4; 1→3; 1→2.

Extent of branching: From unbranched to highly branched chains.

Orientation of chains: From amorphous to « crystalline » superstructure.

TABLE 2 — *Polysaccharide Composition of Microbial Cell Walls and of Soil Extracts.*

Sugar	Fungi			Bacteria			Streptomyces		Soil Extract	
	1	2	3	1	2	3	1	2	1	2
Glucose	5 +	—	4 +	+	+	+	+	+	2 +	3 +
Galactose . . .	—	2 +	2 +	+	+	—	—	2 +	+	2 +
Mannose . . .	+	+	+	—	+	—	—	tr	3 +	2 +
Fucose / Rhamnose	—	4 +	—	—	—	+	—	—	2 +	+
Pentose	+	—	—	—	+	—	—	—	2 +	2 +
Amino Sugar . .	+	3 +	3 +	—	+	+	+	+		
Uronic Acid . .				—	+	—			(+)	
Muramic Acid . .							+	+		

Fungi [6] 1 Phytophthora cactorum 2 Zygorhynchus vuilleminii 3 Aspergillus niger

Bacteria [31] 1 E. coli 2 Proteus vulgaris 3 Pseudomonas aeruginosa

Streptomyces sp. [7] 1 S. antibioticus 2 S. aureofaciens

Soil - 1 Highly organic Fenland Soil [10] 2 - Average of several soils [21]

Analysis of soil extracts, however, does not give an accurate quantitative picture of whole soil. Many of the polysaccharides (like chitin) resist extraction. As a result, the quantity of amino-sugars revealed by analysis of extracts is very low relative to the overall importance of these in the soil. The amino-sugars may account for 5-10% of the total organic nitrogen in soil, glucosamine being more abundant than galactosamine [21]. Together they constitute a substantial part of the total carbohydrate.

Soil polysaccharides are essentially mixtures of the components of the cell walls of the organisms present therein. Analysis of the latter will greatly simplify and promote the identification of the former. Fungal walls consist of a thin primary chitinous (or, less often, cellulosic) substance variously thickened with β-glucans, α-mannans and heteroglycans. Bacteria contain various modifications of the insoluble chitinous wall (e.g., muramic acid), and, in addition, capsular material outside of the wall. The latter is likely to be viscous, and more readily soluble. Perhaps the soil polysaccharides can best be described by the forms in which they are present. First, and most abundant, is the insoluble, particulate form described above. Perhaps the most characteristic feature of the walls is this insolubility. Second, is the soluble fraction, derived from the capsular materials, and from walls following a partial hydrolysis. Finally, there is the adsorbed fraction, that portion of the solubles firmly bound to clay particles.

Soil polysaccharides are constantly being degraded by the soil flora. The rate of decomposition is greatest for the simple polymers of the common sugars, the most rapid rates being for the glucans, xylans, and β-mannans of higher plants. As the polymers increase in complexity, they become more resistant to enzymic hydrolysis. As a result the « residual » soil polysaccharide is mainly derived from the more complex walls of micro-organisms.

At the end of any growing season, a considerable amount of higher-plant polysaccharide returns to the soil. Because of its relatively simple structure, this substance is rapidly converted by the microflora to microbial tissue. The efficiency of conversion is quite low, and the total organic matter in the soil drops quickly. Both fungi and bacteria are involved, fixing themselves to the surface of the substrate, or penetrating into it (Fig. 1). It appears that most digestion is localized at the microbe-substrate interface. Probably little enzyme diffuses to act on substrates some distance away from the organism. Hydrolytic enzymes have been demonstrated in soil extracts, and the amount of a particular enzyme (for example, xyla-

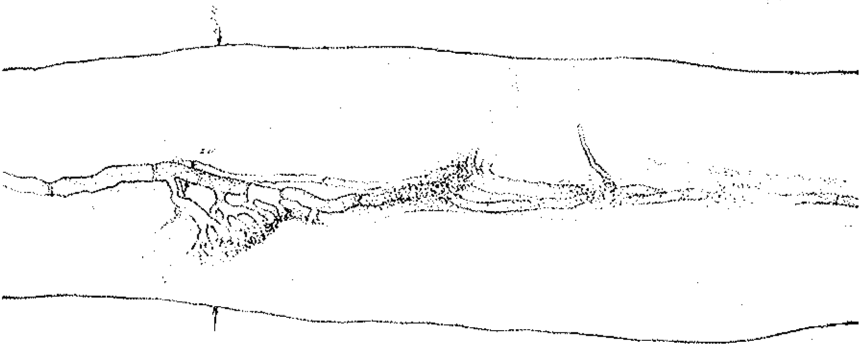


FIG. 1 — Destruction of cotton fiber from within by *Memnoniella echinata*. Drawing by W. L. WHITE.

nase [33], can be increased by incorporating its substrate (xylan) into the soil. But, for the most part, the strong adsorptive action of clay tends to minimize the amount of enzyme diffusing to any great distance from its source.

B. PRODUCTION AND SECRETION OF ENZYMES BY MICRO-ORGANISMS

The digestion of polysaccharides is achieved by the enzymes secreted by micro-organisms of the soil. About half of the types of organism originally present are able to produce the enzymes necessary for hydrolysis of the common polysaccharides (e.g., cellulose). For some substrates, the enzyme is usually constitutive, i.e., it is produced regardless of the substrate being consumed. For others it is induced by the presence of substrate. The organism speeds up the cellulase-synthesizing mechanism, for example, only when it comes into contact with cellulose (provided that no other food stuffs are readily available). Actually, a very small amount of cellulase is constantly being formed, and this is sufficient to produce a little cellobiose from the cellulose. The cellobiose diffuses into the fungus [20] or bacterium [12] where it acts as the true inducer. Thus begins the cycle: more enzyme → more cellobiose → more enzyme ... continuing as long as the cellulosic substrate remains.

In a typical enzyme-inducing system, many factors are involved. As a rule (Fig. 2), readily available sugars like glucose and cellobiose tend do repress the inductive process. It would seem that the organism has learned to refrain from synthesizing enzymes that are not required at the moment.

Digestion of the complex polysaccharides proceeds in a similar way, but the ability to produce the required enzymes is limited to a relatively few organisms. These, then, become dominant members of the microflora.

Digestion is the function of enzymes produced by *living* organisms. After death cells may be digested by their own intra-cellular enzymes acting upon the disorganized structures resulting from death. The extent of such autolysis has not been evaluated. It does suggest that many organisms which have the ability to synthesize a polysaccharide also produce the enzymes required for its digestion.

The location of enzyme synthesis and the method by which the enzyme is secreted are not known. The difficulty in explaining how enzyme molecules penetrate through the cell membrane has led to the suggestion that synthesis may be at the surface of the cell membrane. The cell wall itself is generally assumed to be porous enough to permit diffusion of molecules once they are outside of the membrane.

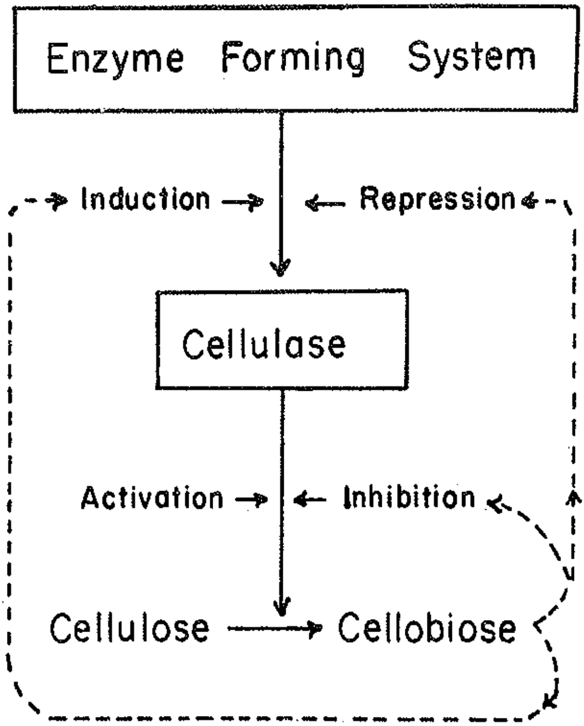


FIG. 2 — Enzyme Forming System.

C. NATURE OF ENZYME ACTION

1. *Solubilization of substrates*

I would like to present a broad view of the enzymes responsible for the hydrolysis of polysaccharides. But first it is necessary to examine the methods by which organisms modify solid foods prior to the action of the normal hydrolytic enzymes.

Mastication, grinding and other means of mechanically disintegrating solids is a common preliminary to digestion in higher animals, and indeed in all animals having mouthparts. Microbes have no such capabilities. Yet it is important that similar changes be brought about, especially in various highly oriented polymers, to increase their susceptibility to hydrolysis. This may involve increasing the ability to take up moisture, and improving the diffusibility of enzyme. Thus, LINDERSTROM-LANG [18] found that splitting the disulfide linkages of wool is necessary before proteases can bring about hydrolysis. The action results in a marked swelling of the wool in water. We have found an enzyme (C_1 in our nomenclature) that acts on *crystalline* cellulose, before the β-1→4 glucanase can bring about hydrolysis. While it has been possible to isolate this enzyme [32], there is no indication of what it does and it can only be measured by adding β-1→4 glucanase. C_1 is a large glycopeptide molecule (molecular weight 60,000 [32]) retained in a dialysis sac and precipitated by solvents. It is an induced enzyme, pH- and temperature-dependent, and inactivated by heat and various chemicals. It is difficult to obtain, except from *Trichoderma viride*, which indicates that usually it is either strongly adsorbed on cellulose, or rapidly inactivated.

An initial solubilization, or swelling, of insoluble polymer (as above) may be a necessary and general prerequisite to the action of hydrolytic enzymes (Fig. 3). The accomplishment of this action may be physical, i.e., mastication; chemical, as in the splitting of disulfide bonds in wool; or enzymatic, as in the case of C_1. The action may simply separate closely bound polymer chains to permit access of water and enzyme; or it may cleave a bond to form two or more soluble fragments from an insoluble one. In complex structures composed of several components, it may even be involved in the removal of an encrusting substance, or of a side group from a polymer chain.

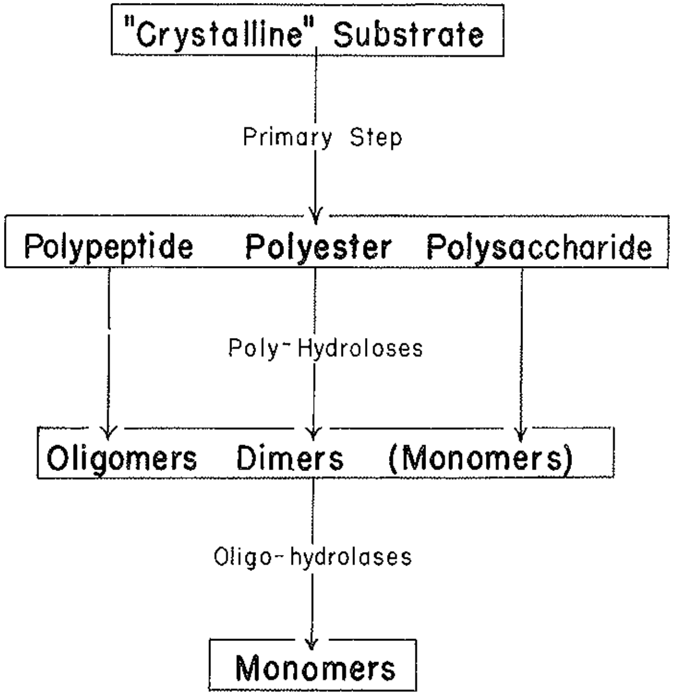


FIG. 3 — Digestion of highly oriented insoluble substrates.

Lysis of complex microbial walls offers another example of the presence of a solubilizing step. The splitting of comparatively few linkages is sufficient to convert insoluble wall to soluble, polymeric products. « The cell walls of *Bacillus subtilis* contain an autolytic enzyme (N-acyl muramyl-L-alanine amidase) which rapidly solubilizes the cell wall by hydrolyzing the amide bond between the carbonyl group of N-acyl muramic acid and L-alanine » [41]. The products include such soluble polymers as polysaccharide, polypeptides and polyesters (teichoic acid). At this stage, the well-known hydrolytic enzymes take over, rapidly hydrolyzing the now readily accessible substrates to much smaller fragments. In this case, it is an amidase which makes possible the subsequent depolymerization, and it is the amidase indeed — if lysis is to be considered solubilization — which must be considered as the lytic agent.

Chemically treated cells are usually much more susceptible to lysis than the living cell. How such agents act is not known, but again they are effective in bringing about those changes which permit the depolymerizing enzymes to function. EDTA is one such agent [29]; sodium dodecyl sulfate is another.

The removal of encrusting agents is required when the primary structural material of a cell is embedded. Old cells are more resistant to lysis than young ones. In many yeasts the chitinous wall is covered by glucan, mannan, etc., which prevents chitinase from reaching its substrate. The action of glucanases effectively removes much of the crust, but the cell retains its structure, i.e., remains insoluble. In this instance, the action of glucanase — a depolymerase itself — precedes the disrupting step.

Many examples of such systems are reported. All are quite diverse in operation, and usually act in such subtle ways that it is almost impossible to determine the initial — and critical — reaction.

Lysozyme is, perhaps, the agent most commonly used to lyse bacterial cell walls. Here, too, pretreatments are often necessary. An EDTA pretreatment is required for action of lysozyme on gram negative bacteria. Phenol extraction of *E. coli* removes components that interfere with lysozyme action. Removal of a rhamnose-glucosamine polymer from Streptococcal walls rendered them sensitive to lysozyme [24]. Removal of O-acetyl side groups led to susceptibility. The iuitial reaction in these instances is not that of lysozyme but of an agent which makes it possible for lysozyme to become functional.

For the lysis of some fungal cells, high concentrations of mannitol (0.8M) are required. In the absence of the mannitol, the same enzymes bring about no lysis. Is this a reflection of tension in the wall, resulting from normal internal pressure, a tension which is released in the presence of high external osmotic concentrations? There are many such questions requiring investigation.

We believe that the first, solubilizing step is extremely important, and relatively uninvestigated. Indeed, in most cases, it is likely that this step has been overlooked. Cells which resist lysis have been killed to make them susceptible. What change did this achieve? Enzymes have been used to effect lysis. What other enzymes, or co-factors, were present therein? What is the effect of pH changes, or of the temperature used? Certainly the products are susceptible to depolymerizing enzymes. But what changes were brought about first?

2. *The endo-polysaccharases*

Polysaccharases are of two general types:

a) *endo-polysaccharases,* those which act on the polymer in a random fashion, and

b) *exo-polysaccharases,* those which remove one monomer, or one dimer, at a time from the non-reducing end of the polymer chain. (The usage of endo- and exo- thus differs here, from usage in some microbiology laboratories, where the terms are used to indicate location of an enzyme within, or outside of, a cell.)

For the sake of completing the group, there are also the

c) *glycosidases,* which do not act on the polymers and are not polysaccharases, but which act on the dimers, trimers and tetramers produced by the polysaccharases.

We will now attempt to describe these types, using only such examples as will illustrate the mechanism involved. In general, information is most complete for enzymes acting on linear homo-polymers. As the polymers increase in complexity, knowledge of the enzymes responsible for their hydrolysis becomes more vague.

The endo-polysaccharases are the characteristic random-acting enzymes responsible for the hydrolysis of high molecular weight, polymeric, carbohydrates. (On such materials, exo-enzymes are inactive because there are so few chain-ends available to them.) The endo-polysaccharases act preferentially on long chains, and with retention of configuration. For example, α-amylase acts on α-linkages to produce α-anomers, and lysozyme acts on β-linkages to produce β-anomers. Cleavage appears to be between C-1 and the bridge oxygen as in glycoside hydrolysis. The isolated polysaccharases are often associated with carbohydrate. Relatively few have co-factor requirements, and usually they are quite stable enzymes. Their molecular size is generally in the range of 12,000-60,000. It has been suggested that endopolysaccharases are usually smaller enzymes than glycosidases [2].

PRODUCTS OF ENDO-ENZYME ACTION

Acting on soluble polymeric materials, the random-acting endo-enzymes cause a rapid increase in fluidity, accompanied by a relatively slow increase in reducing end-groups. The action is not entirely random, the linkages at both ends of the molecule being somewhat less affected than internal linkages. Another limitation is in the lower limit of size for susceptibility. The rate of hydrolysis increases with degree of polymerization (DP) within the limits of substrate solubility. Cellobiose, for example, is not hydrolyzed by endo-β-gluca-

TABLE 3 — *Products of endo-enzyme action on polysaccharides.*

Substrate	Enzyme	Product
Homopolymer: 1 linkage		
β 1,4 glucan $(G\xrightarrow{\beta}4G)_n$	β 1,4 glucanase	$[G]_3+[G]_2+G$
α 1,4 glucan $(G\xrightarrow{\alpha}4G)_n$	α 1,4 glucanase	$[G]_3+[G]_2$
α 1,4 glucan $(G\xrightarrow{\alpha}4G)_n$	*B. macerans* enzyme	cyclic $[G]_6$ to $[G]_8$
Homopolymer: 2 linkages		
Linear		
Mycodextran $(3G\xrightarrow{\alpha}4G)_n$	mycodextranase	G-3G-4G-3G*; G-3G*
Lichenin $(4G\xrightarrow{\beta}4G\xrightarrow{\beta}3G)_n$	β 1,4 glucanase	$[G]_4$; G-3G-4G*; G-4G*
	β 1,3 glucanase	$[G]_4$; G-4G-3G*; G-3G*
	« lichenase »	G-4G-3G*
Fructan (β 2,6 with occ. β 2,1)	levan polyase	$(F2\rightarrow6G)_{5\pm}$
Branched		
Dextrans (α 1,6 with α 1,3 side branches)	α 1,6 glucanase	$G\text{-}\underset{\substack{3\\ \vert\\ G}}{6G}\text{-}6G\text{-}6G\text{-}6G^*$ (etc.)
Heteropolymers		
Linear		
Hyaluronic acid $(\text{-}4GU\xrightarrow{\beta}3NAG\text{-}\beta\text{-})_n$	testicular enzyme	$[\text{-}4GU\xrightarrow{\beta}3NAG\text{-}\beta\text{-}]_n$ $n=1\text{-}7$
	leech enzyme	$[\text{-}3NAG\rightarrow4GU\text{-}\beta]_n$ $n=2$
	bacterial « eliminase »	4-*ene* $Gu\xrightarrow{\beta}3NAG^*$
Branched		
« Chitomuran » $[4\text{-}NAG\xrightarrow{\beta}\underset{\substack{\vert\\ M}}{4NAG}\text{-}\beta]_n$	muramidases	$[4\text{-}NAG\xrightarrow{\beta}\underset{\substack{\vert\\ M}}{4NAG}\text{-}\beta]_n$ $n=1\text{-}2$
	glucosaminidases	$[\underset{\substack{\vert\\ M}}{4\text{-}NAG}\xrightarrow{\beta}4NAG\text{-}\beta]_n$ $n=1\text{-}2$
Galactomannan β 1,4 mannan and galactose	β-mannanase	$M\xrightarrow{\beta}\underset{\substack{6\\ \alpha\uparrow\\ Gal}}{4M}\xrightarrow{\beta}4M^*$
Chondroitin 4-SO_4 $[4GU\xrightarrow{\beta}\underset{\substack{4\\ \vert\\ SO4}}{3NAGal}\text{-}\beta\text{-}]_n$	Proteus enzyme	$GU\xrightarrow{\beta}\underset{\substack{4\\ \vert\\ SO_4}}{3NAGal}^*$
	« eliminase »	4-*ene* $GU\xrightarrow{\beta}\underset{\substack{4\\ \vert\\ SO_4}}{3NAGal}^*$

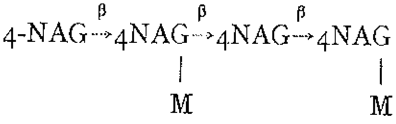
nase; cellotriose may or may not be attacked (depending on the source of enzyme) but cellotetraose is hydrolyzed by endoglucanases of most organisms.

Acting on homo-polymers such as β-glucans, the endo-polysaccharases produce dimer and trimer as the major products (Table 3). Indeed the proportion of trimer to dimer approaches the theoretical ratio (for α-amylase) based on random hydrolysis and resistance of terminal linkages [40]. While dimers and trimers are the most common end-products of endo-polysaccharase action (Table 3), the reaction can be stopped at a stage in which larger products predominate. Tetramers and pentamers, etc., are often observed. In an unusual instance, the major products are cyclic oligosaccharides (Schardinger dextrins).

Increasing the complexity of the polysaccharide leads to hydrolysis products which are themselves complex (Table 3). Very long fragments (DP 11) result from the action of levan polyase on a linear levan (2→6) containing occasional 2→1 links. Branches remain in the products of hydrolysis of branched polysaccharides. Dominant trimers or tetramers result from the action of specific enzymes on polymers of mixed linkage.

When the polysaccharide substrate contains alternating linkage types (e.g. mycodextran), or alternating sugar units, the ultimate products of the endo-enzyme action may be tetramers, or larger fragments, the tetramer containing two of the dimeric units, connected by a linkage of the type susceptible to hydrolysis by the enzyme

$(\mathrm{G}\xrightarrow{\alpha}3\mathrm{G}\xrightarrow{\alpha}4\mathrm{G}\xrightarrow{\alpha}3\mathrm{G})$ from mycodextran by an enzyme which splits α-1→4 linkages, and



$$4\text{-NAG}\xrightarrow{\beta}\underset{\mathrm{M}}{\underset{|}{4\mathrm{NAG}}}\xrightarrow{\beta}4\mathrm{NAG}\xrightarrow{\beta}\underset{\mathrm{M}}{\underset{|}{4\mathrm{NAG}}}$$

produced by lysozyme

While the tetramers are the major products, they may be broken down to dimer, but often at a very slow rate. Such products are characteristic of the initial polymeric substrates and useful for its identification. Their production is often the result of the action of specific enzymes (usually of rare occurrence).

SPECIFICITY AND THE ACTION OF ENDO-POLYSACCHARASES

There are a large number of endo-polysaccharases. Different ones are required for the hydrolysis of each of the various homo-polymers. Thus, there are glucanases, galactanases, chitinases, etc.; and different enzymes are necessary in each group because of the diversity of linkage types. Thus, of eight possible glucan types (Table 4), seven are known to

Table 4. Glucans and Glucanases

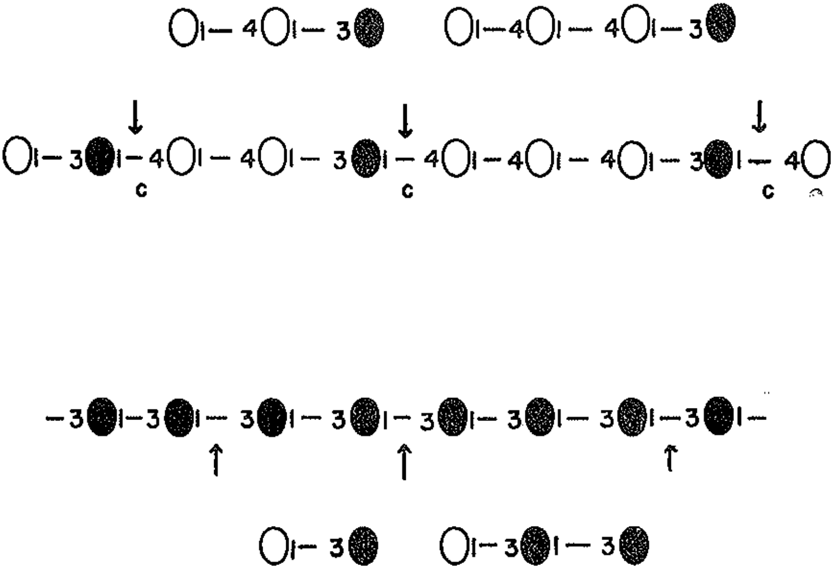
Glucan	Source	Enzyme	
$\alpha\ 1\rightarrow 2$	(Unknown)	—	—
$\alpha\ 1\rightarrow 3$	Aspergillus; Polyporus	Endo	Exo
$\alpha\ 1\rightarrow 4$	Plants; amylose		*Exo-
$\alpha\ 1\rightarrow 6$	Leuconostoc; dextran		Exo-
$\alpha\ 1\rightarrow 4, \alpha\ 1-6$	Amylopectin; glycogen, pullulan		
$\beta\ 1\rightarrow 2$	Agrobacterium		—
$\beta\ 1\rightarrow 3$	Seaweeds; laminarin		*Exo-
$\beta\ 1\rightarrow 4$	Plants; cellulose		Exo-
$\beta\ 1\rightarrow 6$	Umbillicaria; pustulan		—
$\beta\ 1\rightarrow 4, \beta\ 1-3$	Lichenin; lichens; grains	↓	

occur in nature, and a different endo-glucanase is needed for the hydrolysis of each. The high degree of specificity of these enzymes is sometimes overlooked, and it is claimed that a cellulase acts on xylan, or vice versa. Such claims probably arise from inadequate separations, and insufficient information. As enzyme methods improve, the degree of specificity is found to increase. Indeed, within each enzyme type there may be several « isozymes », each acting on the same substrate, but having such different physical properties that they are separable by techniques currently available.

Because of their specificities enzymes have generally received their names from those of their substrates. With additional information on the nature of the substrate, the names may take on different meanings. In general, it is best to apply names that describe the substrate (e.g., endo-α-1→4 glucanase rather than α-amylase) especially for enzymes acting on the homo-polymers.

As investigations move in the direction of more complex substrates, the nature of the enzymes, and of enzyme action thereon, become more difficult to understand. Yet it is from such studies that new light is shed on old systems. Recent investigations of glucans having both β-1→3 and β-1→4 linkages have led to a reconsideration of the factors affecting the specificities of the glucanases (Perlin [27]). Two important facts have emerged from this work:

a) the endo β-glucanases are *not* always specific for the linkage which they split. The enzyme which randomly splits the β-1→3 links of laminarin preferentially splits the β-1→4 bonds of lichenin, even though β-1→3 bonds are also present (Fig. 4). At least three types of enzyme act on lichenin. « Lichenase » may be an endo-β-1→4 glucanase (cellulase), or an endo-β-1→3 glucanase (laminarinase), or a specific enzyme which hydrolyzes lichenin (but does not hydrolyze cellulose or laminarin);



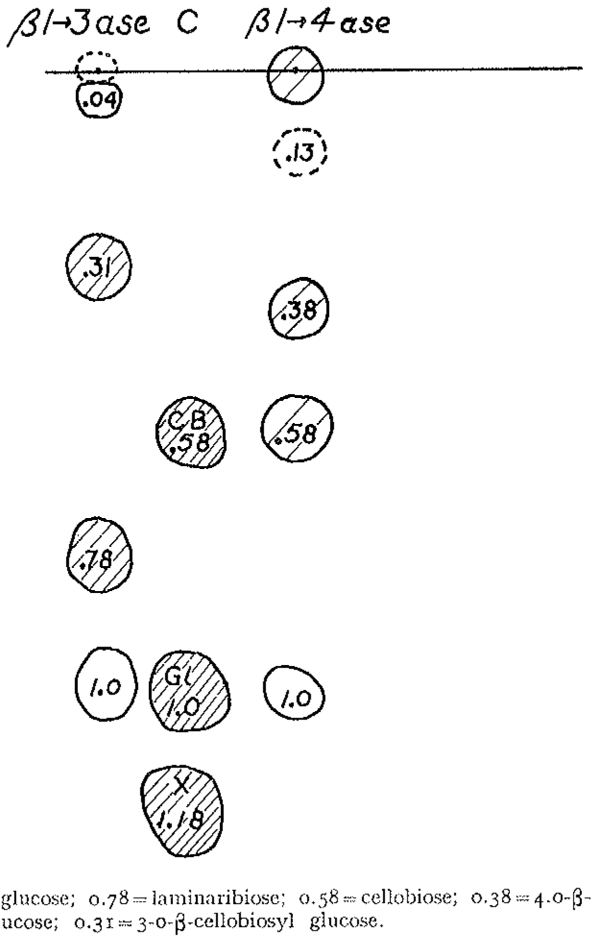
● = Glucosyl unit substituted at C_3; O = Glucosyl unit substituted at C_4.

FIG. 4 — Action of endo-β-1→3 glucanase on a 1→3 linkage in laminarin (lower), and on a 1→4 linkage in lichenin (upper).

b) all products of hydrolysis of a β-glucan by a particular enzyme have the same linkage between the two glucose units at the reducing end of the chain. The products of hydrolysis by a cellulase and by a β-1→3 glucanase are:

Cellulase		β-1→3 glucanase (endo-)	
from cellulose	*G1→4G*	from laminarin	*G1→3G*
	G1→4 *G1→4G*		G1→3 *G1→3G*
			G1→3 G1→3 *G1→3G*
from lichemin	*G1→4G*	from lichenin	*G1→3G*
	G1→3 *G1→4G*		G1→4 *G1→3G*
	G1→4 G1→3 *G1→4G*		G1→4 G1→4 *G1→3G*

Common to all of the cellulase products is a cellobiose (1→4) moiety at the reducing end of the oligosaccharide; common to all β-1→3 glucanase products is a laminaribiose (1→3) moiety (Fig. 5).



R_G 1.0 = glucose; 0.78 = laminaribiose; 0.58 = cellobiose; 0.38 = 4.0-β-laminaribiosyl glucose; 0.31 = 3-0-β-cellobiosyl glucose.

FIG. 5 — Hydrolysis products of lichenin by endo-β-1→3 glucanase, and by endo-β1=4 glucanase. Chromatogram.

The data favor describing the action of these enzymes in terms of the *structure of the glycosyl unit that becomes the reducing end-unit of the product liberated.* Since the substituent on the glycosyl unit is always glucose (in the work reported), we propose extending the concept by substituting « disaccharide » for « glycosyl ». In a specific instance, cellulase has an affinity for a cellobiose fraction of the polymeric chain, hydrolysis occurring at the adjacent cellobiosyl bond. The cellobiose itself is protected from hydrolysis, due to binding of the dimer to enzyme. Endo-β-1→3 glucanases behave in an analogous fashion. Since the bond which is broken may be β-1→3 or β-1→4, it appears that the aglycone portion of the polymer is relatively less important. A similar affinity of β-amylase for a terminal maltose unit in the amylose chain has been reported [38], indicating that this mechanism may be generally applicable to glycanases forming dimeric and trimeric products, whether they be of the endo- or exo- type.

The fragment of the chain for which there is a site on the endo-enzyme need not be limited to a dimeric unit. The specific « lichenase » (of *Bacillus subtilis*), acts on lichenin to give predominantly the trimer, 3-o-β-cellobiosyl D-glucose [27]. In forming this trimer, the *B. subtilis* enzyme closely resembles the endo-β-1→3 glucanases, but its specificity cannot be related *only* to the presence of a β-1→3 dimer unit in the polymer, for it is unable to attack a long chain of such units (i.e., as in laminarin).

In the above examples, the β-glucan with a sequence $(1\rightarrow 4, 1\rightarrow 4, 1\rightarrow 3)_n$ is susceptible to hydrolysis by endo-enzymes which act on β-1→4 glucan and by those which act on β-1→3 glucan. What would be the effect if the linkages *alternated,* i.e., if there were not two of the same linkage in sequence? Mycodextran is such a glucan, having alternating α-1→3 and α-1→4 linkages. It is completely resistant to hydrolysis by endo-α-1→4 glucanase (α-amylase). Similarly, the β-mannan from

Rhodotorula glutinis with alternating 1→3 and 1→4 linkages is resistant to endo-β-1→4 mannanase [11; REESE, unpublished]. It appears that alternation of linkages produces so great a change that the normal endo-enzymes are nnable to attack. However, there are specific enzymes which do act on these mixed linkage substrates, just as there are specific enzymes for lichenin. These, in turn, *cannot* act on the one-linkage polymer. Thus, mycodextranase splits α-1→4 linkages in the (1→3, 1→4) glucan, but it cannot split α-1→4 linkages in starch. In this instance, we believe the enzyme has an affinity for an α-1→3, 1→4, 1→3 tetramer portion of the polymer (tetramer is the major product), with resultant splitting of the adjacent tetrayl-O bond. (Earlier we had believed that mycodextranase had an affinity only for the α-1→3 dimer of glucose and that the enzyme would be able to hydrolyze a glucan having all α-1→3 linkages by analogy with the endo β-1→3 glucanase system, splitting now an α-1→3- rather than an α-1→4-linkage. However, when we subsequently obtained the α-1→3 glucan, we found it to be resistant. The requirement is thus for something more than the dimer itself.)

There are polymers differing from the above in having the same linkage (i.e., β-1→4) but alternating sugar units (-4N-Ac glucosamine$\overset{\beta}{\rightarrow}$4 N-acetyl muramic β-)$_n$. These again require specific enzymes for their hydrolysis. When tetramer is the major product, we believe the enzyme site must be large enough to accommodate such a portion of the polymer chain. On other grounds, the lysozyme site has been considered to be even larger, i.e., for hexamer [30].

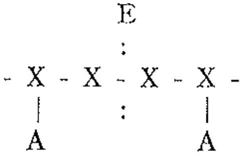
In this section, we have been proposing that the enzyme site is a spacial image of the dominant product of the reaction. The affinity of the enzyme is for this product-portion of the polymer, and for the O-atom connecting it to the rest of the « aglycone ». The tail of the « aglycone » is somewhat less important, but it certainly is not without effect.

EFFECT OF ADDITION OF A SUBSTITUENT TO THE SUBSTRATE ON HYDROLYSIS BY ENDO-POLYSACCHARASES

Substituents added to the sugar units of a linear polysaccharide affect hydrolysis by interfering with the approach of the enzyme to the site to be hydrolyzed. The most common substituents are other sugars, or chains of sugars, and the resulting products are branched oligomers (Table 3). The size, or nature, or even the position of the substituent appears to be relatively unimportant. It is the presence of a substituent, or the absence of a substituent, which is significant. Xylanase acts on a chain of xylose units where the C_5 substituent is H, but does not act on similar polymers when the C_5 substituent is COOH, CH_2OH, etc. Cellulase acts on a β-1→4 glucan where the C_5 substituent is $-CH_2OH$, but not on the similar polymers modified at C_5 either to a smaller (-H) or a larger size ($-CH_2O-CH_2-CO-O$ Na). These examples emphasize the fact of specificity.

The frequency of the substituent affects both the *rate* and the *extent* of hydrolysis. The introduction of a group does not always slow down the reaction. When the initial suhstrate is insoluble, as in cellulose, substitution often improves solubility by preventing aggregation of linear chains, and thus greatly increases the *rate* of enzymic hydrolysis. At the same time, these groups inhibit hydrolysis in the neighborhood of the sugar unit on which they occur, and so limit the *extent* of hydrolysis. As their frequency (degree of substitution, DS) increases, the extent of hydrolysis approaches zero. The hydrolysis of carboxymethyl cellulose by cellulase illustrates these points. At low DS, hydrolysis is limited by solubility; at high DS hydrolysis is prevented, due to interference by the carboxymethyl groups.

The cellulose investigation led to the conclusion that no enzymatic hydrolysis could occur if each glucose unit bore a substituent. The question remaining is, is it necessary that every unit be modified? Dr. PERLIN [25] re-examined the problem, using as his substrate a xylan chain having arabinose side groups. By his techniques, he was able to determine the nature of the *branched* hydrolysis products. He found that both of the terminal xylose units in these products were unsubstituted. The xylanase (*Streptomyces* sp.), therefore, had a *minimum* requirement of two adjacent unsubstituted units.



$$\begin{array}{ccccccccc} & & & & E & & & & \\ & & & & \vdots & & & & \\ - & X & - & X & - & X & - & X & - \\ & | & & & \vdots & & & | & \\ & A & & & & & & A & \end{array}$$

(Conversely, the degree of substitution required to prevent the action of this endo-polysaccharase is 0.5, i.e., one arabinose on every other xylose.) Recent results [15] using cellulase on one of the cellulose derivatives confirm these observations. Here, however, there is some indication that a substituent at C_6 (but not at C_2 or C_3) of the « aglucone » can be tolerated. Data on other glucanases [13] support the requirement for adjacent unsubstituted units. As a result, branched products from hydrolysis of complex polymers usually have the branch on an internal unit, and the terminal sugars are unsubstituted.

The presence of O-acetyl groups on amino sugars of a polymer, or of other types of substituents, can similarly and effectively inhibit hydrolysis by endo-polysaccharases. In order to permit action by the latter enzymes, the substituents must be removed. In nature, this is accomplished by other enzymes.

[15] *Reese* - pag. 21

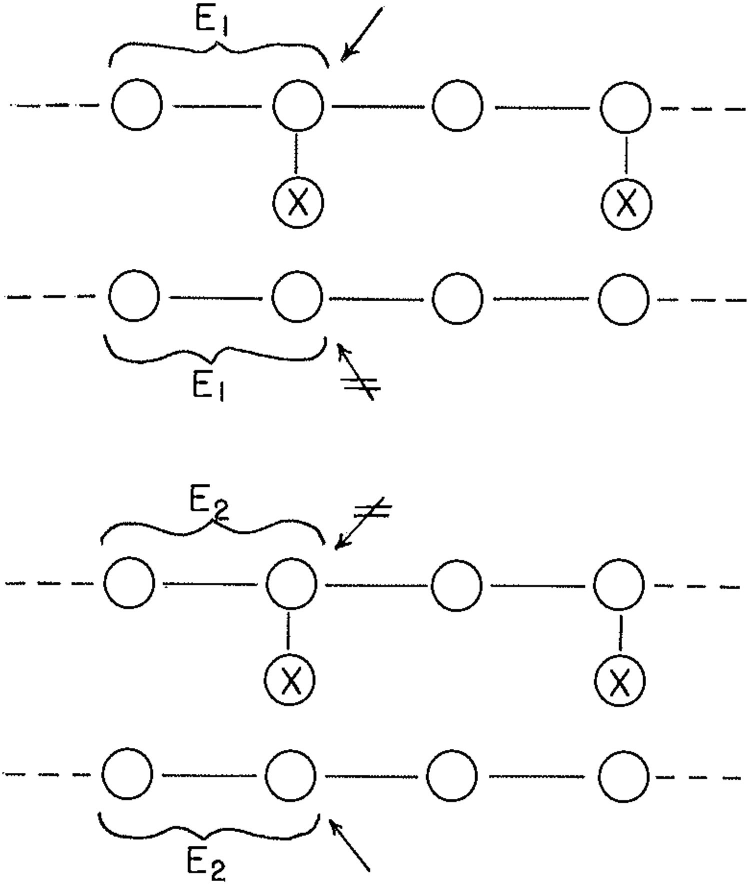
EFFECT OF REMOVAL OF A SUBSTITUENT FROM A POLYMER ON ITS SUSCEPTIBILITY TO HYDROLYSIS BY ENDO-POLYSACCHARASES

While the addition of a substituent to a normal substrate inhibits hydrolysis by endo-polysaccharases, there are several enzymes specific for *branched* polymers:

Muramidase: on the N-acetyl glucosamine polymer having every other unit substituted with a large group at C_3. (I suggest we call the lysozyme substrate « chitomuran », Table 3, to emphasize its relationship to chitin, from which it differs in having a substituent on C_3 of every other N-acetyl glucosamine unit. In this name we would define the substituent as the lactic acid ether plus its peptide side chain. The endo-enzymes would become chitomuranase *a* and *b*, depending on whether the terminal unit in the product was the more simple (i.e., NAG) = a, or more complex $\underset{\overset{|}{\mathrm{M}}}{\mathrm{(NAG)}}$ unit = *b*.)

Fucoidanase of abalone [37]: on $[\alpha\text{-}1\rightarrow 2\ \text{L-fucose, } 4\text{-SO}_4]_n$. The enzyme action is such that the branch remains on the products. Unfortunately the amount of good information regarding the specificity of such enzymes is very small. Comparative data are needed for the action of these enzymes on related substrates, and especially on the same polymer devoid of part, or all, of the original side group.

The question we ask is: How does deletion of a side group from its normal substrate affect the activity of an enzyme? In terms of the enzyme, the groove into which the branched polymer fits must have a hole to accommodate the side group (lactic-peptide, or SO_4 in the above examples) and this hole is close to the site of hydrolysis. Can a substance which leaves the hole unfilled but otherwise resembles the substrate be hydrolyzed? Some muramidases cannot attack chitin; others do



E_1 normally attacks a polymer at the branch point, and is unable to attack when the branch is removed.

E_2 normally attacks an unbranched polymer, and is unable to attack when a substituent is added.

Fig. 6 — Effect of substitution, and of removal of a substituent, on endo-enzyme activity (diagrammatic).

so slowly. In these, the absence of the lactic-peptide group on the chitin backbone, and so the « unfilling » of the hole, does interfere with enzyme activity. (Some muramidases, e.g., lysozyme, do attack chitin; but the comparative rates and affinities are not defined. It seems that any hydrolysis of chitin is quite slow.) A similar situation applies to chitinase. This enzyme hydrolyzes chitin. When the acetyl group is removed (from the nitrogen of chitin), the chitosan formed is resistant to hydrolysis. When the entire N-acetyl group is replaced by an OH, we have cellulose, on which chitinase is totally inactive. Similarly many endo-pectinases are unable to hydrolyze polygalacturonic acid (= pectin from which the methyl ester groups have been removed). (The inability of cellulose to act on β-1→4 xylan is still another example.) In other words, the looser fit of the unsubstituted substrate (obtained by group removal) to the enzyme site interferes with activity. We may conclude that filling the enzyme void is important for activity. Tentatively we suggest — in the face of some contradictory data — that the *removal* of a substituent from a normal substrate makes of it a poor substrate — or non-substrate, just as surely as does *addition* of a substituent (Fig. 6). (By non-substrate, we mean one whose rate of hydrolysis is so slow that it is not detectable under the experimental conditions.)

3. *Exo-polysaccharases*

ACTION ON HOMO-POLYMERS

The *exo*-polysaccharases are important in the breakdown of polymers only after endo-enzymes have brought about a considerable increase in the *number* of chains. The exo-enzymes act on the non-reducing terminal units of a chain, and these ends become much more abundant as the result of endo-enzyme action. As a rule, single sugar units are removed one at a time; the only authentic exception appears to be β-amylase which splits off 2 units (i.e., maltose) at a time (but note below the odd behaviour of exo-β-1→3 glucanase).

Investigation of the exo-polysaccharases, as a group, is relatively new (except for β-amylase). Their history is less than 30 years. In this period, glucamylase — an exo-α-1→4 glucanase — was discovered, its specificity determined, and it was put to use commercially to produce over a billion pounds of glucose per year in the U. S. alone.

Exo-polysaccharases act most rapidly on the longer chains (for equimolar concentrations), the rates falling off rapidly from tetramer to trimer to dimer. These enzymes act by inversion of configuration (opposite from endo-enzyme action). The exo-α-glucanase thus acts on α-links to form β-glucose, and the exo-β-glucanase acts on β-links to form α-glucose. β-Amylase activity conforms to this. Even though it removes a dimer fragment from starch, α-links are split to form the β-anomer of maltose.

The best known of the exo-polysaccharases — and indeed of the endo- as well — are the glucanases. Glucans are by far the most abundant polysaccharides in nature, and nearly all types of linkages exist between glucose units. There are known single-linkage glucans of all types except α-1→2, and there are known enzymes for the hydrolysis of each (Table 4). By far the most common of these enzymes are the endo-glucanases. Exo-glucanases have been found for 5 of the glucan types. The best known in the α-series is glucamylase or amyloglucosidase; in the β-series, exo-β-1→3 glucanase. The other 3 exo-glucanases have been studied by only a single investigator, and their properties are less well-known. They will receive much more attention in the next few years.

Like the endo-enzymes, the exo-polysaccharases have a high degree of specificity. Glucamylase — the most studied — acts predominantly on the α-1→4 glucan. It also acts on α-1→6 glucan, but at about 1/100th the rate. The exo-β-1→3 glucanase of fungi appears to be even more specific (see below). The only exceptions at present appear to be the yeast β-glucanases where a wider range of activity has been described. More information on these is required. The linkage specificity of the exo-glucanases extends also to their activity on the short chain oligosaccharides.

The question of whether the exo-enzyme jumps from substrate molecule to substrate molecule, or completely degrades one polymeric molecule before going on to the next has been investigated. EVELEIGH (pers. comm.) showed that the exo-β-1→3 glucanase acts in the latter manner, i.e., by unzippering mechanism. The proof rests on the fact that the product at 50% hydrolysis consists of glucose, plus a residue that maintains its original size. Had the enzyme jumped from molecule, at 50% hydrolysis, the glucan should have been reduced to half its size.

ACTION ON MORE COMPLEX POLYMERS

From tests on trimers of glucose having mixed linkages, it can be seen that susceptibility depends not only on the linkage itself, but on the nature of the following linkage (Table 5). For glucamylase, ABDULLAH, et al. [1] have shown that the rate of hydrolysis of the α-1→4 linkage is greatest when it is followed by another α-1→4. It is less rapid when followed by an α-1→6, and least rapid when followed by an α-1→3. The α-1→6 linkage is hydrolyzed more rapidly when the following linkage is α-1→4, than when it is α-1→6. In the β-series, the 1→3 linkage is most rapidly hydrolyzed when followed by another 1→3. When the following linkage is 1→4, the rate is *very* low, another indication of the greater specificity of exo-β-glucanase, as compared to glucamylase.

When glucamylase acts on the branched glucan, amylopectin, containing two linkage types, it proceeds down the chain

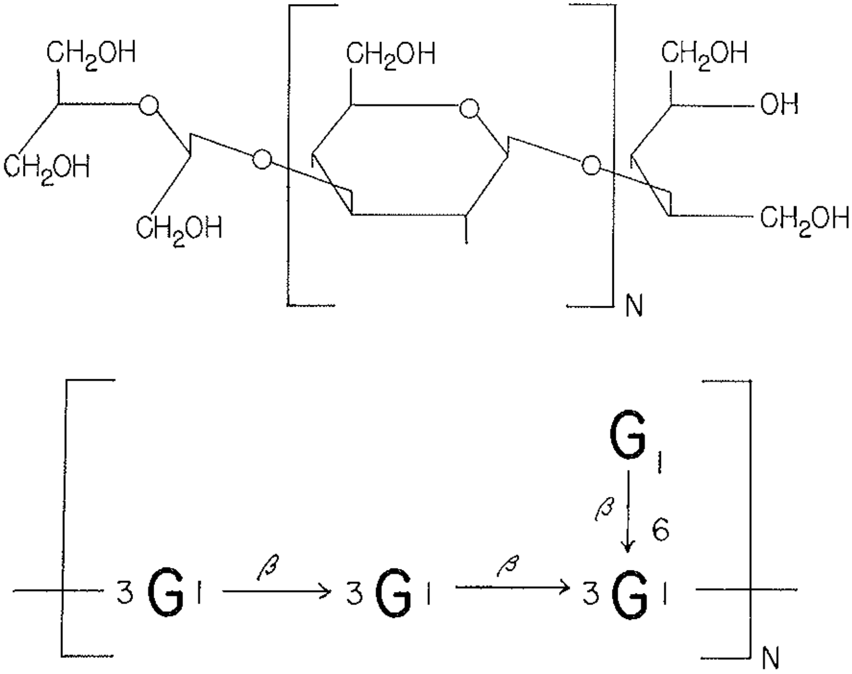
TABLE 5 — *Hydrolysis of Glucose Trimers by Exo-Glucanases.*

β-Trimers of Glucose	Relative Susceptibility by Exo-β 1→3 Glucanase
1→3, 1→4	1.2
1→4, 1→3	0.0
1→3, 1→3	100.0
1→4, 1→4	0.7
1→6, 1→4	0.0
α-Trimers of Glucose	by Glucamylase of *A. niger* (1)
1→4, 1→4	100.0
1→4, 1→3	39.0
1→4, 1→6	72.0
1→3, 1→4	1.0
1→6, 1→4	20.0
1→6, 1→6	2.0

(1) ABDULLAH et al. [1].

to a 1→6 branch point, hydrolyzing it and carrying the reaction to completion. The exo-β-1→3 glucanase proceeds in a different fashion. Acting on a β-1→3 glucan having β-1→6 glucose side groups (Fig. 7), it cleaves 1→3 linkages until it comes to the branch point, leaving the β-1→6 as a terminal linkage. It is unable to split this linkage, but it has the rather remarkable ability to by-pass it, hydrolyzing the penultimate, a 1→3 linkage [22]. As a result, it produces from the branched molecule glucose and gentiobiose, and behaves, in this respect, like a cross between a normal exo-glucanase and β-amylase.

Next in complexity of substrate is one in which a single sugar unit is connected by different, alternating linkages.



Upper: β-1→3 glucan chain modified at both terminal units.
Lower: β-1→3 glucan with glucose side groups attached β-1→6.

FIG. 7 — Effect of substrate modification on action of exo-enzymes.

Exo-α-1→4 glucanases can hydrolyze oligosaccharides of the mycodextran series (alternating α-1→3, α-1→4 linkages). There is no comparable substrate for the β-series. Instead, there is lichen $(\beta\text{-}1\rightarrow4,\ 1\rightarrow4,\ 1\rightarrow3)_n$. This is resistant to hydrolysis by the exo-β-1→3 glucanase. Here again, the latter enzyme is more specific than glucamylase.

Limited studies have been made to determine the effects of branching, or of substitution (essentially the same thing) on the activity of *exo-enzymes*. Addition of a substituent to a polymeric substrate has an inhibitory effect which is much greater against the exo-enzymes than against the endo-enzymes. By this we mean that the effect at low degrees of substitution (DS) is much greater. The exo-enzyme progresses down the substrate chain until it reaches a substituted unit at which point it can go no further. The endo-enzymes act at many sites, and are less limited in their approach. The extreme example is a single modification of a long chain obtained by altering the non-reducing terminal unit of the chain [22]. This one change is sufficient to prevent the action of exo-β-1→3 glucanase; yet it has almost no effect on the endo-β-1→3 glucanases. Another example concerns glucamylase. 6-O-Methylamylose has been prepared [39] with 1/5th of the C_6 groups substituted (DS 0.2). It is resistant to exo-α-glucanase, but susceptible to endo-α-glucanase. Thus, even so small a substituent as the methyl group is enough to prevent action of the exo-enzyme. The general picture, then, is that the presence of any branch on the non-reducing terminal unit effectively blocks the action of exo-enzyme at this point. There does seem to be a conflict, however, in explaining the action of the exo-β-1→3 glucanase:

- — with 6-O glucose as substituent, hydrolysis of the 1-3 bond takes place;
- — with 3-O degraded-glucose as substituent, hydrolysis of the 1-3 bond does *not* occur.

This is reminiscent of the relative effects of substitution at these two carbon atoms on the action of glycosidases (next section).

4. *Glycosidases*

Glycosidases represent the terminal enzymes in the process of hydrolyzing polysaccharides to simple sugars. There are basically two types, depending upon the nature of the aglycone:

a) aglycone = another sugar unit;

b) aglycone = an alkyl or aryl group.

Usually a single enzyme is highly active either on the one or the other type, and data based on the use of aryl glycosidases may have no significance for action on sugar dimers. Our interest here is in the enzymes active on the dimers. The reaction is essentially a glycosyl transfer from dimer to an acceptor, the usual acceptor being water.

$$\mathrm{G - O - G + H - OH \xrightarrow{E} G - OH + H - OG}$$

LINKAGE SPECIFICITY

Most glycosides are O-glycosides, and relatively little information is available on the enzymes which act on the N<, and S-glycosides. Where such information is available [14], there appears to be a high degree of specificity, depending upon whether the linking atom is O, N, or S. An analogue of gentiobiose having an -S- atom linking the two glucose units [13] is resistant to cleavage by the O-β-glucosidase which acts on gentiobiose. It may, however, complex with the enzyme, and act to some extent as a weak inhibitor.

In view of the importance of the glycosidic atom (O, N, S), it is, perhaps, a little surprising to find that α-glucosyl fluoride behaves like an α-glucoside. Here the OH of α-glucose is replaced by a fluoride atom, and the entire aglucone is reduced to a single atom. BARNETT recently [3] has shown that this C-F bond is as susceptible to α-glucosidase as is maltose, and much more susceptible than the α-aryl-glucosides. This compound is susceptible also to exo-α-glucanase (i.e., glucamylase of *A. niger*), the exo-enzyme and the α-glucosidase having comparable specificities.

What is the effect of substitution on rate of hydrolysis? If we consider first the «aglycone » unit of a disaccharide, we can make some generalizations:

a) the effect of modification at any position will be much less than the corresponding change in the « glycone »;

b) modification at C_1 of the « glycone » leading to ring opening, greatly decreases the rate of hydrolysis (usually to $<10\%$ of the initial rate).

Modification of the sugar moiety invariably reduces the rate of hydrolysis. Usually no modification is permissible at C_2, C_3 or C_4. However, there is an apparent exception to this rule for enzymes of almond emulsin. It has been claimed that the same enzyme acts on both β-galactosides and β-glucosides; that is that a change in position of OH at C_4 can be tolerated. However, those who have made this claim seemed to have overlooked the data of HELFERICH [26] in which he shows a marked difference in the adsorption of the β-D-glucosidase and the β-D-galactosidase on various polymers which he had prepared for their separation.

Modification of the sngar moiety at C_6 is less inhibitory than at other carbon atoms. Forty years ago, HELFERICH [26] showed that the smaller the substituent at C_6 of β-glucosides, the faster the hydrolysis by β-glucosidase of emulsin. The 6 deoxy — the smallest group — was hydrolized even faster than the ummodified glucoside. We have re-examined this problem, thanks to a supply of samples from Dr. F. PARRISH and from Dr. M. JERMYN. We do *not* find the 6-deoxy derivative to be highly susceptible — even with the enzyme from almond emulsion, and conclude that any modification of the sugar moiety tends only to decrease the rate of hydrolysis [28].

Another feature of specificity has to do with the ring form. The glucopyranosides are susceptible, the glucofuranosides

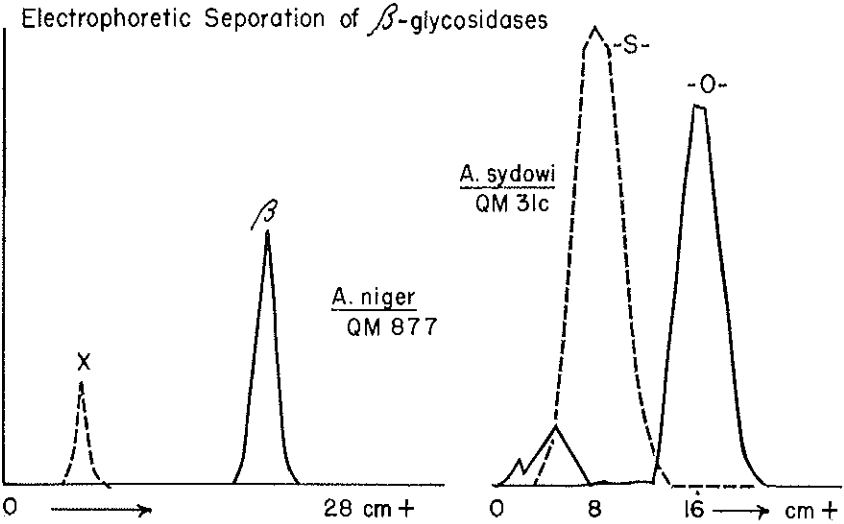


FIG. 8 — Left: Separation of β-xylosidase (x) from β-glucosidase (β) of *Aspergillus niger*. — Right: Separation of β-glucosidase (-O-) from β-thioglucosidase (-S-) of *Aspergillus sydowi*.

nearly — or completely — resistant to glucosidases. Our data extend this well-known principle to several additional sources of enzymes [28].

COMPARISON OF GLUCOSIDASES AND EXO-GLUCANASES

It must now be apparent that exo-glycanases and glycosidases have much in common. Indeed the « newer » exo-enzymes have sometimes been confused with the « older » and better-known glycosidases. There are, however, several means of distinguishing between the two types (Table 6).

TABLE 6 — *Criteria for the Characterization of Glucosidases and exo-Glucanases* (28).

Criterion		Glucosidase α	Glucosidase β	exo-glucanases α	exo-glucanases β
Effect of DP on Hydrolysis		2>3>>4		6>5>4>3>2	
Conformation of Product		Retention		Inversion	
Effect of Inhibitors					
Δ-Gluconolactone	R^{I}/ S 50		<0.01		>1.0
CH_3-α-Glucopyranoside	R^{I}/ S 50	3.		30.	
Maltitol	R^{I}/ S 50	10.		1.	
Transfer		+	+	?	?
Dimer Specificity		Less specific		More specific	

One of the more important differences is the effect of the degree of polymerization (DP) on the rate of hydrolysis. The rate of activity of both the α and β exo-enzymes increases as the chain length increases. With the glucamylases, the effect is essentially the same for members of the α-1→4 and the α-1→6 series. (The absolute rate is, of course, much lower in the α-1→6 series.) In the β-series there is no activity on the β-1→4 or β-1→6 oligomers; only the β-1→3 are susceptible. The glucosidases, on the other hand, present quite a different picture. The dimer and trimer are often of very nearly equal susceptibility to hydrolysis, but the rate falls off rapidly as one goes on to the tetramer and higher members of the series. With almond emulsin the rate falls off rapidly even for the trimer. With the exo-glucanases, the rate increases with the chain length; with the glucosidases the rate decreases.

Specificity differences separate exo-enzymes from glycosidases. The α-glucosidases act on all of the α-dimers of glucose except αα-trehalose. For trehalose, a separate enzyme is required. In general, the 1→4 dimer is the most susceptible, but for some preparations the 1→6 (iso-maltose) is most susceptible to hydrolysis. The β-glucosidases hydrolyze all five of the β-dimers of glucose. There is no separate requirement for hydrolysis of ββ-trehalose. Here the β-1→3 dimer, laminaribiose, is generally the most susceptible of the dimers. The *exo-glucanases* generally have greater specificity, action being predominately on *one* of the dimers. These are not absolute differences, but generalizations that may prove useful in characterizing the exo-glucanases.

A third means of differentiating between glucosidases and exo-glucanases is in the nature of their action on the substrate. Until recently, retention or inversion of configuration during a reaction was determined by changes in optical rotation. In our work, Dr. PARRISH suggested the use of gas liquid chromatography (GLC) to measure α and β glucoses directly and separately. In GLC glucose at equilibrium gives a ratio of β-glucose to α-glucose of 1.35 (Table 7). Low values for the ratio indicate α-glucose as the product; high values indicate β-glucose. The data show that the exo-β-1→3 glucanase produces α-glucose, that is, it acts by inversion. In a similar way, the exo-α-glucanase produces β-glucose, again acting by inversion. On the other hand, β-glucosidase produces β-glucose, and α-glucosidase produces α-glucose, both retaining configuration. While we must admit the number of exo-enzymes studied is very small, it does seem that a generalization can be made, e.g., that exo-enzymes act by inversion and glucosidases act by retention of configuration.

Transfer is usually associated with glycosidase action. A glycosyl group is transferred to an acceptor other than water. When the acceptor is another dimer molecule, a trimer and then a tetramer may be built up. Usually transfer is to all possible positions (C_2, C_3, C_4, C_6), though there are many examples of transfer products where the action has been spe-

Retention and Inversion of Configuration by Carbohydrases

Enzyme	Substrate	Time (min)	R β/α Glucose
Control 0	glucose at equilibrium	4000	1.35
Exo-β-1,3-glucanases			
Sporotrichum pruinosum	Laminaritetraose	10	0.39
Basidiomycete sp.	Laminaritetraose	10	0.46
	Laminarin	10	0.59
β-glucosidases			
Aspergillus niger	Laminaritriose	6	1.59
Aspergillus luchuensis	Salicin	5	1.55
Almond emulsin, Richt.	"	4	1.60
Exo-α-glucanases (glucamylase)			
Aspergillus niger (Diazyme)	Maltodextrins	5 FD	4.5
	"	5 BD	3.8
Endomyces sp. (Matulase)	"	5 FD	4.1
	"	5 BD	4.0
α-glucosidases			
Aspergillus niger	Maltotriose	10	0.57
Paecilomyces varioti	"	6	0.54
Penicillium parvum	"	10	0.0

cific. Products which accumulate are often those least susceptible to further hydrolysis by the enzyme which has formed them. Exo-glucanases are much less likely to transfer glycosyl groups to anything but water.

A fifth means of differentiating glycosidases from exo-glycanases is by means of inhibitors. LEVVY and CONCHIE [17] have demonstrated the inhibitory action of gluconolactone on β-glucosidases. We have subsequently shown that the exo-β-1→3 glucanases are quite resistant to the effect of gluconolactone. The differences are of a magnitude of 1000 times. Unfortunately, the effect of the lactone is much less on the α-enzymes and there is no means of differentiating them on this basis. We have found, however, that α-methyl-glucoside tends to inhibit α-glucosidase more strongly than it inhibits exo-α-glucanases. Here, however, the difference is only one order of magnitude. It may be that other compounds can be found that are much more effective for differentiating these.

5. *Other enzyme systems*

One occasionally needs to be reminded that hydrolysis is not the only enzymatic means of depolymerization and that the products of such reactions may be quite different from those of hydrolysis. Phosphorylation is well-recognized in the α-1→4 glucan system, and its role in the breakdown of cellobiose has recently been demonstrated. More unusual is the action of the recently discovered « eliminases » where chain scission does not involve the addition of water. As a result of a β-elimination, a disaccharide is formed having unsaturation in the non-reducing sugar moiety between C_4 and C_5 (Fig. 9).

At present, eliminases seem to be restricted in their action to polymers containing a uronic acid group: Hyaluronic acid, pectic acid, pectin and alginic acid (i.e., polymers containing glucuronic, galacturonic or mannuronic acids). The linkage may be α or β. The hydrogen on C_5 may be cis or trans to the oxygen on C_4. These enzymes bring about depolymerization, the products of hydrolysis having reducing properties and lowered viscosity. As a result — unless the products are further characterized — one is not likely to suspect that the action is anything but hydrolytic. There is, however, an easy way to detect the « eliminase », namely, the appearance

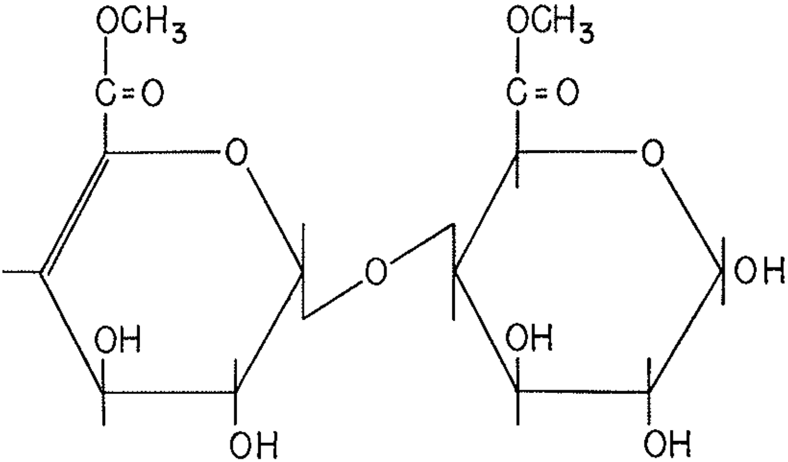


FIG. 9 — Unsaturated dimer produced from pectin by bacterial eliminase.

of a strong absorption by the unsaturated products at 232 mu. Another difference from the hydrolases is in the position of cleavage. In the eliminases the split is between C_4 and the bridge oxygen; in the hydrolytic enzymes, it is between the C_1 and the oxygen. While most of the reported eliminases are endo-enzymes, an exo-polygalacturonic acid trans-eliminase has been described [19]. It is unusual among exo-polysaccharases in that it acts from the *reducing* end of the chain. It does not act on pectin.

The variety of enzymes acting on pectic substances [8] appears to be even greater than that acting on glucans or other homo-polymers, including, as they do, hydrolases, both exo- and endo-; eliminases, both exo- and endo-; methyl esterases; and separate systems for pectic-versus pectin-type structures. This further emphasizes the high specificities of polysaccharases.

D. HYDROLYSIS OF COMPLEX POLYSACCHARIDES

With the above knowledge of the enzymes and their capabilities, we can now direct our attention to the decomposition of the more complex polysaccharides. The analysis of these heteropolymers is a problem of the same magnitude as sequence analysis of proteins. As yet, comparatively little use has been made of enzymes for this purpose.

Substituents attached to the polysaccharide by an *ether* linkage, e.g., methyl cellulose, carboxymethyl starch, etc., cannot be removed enzymatically. When the frequency of such groups is greater than one every other sugar unit (DS>0.5), the polymer cannot be degraded by micro-organisms.

Substituents attached to the polymer chain by an *ester* linkage are capable of being removed both by physical and by enzymatic agents. The more common natural esters are the acetates, sulfates and phosphates. The enzymes acting on these are quite specific. For example, acetyl esterase removes acetyl groups from cellobiose octa-acetate, but not from cellulose acetate. A sulfatase, which cannot remove sulfate from chondroitin sulfate, readily removes sulfate from oligomers derived from the same substrate. On the other hand, there are sulfatases which remove sulfate from cellulose sulfate, but which cannot remove sulfate from glucose sulfate [35]. In addition to specificity based on chain length, there is specificity based on the nature of the linking atom. The enzyme removing an acetyl group from N-acetyl glucosamine is different from that removing an acetyl attached through an oxygen atom. And there is specificity based on the nature of the acyl and of the alcohol groups. Information regarding esterases capable of removing acyl groups other than the above from polysaccharides is sparse. In all of the above, an acyl group is removed from the polysaccharide. There are other esters where the acyl group *is* the polysaccharide, and alcohol the added substituent. Such are the pectins, the methyl esters of polygalacturonic acid. Enzymes active for this substrate are also common.

Substituents attached to the main chain through a *glycosidic* linkage, can be removed enzymatically. Some time ago, DEUEL [9], and later COURTOIS [5] indicated that an α-galactosidase removes the galactose group from the side of a β-1→4 mannan chain (carob gum; guar gum). This is a system we have re-examined. There is no doubt that galactose is liberated. But carob gum can be extensively hydrolyzed *without* liberation of galactose, i.e., its removal is not required for depolymerization by endo-enzymes. Furthermore, the galactose-containing oligosaccharides can be hydrolyzed enzymatically to galactose and mannose. We have not — as yet — been able to determine whether the galactose unit can be removed prior to depolymerization; or indeed whether a special configuration in the oligosaccharide is required for susceptibility.

There are two approaches to the biological decomposition of a complex natural polysaccharide, either:

a) the main chain is hydrolyzed to give products containing the branch, and the branch is subsequently removed; or

b) the branches are removed first by various enzymes to leave an unbranched polymer susceptible to the common endo- and exo-polysaccharases.

Both methods are well documented. There are, however, many unsolved problems. Some of these are mentioned below.

a) Are the enzymes which remove the sugar side group from a polymer glycosidases, or exo-glycanases? We have shown that glycosidases have a preference for short chains, i.e., dimers, but we don't know whether the same enzyme can remove a single unit side-group where the bulky polymer acts as a mammoth aglycone. We have found that the enzyme which removes the α-galactose side group from a mannan chain cannot hydrolyze the common α-galactosides (as methyl-α-galacto-

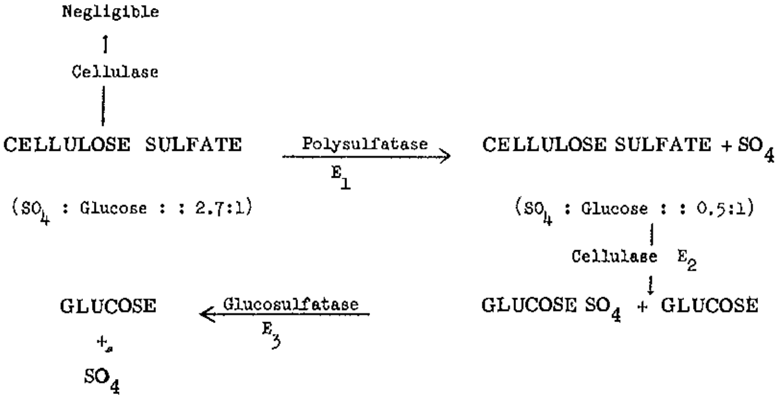


FIG. 10 — Utilization of cellulose sulfate by Charonia (after 35).

side, melibiose, and raffinose), and that galactosidases which attack the latter *cannot* remove galactose from galactomannan. The required enzymes may, therefore, have high specificity, and indeed their properties seem to be those of exo-glycanases. This argument is not simply a matter of names. As shown above, the selection of an enzyme to remove a side group from a polymer cannot rely on the fact that a similar sugar is split off from a simple aglycone.

b) Are the enzymes which attack highly branched structures appreciably smaller in size, than their counterparts acting on unbranched polymers? Do they bind to a smaller portion of the substrate, i.e., are they taking a smaller bite?

c) How do organisms bring about the first step in solubilizing a highly oriented and insoluble polymer?

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DISCUSSION

Chairman: A. G. NORMAN

NORMAN

Thank you Dr. REESE for your enlightened discussion of microbial enzymes. So much of the carbon of plant materials is in the form of polysaccharides of one sort or another. Those large figures which Prof. KOVDA put in his paper as being annually produced or annually degraded impel recognition of the type of hydrolysis which you described. This paper is now open for discussion.

PRIMAVESI

Do you think, Prof. REESE, that the lysis of bacteria is always caused by external chemical substances, or also, by secreted chemical substances by phages that live in the body of the bacteria?

REESE

I believe that a great deal of the lysis of an organism has to be by its own internal enzymes. If there is lysis of an organism without the addition of external enzyme, then all of the breakdown must be the internal enzyme system.

PRIMAVESI

It has been proved by this excellent paper that, the more diversified the micro-organisms, and especially, the bacteria, the more diversified the enzymes and, therefore faster the decomposition of the polysaccharides, including cellulose, chitin, pectin and polymers etc.

This is the chemical explication, why there does not exist humus accumulation on ploughed soils in the tropics. The humus depends, therefore, on the lack of determinate enzymes which permit the permanence of certain substances in the soil, and those substances by one's turn, can hinder the activity of the enzymes, enabling the accumulation and synthesis for these substances.

REESE

Yes, it is true that any particular micro-organism will be able to attack only certain substrates. If we consider first the cellulose of the soil, then about half of the micro-organisms present can attack it, producing the enzymes required. As the cellulose is consumed fungal walls are produced. These are more complex than cellulose and therefore there are relatively few organisms which will have the enzymes systems required to attack it. As fungal wall is converted by bacteria and actinomycetes, the new wall substance again will become increasingly complex. The flora that is required to digest these is highly selective. As to the effect of the presence of other materials in the soil on the activity of the enzyme; this is precisely why the fungus or the bacterium must come into close contact with the substrate. The materials that are present — not only the clay, as indicated before, but other types of materials — tend to be very strong adsorbants of enzymes. Where there is adsorption, there is no enzyme activity.

SWABY

Dr. REESE, most of the groups sterically hindering enzyme attack of the polysaccharides you are dealing with, were groups that were linked by co-valent bonds. I wonder if you could tell me whether you have looked at other types of sterically hindering groups, such as chelation with borates and diol groups, or uronic acid groups ionically bonded to metal ions. Are these sufficiently strong to block some of your enzymes?

REESE

No, we have no data showing effects of bondiug - other than co-valent.

ALEXANDER

Is it the size of the substituent necessarily which determines the degree of inhibition of the enzymatic hydrolysis of substituted polysaccharides?

REESE

The size of the substituent does not make much difference. A methyl group seems to inhibit as much as some larger group on the molecule. In work done in Holland, a methoxy substituent on cellulose was found to inhibit both endo-enzymes and exo-enzymes.

ALEXANDER

Are the inhibitions associated with substituent necessarily the result of steric effects?

REESE

Yes, I believe so. We have ruled out ionic factors. The effects are observed whether the group is a methyl group, or a uronic acid group or a sugar moiety. I do not think there is any possibility that the effect is ionic or anything except steric.

STABILITY OF SOIL ORGANIC MATTER AND ITS SIGNIFICANCE IN PRACTICAL AGRICULTURE

R. J. SWABY
Commonwealth Scientific and Industrial Research Organization
Division of Soils
Adelaide - South Australia

INTRODUCTION

In most soils 98% of all N, 80% of all S and 60% of all P are in organic forms unavailable to the majority of plants until mineralised during microbial decomposition. An acre of soil containing 2% humus, stores N, P, and S in organic substances equivalent to 5 tons of sulphate of ammonia, 1 ton of superphosphate and ½ ton of gypsum, which if induced to turn over rapidly could greatly benefit crops. Under arable systems of agriculture involving cultivation, the plant debris from a crop decomposes and mineralises almost completely in the twelve months before the next crop matures. But under long term pastures or forests, organic matter often accumulates at alarming rates, immobilizing large quantities of applied fertilizers as relatively stable organic compounds. Thus WALKER et al. (1959) in New Zealand and WILLIAMS and DONALD (1957) in Australia have shown that the rate of accumulation of organic matter under pasture exceeds the rate of decomposition resulting in a net gain of soil humus. WILL (1959) and MILLER (1963) in New Zealand and HATCH (1955) and McCOLL (1966) in Australia found similar accumulation of litter under forests.

PAUL et al. (1964) using the technique of carbon dating found that the approximate half life of humus in a grey wooded podzol was 360 years while that in a grassed chernozem was 2,200 years and even after 33 years under wheat, clover rotation the mean residence time of the ^{14}C was still 1,700 years. However some humus fraction are much more stable than others. Thus when the organic material from another chernozemic soil, with a mean residence period of 990 years, was fractionated the recognizable plant remains were of very recent origin, the fulvic acid was 360 years old, while the humic acid and humin were 1,300 years.

During the process of decomposition of plant remains labelled with ^{14}C MAYRUDON and SIMONART (1959a, 1959b) discovered that various constituents contribute differently to humic fractions. Table 1 compiled from their data shows that substrates, like glucose, almost completely decomposed in 30 days at 25°C to carbon dioxide contributing very little to fulvic acid and only slightly more to humic acid and humin. Cellulose and protein decomposed more slowly and added greater amounts to all three humus fractions. Resistant substances, such as lignin, decomposed very little and mostly ended up as very stable humic acid and humin.

TABLE 1 — % ^{14}C *activity in humic fractions.*

Substrate	Undecomp	Fulvic	Humic	Humin
Glucose	11	20	35	45
Cellulose	20	25	30	45
Protein	25	18	43	39
Lignin	70	10	49	41

After MAYAUDON and SIMONART (1959).

THE PROBLEM

Since the crumb structure of most soils can be preserved by incorporating readily decomposable plant debris this raises the question whether methods could be found for exploiting the minerals imprisoned within resistant humus. Affluent countries often do not consciously strive to conserve humus. By applying heavy dressings of fertilizers they obtain large crops which in turn produce large residues and these seem sufficient to maintain stable agriculture. Less developed countries cannot afford these fertilizers so carefully return all organic debris. All might better exploit the mineral reserves in humus if more were known of the factors contributing to its stability.

This paper reviews: 1) soil conditions which are known to depress microbial decomposition, 2) mechanisms whereby organic materials are protected from degradation, 3) intrinsic properties of organic substances imparting stability and 4) agricultural practices which accelerate decomposition and mineralization of humus. Australian and New Zealand experience is quoted most often, but many findings are probably of world wide importance.

FACTORS DEPRESSING DECOMPOSITION

BROADBENT (1962) reviewed some of the soil factors controlling decomposition of organic matter and mineralization of N, P and S.

a) *Absence of decomposers*

Most soils contain an abundant microflora and fauna capable of decomposing a wide variety of organic materials.

However surface feeding earthworms were absent from certain New Zealand pasture soils and STOCKDILL (1958) successfully introduced these to hasten burial and turn-over of matted leaves. Partial sterilization of soil by bush fires, by volcanic ash, by steam or by fumigants, such as methyl bromide and formaldehyde, is not particularly serious according to WARCUP (1957) since re-colonization quickly occurs from below. However PETERSON (1962) found that toxins were produced in autoclaved soils which adversely affected the rate of re-colonization with various micro-organisms.

b) *Toxicity*

Occasionally decomposers may be temporarily depleted by the use of toxic chemicals, such as certain pesticides, fungicides and herbicides. Fortunately most spray residues are degraded in time by micro-organisms, allowing the normal decomposers to return. However some organochlorine chemicals are extremely persistent and in the affluent countries, where they are used mostly, they could retard decomposition for years. Injection of anhydrous ammonia briefly sterilizes the soil near the point of injection; but nitrification quickly occurs thereby restoring the pH to more normal conditions. In naturally acidic peats or in soils rendered acidic by excessive use of sulphur or ammonium fertilizers, many soil animals, bacteria and actinomycetes are suppressed and decomposition is retarded. Mildly alkaline conditions induced by over-liming or applications of alkali nitrates tend to speed up decay; but pH values higher than 9 preserve organic matter in solonetzic soils. The high salt of solonchaks also protects humus a little by suppressing the activity of many decomposers. HARRIS (1963) found that toxic substances from many Australian soils inhibited respiration of a wide spectrum of soil bacteria. KIMBER (1967) demonstrated several toxic substances in cereal straws before and after rotting. Most of these toxic substances disappeared on further incubation. LEE and WOOD (1968) found that over 300 kg of organic matter accumulated in termite mounds scattered over a hectare where it remained preserved for over 50 years, presumably due to antibiotic substances.

c) *Low temperature*

At the low temperatures of frozen soils in tundras and alpine regions decomposition ceases until after the thaw. High temperatures on the other hand accelerate breakdown which is brought to a halt only by the associated effect of drying.

d) *Dehydration*

Absence of soil fauna in arid areas is a serious problem since organic wastes may persist undecomposed for years. In Australia BORNEMISSZA (1960) suggested introducing dung beetles into cattle areas where dung remains unburied for years. BOND (1964) found that certain soil fungi made sands hydrophobic so that rain would not penetrate and under these conditions decomposition would be very slow.

e) *Lack of Oxygen*

Temporary or permanent waterlogging of soil leads to lack of oxygen, thus suppressing obligate aerobes, such as most animals and fungi, and the anaerobic types which persist are not only less efficient at decomposition, but may inhibit themselves by the production of organic acids. Decomposition of straw in flooded rice fields often leads to the accumulation of butyric acid, which hinders further breakdown until irrigation ceases. Soils of heavy texture, high in clay and poor in aggregation, may also lack sufficient oxygen for rapid aerobic decomposition.

These five factors may explain the slow decomposition of organic materials in particular soils, but other explanations are needed to account for the fact that much of the humus in all soils is stable.

PROTECTIVE CRYPTS

Organic substances may survive decay if lodged in crypts inaccessible to micro-organisms or their enzymes. These crypts may be quite large or extremely minute. Deep mass burial of plant and animal debris leads to anaerobic fermentation and the production of either organic acids or amines, each hindering further decomposition. Nye and GREENLAND (1960) cite cases of this happening during primitive methods of cultivation. Whole trees may be preserved in the acid waters of peat bogs, or in the dry sands of desert dunes.

All soils contain cells with resistant walls, such as cork cells, wood fibres, pollen grains, fungal sclerotia and bacterial spores, which may serve as micro-crypts. Protective coatings may be organic, such as waxes, lignin, melanin and humic acid or inorganic, such as silica, clay, sesquioxides, limestone and manganese dioxide. ROVIRA and GREACEN (1957) considered that micro-pores less than 1 μ in dimensions exclude most micro-organisms, so non-diffusing organic polymers lodged in such crypts are protected, except from enzyme attack. Disturbance of such micro-niches by cultivation, by alternate wetting and drying or by passage of the soil through the gizzard of an animal exposes the organic matter once again to decomposition.

ENSMINGER and GIESEKING (1942) showed that clays trapped organic substances between platelets and inside the crystal lattice of expanding types, thereby preventing their breakdown. McLaren et al. (1958) found that clays sorbed and partially inactivated a number of enzymes. More recently Ladd et al (1968) discovered that humic acids from peats and soils can sorb both proteolytic enzymes and their substrates, thereby preventing hydrolysis to amino acids. Table 2 from their data shows that free acidic groups on the humic acids are involved, since pronase activity can be partially restored by the addition of calcium ions and almost completely by cobalt ions. Suppressing carboxyl groups by methylation also prevents sorption. Only a proportion of the carboxyls are implicated suggesting that ionic bonding is less likely than chelation.

Table 2

Reaction mixture	% pronase activity
Peptide	100
Peptide + humic	39
Peptide + humic + Ca^{++}	76
Peptide + humic + Co^{++}	97
Peptide + methylated humic	92

After Ladd, Brisbane and Butler (1968).

Although a proportion of the organic matter in soils may escape the attention of micro-organisms or enzymes by hiding in crypts, nevertheless thin sections of soils often reveal free humic particles apparently possessing intrinsic properties immunizing them from attack.

INTRINSIC STABILIZING PROPERTIES

a) *Unusual chemical bonds*

Bonds between atoms in organic molecules differ considerably in their strength, some requiring much more energy to sever them than others. Nevertheless micro-organisms are adept at breaking most types of bonds between C, H, O, N, S and P, the principal elements in both easily decomposable and resistant humus. LADD and BUTLER (1966) found that the C-N bonds in peptides were more easily acid hydrolysed than those between the C in aromatic rings and the N in substituent amino acids in substances such as N-phenyl glycine, which broke only after the addition of peroxide. However LADD (1964) also found that *Achromobacter* sp. quickly adapted itself to degrade a related substance, N-(o-carboxyphenyl) glycine in a series of steps involving the gradual terminal erosion of the glycyl side chain. ALEXANDER (1965) mentioned recalcitrant molecules, such as synthetic organochlorine biocides, but KEARNEY et al. (1967) reviewing the subject refer to a number of organisms which can degrade even these toxic substances. Infra red absorption data on humates reveal no uniquely strong bonds and the reported shifts in bond absorption due to the presence of neighboring groups differ little from those encountered in readily degradable molecules. Unusual bonds can hardly explain the stability of humus.

b) *Steric Hindrance*

The presence of large substituent groups on substrates too close to the sites of attachment of enzymes sterically hinders enzyme attack. Thus substitution of long chain alcohol for short chain alcohols in esters blocks their hydrolysis by carboxyl-esterases. Removal of the steric block by other enzymes opens the way to further degradation of the remainder of the molecule. It seems likely that steric hindrance could be important in preventing rapid decomposition of humic polymers, but practically nothing is known of the chemical nature of such groups. It is significant, however, that STEELINK and TOLLIN (1967) found free radicals imprisoned in humus, suggesting that steric groups hindered further polymerisation or their quenching. Table 3 taken from LADD and BRISBANE (1967) shows that peptide bonds in both natural and synthetic humic acids were more readily attacked by tiny hydrogen ions than by large proteolytic enzymes.

TABLE 3

Humic acid or protein source	Total N (%)	% amino acid-N hydrolysed		
		HCl	Papain	Pronase
Peat	2.09	0.98	0.02	0.23
Fen	1.91	0.80	– 0.01	0.19
Sandy loam	2.85	1.19	0.08	0.32
Benzoquinone-casein	5.55	3.12	– 0.04	1.41
Casein	15.8	9.6	2.34	8.75

After LADD and BRISBANE (1967).

c) *High Molecular Weight*

Large molecules diffuse less easily than small ones so move more slowly towards decomposers and on through cell walls. They are mostly attacked by extra-cellular enzymes which themselves are only slowly diffusable and very vulnerable to sorption and inactivation on clays. Molecules with high molecular weights are therefore more stable than similar smaller molecules. The molecular weights of humic fractions vary from 5,000 to 100,000, thus making them rather sluggish, non-diffusable polymers.

d) *Globular Shape*

Molecules consisting of extended polymeric chains present more sites for enzyme attack than those which are folded or globular. Judging by sedimentation constants, humic acids are approximately globular, having one axis twice that of the other. Even under alkaline conditions, when the negative charge is highest, they are not linear polymers.

e) *Smooth Topography*

Long side chains protruding from a large molecule are often the first to be degraded by enzymes. Humic acid molecules may have smooth topographies since proteases, poly-saccharidases, lipases, nucleases and other de-polymerising enzymes have very little effect. Even hot acids and alkalies release only small quantities of amino acids, ammonia and phenolics from humic acid.

b) *Surface Charge*

The net charge on humic acids is negative because the number of anionic groups far exceeds the cationic. This negative charge attracts cations and repells anions. Surface charge of substrates sometimes hinders and at other times aids enzymic attack. Negative humus might well attract positively charged enzymic proteins and stimulate attack or denature such enzymes and hinder attack. Carboxypeptidases might be expected to be more effective than amino peptidases on humic peptides, with free terminal carboxyl groups. On the other hand, humic acids possess strong chelating properties and enzymes like carboxypeptidases requiring metallic cations such as Zn as co-enzymes might be rendered incapable of action by humus. Not enough is known of the effect of substrate charge on enzymic action to predict the effect of negative charges and sorbed cations on the numerous enzymes required to decompose humic acid.

g) *Disorderly polymerization*

Orderly polymers with regular repeating monomer units, linked by identical bonds are usually de-polymerised more readily than branched of disorderly ones, where discontinuities and disjunctions occur. Thus β-amylase quickly hydrolyses amylose to maltose units, but is prevented from completely hydrolysing amylopectin by the branched chains. The poor crystallinity of humic acid, as revealed by X-ray diffraction, suggests that it contains no repeating monomer units, and therefore no repetitive bonds that might be un-zipped enzymically. SWABY and LADD (1962) believe that it would be impossible for one enzyme to degrade such a chaotic polymer or condensate and even more difficult to understand how humic acid could ever by synthesised by enzymes.

h) *Co-polymerization*

Co-polymers and co-condensates formed from several different monomers contain different bridges so more steps are needed to degrade them. Thus at least three enzymes are needed to decompose ribonucleic acid to its constituents, ribose, purines, pyrimidines and phosphate.

During the chemical disruption of humic molecules, numerous substances have been identified, including phenolics, such as catechol and caffeic acid; lignin - derived substances, like vanillyl alcohol and syringic acid; flavanoid - derived moieties such as phloroglucinol and 3,5-dihydroxybenzoic acid; polycyclics, like anthroquinone and perylene; several carbohydrates, and a large assortment of amino acids. They cannot all be artifacts so many represent building units of humic acid, thus making it one of the most complex co-polymers known. It is difficult to imagine enzymes controlling the actual polymerization or condensation of such a heterogenous collection of monomers, although by creating quinoid radicals they might initiate chemical condensation with peptides, amino acids and ammonia. Many types of bonds would be involved in this co-polymerization, few occurring in a repeating pattern, so many different enzymes from many types of organisms would have to take their turn at dissembling humic acid, piece by piece from the outer surface.

i) *Cross-linking*

The cross-linking of polymeric chains confers greater stability on the molecule. Thus hydrogen bonding between neighboring polycellobiose chains renders cellulose more insoluble and more resistant. In keratin, disulphide co-valent links between opposite cysteine groups in parallel peptide chains renders this protein immune to many proteolytic enzymes. Sclerotin is even more resistant since it is a cross-linked co-polymer of polyphenols and protein.

Considering the complexity of humic molecules cross-linking is bound to occur, ranging from weak Van der Waal forces, to hydrogen bonds, to ionic links through to strong co-valent bonds. Infra-red spectrograms have already revealed some; but others remain to be detected by more precise techniques. Even more enzymes will be needed to sever these cross links.

Co-polymers with constituents linked together by short chains disintegrate partially if enzymes break the chains. This is a possible explanation of results obtained by LADD and BRISBANE (1967) and presented in Table 4. They fractionated large and small molecular entities of natural and synthetic humic acids on Sephadex columns before and after treatment with pronase. They found that the weight of amino acids released was much less than the amount of large humic molecules converted to smaller ones. Evidently hydrolysis of peptide chains splits aromatic constituents apart also.

TABLE 4

Humic acid	Total N (%)	% amino acid released by pronase	% digestion of high to low polymers
Peat	2.09	.94	4.1
Red brown earth . . .	4.82	1.87	3.0
Benzoquinone-casein . .	5.55	5.75	16.3

After LADD and BRISBANE (1967).

Since cross linking often occurs in three dimensions, this tends to reinforce the molecule into a dense mass not easily penetrated by large enzyme proteins. The energy liberated by the enzymic severing of bonds scattered at random through a cross-linked co-polymer might well be inadequate for metabolic purposes. While waiting for its next quanta of energy or of essential metabolite from a resistant molecule a micro-organism might well perish.

In summary humic acid is a resistant molecule because it is: 1) large, 2) non-diffusible, 3) easily trapped in crypts, 4) globular, 5) smooth, 6) negatively charged and often surrounded by protective metallic cations, 7) capable of sorbing and inactivating enzymes, 8) disorderly, without repeating units, 9) co-polymerized, 10) multi-cross-linked, 11) condensed and 12) yielding energy and metabolites at rates too slow for sustaining microbial metabolism. Organic chemists regard such stuff as intractable « gunk » and toss it down their sinks. Agriculturalists want to know how to exploit the plant nutrients stored in such stable substances and the next section summarises what is known.

AGRICULTURAL PRACTICES ACCELERATING DECOMPOSITION

a) *Inoculation of Missing Organisms*

Sterilized soils lack most types of decomposers, so inoculation with organisms from non-sterile soil is sometimes advocated, despite the risk of introducing pathogens and pests. Earlier it was mentioned that earthworms and dung beetles were successfully introduced into pasture to accelerate burial of organic materials. Other animals have rarely been tried, but observations on ants suggest they might be worth testing. Animals that ingest soil particles and not merely root fragments might disturb more micro-crypts and expose hidden humus to microbial attack, either within their intestines or their faecal pellets. For most field soils there seems little purpose in introducing more types of micro-organisms since those already present appear to be adequate. Mostly microbial inoculants have been advocated for stimulating plants by providing extra vitamins and hormones, for dissolving minerals or for antagonizing pathogens rather than speeding up decomposition of humus. Research is badly needed to determine whether specific organisms can be used for degrading toxic substances, either of natural origin or synthetic. If suitable micro-organisms were inoculated in a soil soon after the application of persistant toxic sprays they might well shorten the fallow period.

b) *Addition of Energy Substances*

Resistant humus has little food or energy value for organisms so the addition of readily decomposable organic matter such as green manures, increases both microbial populations and their enzymes. Succulent plant debris might then positively prime the degradation of resistant humus, while lignified strawy materials might have the opposite effect. The greater the variety of foodstuffs, the greater the variety of organisms, ensuring a greater battery of enzymes to decompose stable humates.

c) *Application of Mineral Fertilizers*

Soils deficient in the major elements N, P and S produce plants and humus also low in them. The addition of fertilizers, particularly nitrogenous types, improves both the quantity and quality of plant debris. This supports a bigger, richer microflora and fauna thereby increasing once again the chances of decomposing intractable humic molecules.

d) *Correcting Soil pH*

The optimum pH range for decomposition of many substances is from 5.5 to 8.0, which favours most of the soil fauna and microflora. At lower pH values many plants, soil animals and actimonycetes are suppressed partly by hydrogen ions and partly by metallic ions, so neutralization with lime or alkali nitrates re-establishes them. Above this pH range many plants, animals and fungi suffer, but acidification with sulphur or ammonium fertilizers restores them. In a heterogenous material, like soil, the pH of micro-niches probably fluctuates quickly and widely, particularly in un-buffered light soils. An organism probably occupies a niche for a very short time then is displaced by another more suited to the changed environment. Decomposition of resistant materials like humates depends upon changing microflora, which is partly fostered by fluctuations in the pH of micro-niches. However, changes in pH must not be so rapid that micro-organisms have no time to multiply and produce extra-cellular enzymes.

e) *Improving Soil Aeration*

Tilling compacted or crusted soil improves aeration, but it is doubtful whether it improves the oxygen content of well structured soil, such as occurs under pasture. Certainly aerobes decompose most organic substances more rapidly and completely than anaerobes; but many soils provide niches for both aerobes and anaerobes on the surface and in the interior of crumbs respectively, once more enriching the enzyme pool. Draining waterlogged soils greatly improves aeration and favours aerobes, which rapidly decompose much of the organic matter preserved under anaerobic conditions.

f) *Increasing Soil Moisture*

Most plants die when the soil reaches permanent wilting point, but many soil organisms and enzymes remain active below this moisture level. However the majority of soil animals and micro-organisms are most active over the same range of moisture favouring plants. Decomposition of resistant humus occurs slowly over this range, tailing off on either side. BIRCH and FRIEND (1961) showed that alternate wetting and drying cycles often promote more rapid turnover of organic matter than continual moisture, because micro-crypts are disturbed and fresh organic matter is exposed to the decomposers. Cultivation often improves water, including dead organisms, intake and reduces run-off, thereby increasing the store of soil moisture and permitting decomposition over a longer period. Mulching with soil or straw wastes also improves the moisture regime. While spray irrigation preserves the aerobic environment of a soil, flood irrigation may temporarily destroy it long enough to reduce seriously the number of soil animals responsible for burying trash. It is very doubtful whether enzymes leach out of any but sandy soils, since clays or sesquioxides sorb most types.

g) *Desorbing Enzymes*

Extra-cellular enzymes arise in soils from living micro-organisms, while intra-cellular ones are liberated only after their death and lysis. Both are capable of helping to disrupt resistant humus; but most of them are used by other organisms as food. Toluene and carbon tetrachloride check microbial growth leaving many enzymes intact. Many of them are inactivated by sorption on to clay, sesquioxides or humus. Some sorbed enzymes may be re-activated by displacing them with cations. This is one possible explanation why lime and gypsum stimulate decomposition of organic matter.

There are many examples of single extra-cellular enzymes de-polymerizing substrate molecules by hydrolysis. It is more difficult to envisage oxidative degradation of humus since this often requires an integrated system of several enzymes and

H- acceptors working in sequence. Research is needed on methods for desorbing and re-activating the many enzymes in soil in order to develop suitable agricultural practices.

h) *De-toxication*

Numerous toxic substances have been isolated from soils. Some of these are anti-microbial and could hinder decomposition until removed. Long periods of fallow help. Leaching with water removes small anionic or neutral organic molecules, but is useless for cationic toxins. By sorbing many toxic substances, clays probably reduce inhibitory effects. Inocula of organisms specially adapted to decompose specific toxins have rarely been tested. The chance of successfully establishing de-toxicating organisms depends on many factors, including, paradoxically, a steady supply of toxic substances. It is conceivable that suitable organisms for de-toxicating spray residues might be maintained on non-toxic substrates containing similar bonds to induce adaptive enzymes.

SUMMARY

In most soils 98% of all N, 80% of all S, and 60% of all P are present as organic compounds, not inorganic, and therefore need to be decomposed and mineralised by micro-organisms before becoming available to plants. Under arable systems of agriculture, organic matter decomposes and mineralises almost as rapidly as it is added; but under permanent pastures or forests, organic matter accumulates sometimes at an alarming rate immobilizing large quantities of applied fertilizer as stable organic compounds. By radioactive carbon dating it has been shown that the half life of humus in soils ranges from hundreds to thousands of years. Humin and humic acid fractions are most resistant to microbial decompo-

sition, fulvic acids are intermediate in stability, while cellulosic materials are readily degraded. Most of the resistant humin and humic fractions are derived from lignins and phenolics combined with peptides. Methods might be devised for accelerating decomposition of stable humic materials, without wrecking crumb structure, and releasing minerals for plants if more were known of factors contributing to stability. This paper reviews: 1) soil conditions which are known to depress microbial activity, 2) mechanisms whereby organic materials are protected in crypts from decomposition, 3) instrinsic properties of humus imparting stability and 3) agricultural practices which might be used to accelerate decomposition and mineralization.

Decomposers are rarely completely absent from most soils, but earthworms and dung beetles have been successfully established in pastures lacking them. Their numbers may be temporarily depleted by partial sterilization with heat or chemicals. Extremes of acidity or alkalinity suppress some decomposers, but neutralization restores them. Toxic substances of microbial origin probably hinder other decomposers. Freezing soil temperatures, dehydration and lack of oxygen all inhibit decomposers activity.

Organic materials may often escape the attention of decomposers by hiding in soil crypts varying greatly in dimensions. Plant residues buried deeply ferment and become preserved as compost. Whole cells encrusted with resistant waxes, lignin, melanin and sclerotin often survive in soil, eg. cork cells, wood fibres, pollen grains, fungal sclerotin and bacterial spores. Micro-pores less than 1 μ diameter exclude most micro-organisms, but not their enzymes, so complex organic materials within clay micro-aggregates are partly protected. Sub-micropores less than a few Angstroms exclude not only organisms, but also enzymes, so organic substances wedged between clay sheets are fully protected. Clays and humic acid sorb and inactivate certain enzymes; but some are re-activated when displaced by cations.

Intrinsic properties of organic molecules make some more stable than others. Unusual bonds can hardly explain the stability of humus. Steric hindrance probably plays a part in stabilizing humic substances by preventing attachment of enzymes; but not enough is known of the groups involved. Humus contains large molecules which do not diffuse in soil water or pass through cell membranes, so they are attacked by extra-cellular enzymes only. Globular molecules with a smooth topography present few surfaces for attachment of enzymes. Negative charges sorb and inactivate certain enzymes which resume their attack on humic constituents when displaced by cations. Humic polymers probably contain numerous buildings units, linked by many different bonds, in a disorderly way, and cross-linked in three dimensions so that many enzymes are required to dissemble each constituent piece by piece over a very long period.

Agricultural practices which accelerate decomposition and mineralization of stable organic forms in soils include: *a*) inoculating soils with organisms such as earthworms and dung beetles when these are absent, *b*) green manuring and incorporating strawy wastes which temporarily increase the number and variety of organisms and enzymes, so priming an attack on humus, *c*) applying fertilizers, particularly nitrogenous types, which correct deficiencies in plant debris making it more attractive to decomposers, *d*) correcting extreme acidity and precipitating metallic cation by liming, also extreme alkalinity by applying sulphur, thus stimulating both microflora and fauna, *e*) improving aeration by tillage of compacted soil and by drainage of waterlogged soil, *f*) increasing moisture intake by cultivation and by irrigation and reducing evaporation by mulching, *g*) de-sorbing enzymes from clay and humus by liming, *h*) de-toxicating soils by leaching, by fallowing and possibly by inoculating with organisms capable of destroying specific toxic substances.

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DISCUSSION

Chairman: M. ALEXANDER

JENNY

This has been a most interesting and stimulating discussion. I am curious about enzyme actions. The way it is presented, all an enzyme needs is access to a substrate and then it starts working. It is not true that the enzyme must have a certain ionic environment to function in a maximum way? What is the situation?

SWABY

I think you are quite correct that enzymes do require a suitable environment and one in particular is water. This is usually found in soils in sufficient quantities, secondly you need also the right pH for enzymes to function and sometimes you need metal co-factors to help in catalysis, but I would think that these are mostly adequate in soils. Therefore, I do not think that it is environment necessarily that is interfering much with enzyme function, except if soil constituents absorb the enzyme.

JENNY

I did not make myself clear. I had in mind the *ionic* environment including electrolyte concentrations, DONNAN equilibria, isoelectric points, etc. Are these things important in your theoretical discussion? I did not see any reference to ion activities or electric potential.

SWABY

I think you are possibly correct that double layers of ions around colloids can sometimes hinder enzyme action. I have not got any very good evidence for this. It is an unexplored field I would say. I think that there are often, as you know yourself, double layers around organic materials in soils as there are around clays and this could be a very adverse environment sometimes for enzyme attack. This has not been explored much either. We have a team doing this sort of work right now, but so far as I can recall altering the suite of ions on the humate does not hinder protease activity. Russian workers claim that ferric ions stablise humic acids. In fact Dr. LADD has used cobalt and calcium ions to release enzymes so that they can get to work again and hydrolyse proteins.

HERNANDO

I am sorry I lost part of your paper because I had to leave the room. Did you say that the application of earthworms, bacteria and beetles to the soil is a good method to improve the soil conditions? Do you think that in natural conditions earthworms, nitrification bacteria etc. in soils can be increased by inoculation?

SWABY

I think I can explain myself a little better. We do not believe that inoculation of many of the micro-organisms is necessary to speed up decomposition. We do think, however, that inoculation with some types of the flora and fauna is beneficial. It is a peculiarity of our country that we lacked European earthworms, and dung-beetles, which did not evolve in our area. We are so far away from the main continental masses of the world they just never got to us. So if you introduce these, normal burial occurs. I do not think we lack too many of the world's share of micro-organisms. They can come in dust and in water and in many other ways to our continent so we do not seem to lack these. I would not think you would need to inoculate with micro-organisms except in one case that I know of, and that is if you sterilise the soil you often have to replace decomposer micro-organisms.

HERNANDO

I understand that you have the same idea about the application of earthworms and beetles to the soil. Is that right?

SWABY

Australia has not many experiments on inoculation of soils with earthworms. We are about to introduce dung beetles. New Zealand has benefited by worm introduction.

HERNANDO

There are two more questions. As you have shown in the last table, it is possible to improve the aeration with cultivation. I think this can immediately be obtained, but in continuing this method the effect would get worse. Also when you spoke about detoxication, you leave in the end a question mark. In my opinion the best method to detoxicate the soil is to change the plant growth, that is, the type of the plant that is grown there.

SWABY

I think I agree with you that rotation does help to overcome certain toxic materials.

FLAIG

Dr. SWABY, I have been very much interested in your structure scheme of humic substances and I have some questions. You say that you also found vanillyl alcohol by degradation of humic substances. We found only until now vanillin and vanillic acid.

SWABY

We have not found any of these thinks. This is a summary from HURST and BURGES's chapter in « Soil Biochemistry » where they mention these things, so I really copied them out.

FLAIG

Benzopyrene or perylene derivatives have been found by HAWORTH with zinc dust distillation in humic substances. Zinc dust distillation needs a higher temperature about 300°C and many of polymeric reactions can occur which form these polyaromatic cyclic compounds. I would like to ask you, have you further results which confirm the presence of perylene or benzopyrene in the structure of humic acids.

SWABY

Don't think that I did all that work, because I did not. As my paper shows, I give references for some of the sources of information. The only time we have ever seen a perylene-like compound is when we isolated from a green soil a perylene-like, chlorinated, quinonoid, compound which is a brilliant red colour.

FLAIG

You mentioned a structure of diphenyl ether. It is known that 4,41-dihydroxy-diphenyl ether is easily split off with mild oxidation agents. Two molecules of *p*-benzoquinone are formed. How much diphenyl ether structure would be resistant against oxidation in the molecules of humic substances. Is it possible that this structure occurs in humic substances?

SWABY

Dr. FLAIG, please do not expect me to be as precise as you organic chemists. This was'nt my aim. That very diagramatic formula I put up for humic was to illustrate that there were many units in it, there were many bonds that have been detected; it was by no means a repeating molecule; it was non-crystalline; it has all the properties of a resinous material which was intractable to enzyme attack and I did not want you to believe that the chemistry was known.

FLAIG

But nevertheless, I would say that one should some time make proposals of the structure of humic substances to show the results which have been achieved in the elucidation of chemical structure of humic substances. Therefore, it is important what you have shown us. By this one gets an idea how much progress for elucidation of the humic substances have been made.

PRIMAVESI

Prof. SWABY, it is very interesting to know, that whilst we are fighting to increase organic matter in our crop soils, you struggle to hinder its excessive accumulation in your pasture soils. It is most interesting to know, that: *a*) as well too low as too high humus levels are injurious; *b*) it shows clearly the principal problem is *not* the humus, but the « soil life »; *c*) all methods you enhance to increase humus decomposition are to be reduced in countries with the problem of too fast turnover of organic matter; *d*) world problem is the control of soil life (microflora and mesofauna). By its control, humus will be in the right quantity in soil or: the right quantity of humus indicates the right management of soil.

SWABY

I suppose you could say that by excessive use of artificial fertilizers we have brought this on our own selves and I would agree with you that we have accumulated a lot of organic matter which is tying up fertilizers and if we knew how to apply fertilizers more efficiently so they did not get tied up, we would do better. We do not yet know how to do this. We get such enormous increase in growth with the artificial fertilizers that we will do this despite the build-up of organic matter. However, it is rather expensive because much of our fertilizer goes into this organic fraction which turns over so slowly. So as a person who is interested in the economics of farming I think we would like to see these minerals coming back, to save the fertilizer bill. Now you say we might be also doing something wrong to the fauna and the micro-flora. I do not think we are really. I think it is just the heavy use of the fertilizer producing so much plant debris which has brought about this condition. Only the economics is worrying me. Everything else is right. The structure is beautiful. When you clear the land and till it again it is marvellous, you get a lot of it back again on ploughing. But while you have your permanent pasture or forest there, you just cannot get this organic matter turning over quickly enough.

FRANZ

I am very sorry that I had'nt the possibility to hear the whole Report but I tried to read the manuscript. I think that we can study these problems of accumulation of organic matter in the biochemical way but we can study them also from the ecological point of view. From the ecological point of view there is the question why the accumulation of organic matter took place. Generally, the whole complex of factors in a certain place is in a dynamic equilibrium. If we have unfavourable conditions for the decomposition of organic matter, this can be caused by the climate, the composition of the vegetation etc. It can also be caused by the fault of certain organisms like earthworms or heetles which destroy the excrement of animals so it is the case in Australia. It is also possible that the accumulation of organic matter is caused by artificial conditions, like degradation of the fauna and degradation of the vegetation hy man. This is the case in many forests in Europe, for instance, hy monocultures of Pinus or Pina excelsa etc. If the accumulation of organic matter is the result of the natural evolution of soil, especially if the evolution of organic matter is a part of the climax stadium of soil, we can recommend to change it only if we reach the changement with economically acceptable means. Many times such a changement is very expensive and not interesting from the economic point of view. If humus accumulation is caused by man, then we must also know the factors which cause the accumulation of organic matter, and also in this case it is a question of whether correcting these conditions is economically interesting or not.

BRADFIELD

In all of the countries in which I have ever worked, we have been more concerned with the problem of too rapid depletion of organic matter rather than too slow decomposition. I am not too clear about the circumstances under which this slow rate of decomposition occurs. What do you consider a reasonable rate, a desirable rate of decomposition for soil organic matter in some of your highly fertilized pastures?

SWABY

I think if you can maintain virgin level you are doing fine. We are up to three times the virgin level in some cases and I think that is very bad. This leads to the tie up of so much of our fertilizer — in fact we can work out the percentage that is tied up — it is quite an appreciable amount: something like 60% of what we apply is getting tied up in this way. I think economically this is a great loss. We know we can recover it ultimately if we plough the pastures or if we cut down the trees then plough the land. We can recover it in our next crops. The problem is; how to recover it while you have still got your permanent pasture, while you have still got your permanent plantations of trees. That is the real problem, we do not know how to do it under these conditions.

BRADFIELD

We are more troubled with too rapid decomposition. I should think that the periodic ploughing up of pastures and re-establishment would result in an improvement of the pastures and a release of the fertility that has been stored in long heavily fertilized lays.

SWABY

Sometimes I will agree with you that this is true, if you tear up a pasture, but in some areas, they are almost entirely for grazing purposes and so these graziers are not inclined to become croppers. If they did rip these pastures up with the plough they would then put down new pastures. This can be done, but usually these high yielding pastures are still so good there is no good reason for ripping them up, other than the fact that they are becoming a sink for fertilizer. They are still productive and they are giving high yields of meat products and wool and milk, so that there is no good reason to rip them up. It is certainly true in the forest areas that there is no good reason again for ripping these up, except that the fertilizers have to be piled on in larger quantities when you get this enormous build up of litter.

BRADFIELD

Can you conceive of any technique which would be simpler than ploughing them up? This would also provide opportunity for receding to improve the flora.

SWABY

This is what I tried to summarize in my last slide. The many things that you could use are just about out of the question in these two environments.

L'INFLUENCE DU CLIMAT SUR LA COMPOSITION DES ZOOCENOSES TERRICOLES ET SA REPERCUSSION SUR LA FORMATION DE L'HUMUS

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Les sols et les couches de litière, qui les couvrent souvent, sont habités d'innombrables êtres vivants. Les biocénoses terricoles se composent surtout de Bactéries, de Champignons et de petits animaux endogés. On sait dès longtemps que la population animal des sols a une très grande importance pour la transformation des résidus organiques en humus, et que le travail effectué par les divers espèces est très differencié. Déjà H.v. Post (1861-62) et P.E. Müller (1887) ont montré que la formation des différentes types d'humus est étroitement liée avec la composition en espèces des zoocénoses terricoles qui de leur côté sont influencées par les conditions climatiques données.

Il est nécessaire, avant de discuter l'influence du climat sur la composition des zoocénoses et de sa répercussion sur la transformation de la matière organique dans les sols, de parler en général du travail effectué au cours de ce procès par les différentes groupes d'animaux endogés.

Sans doute des travaux mécaniques ont la plus grande importance parce qu'ils ne peuvent pas être substitués par l'activité des microbes.

Les animaux détritophages partagent les résidus végétaux en petits débris en se nourissant d'eux et facilitent ainsi leur décomposition microbienne. A la surface des sols habités d'une zoocénose nombreuse et variée ne s'accumulent jamais des couches épaisses d'humus défavorable, tandis que c'est le cas fréquemment quand les animaux endogés sont peu nombreux et peu actifs.

Les vers de terre, surtout certains représentants de la famille Lumbricidae réalisent un travail spécial. Ils ne mangent pas seulement des substances organiques mais aussi la terre fine, surtout les argiles et produisent dans leur tube digestif des complexes argilo-humiques (BREMNER). Ces complexes sont la partie intégrante du type d'humus Mull qui par conséquence ne peut être produit que dans un horizon minéral humifère du sol.

Les vers de terre ont encore une autre fonction importante. Ils mélent continuellement le matériel des différentes horizons du sol en se nourissant de la terre et en creusant leurs galéries. Le résultat de ce travail fondamental pour l'évolution du sol est l'homogénisation de la terre, inclu l'intégration des résidus végétaux accumulés à la surface dans le sol minéral. Par conséquence il ne se peut former sur les sols forestiers habités d'une nombreuse population de Lombrics qu'une mince couche de litiere qui se décompose rapidement. On peut observer que les grandes espèces de la famille Lumbricidae ramassent les feuilles et petits débris de bois et les tirent dans leurs galéries, ou ils subissent une décomposition rapide.

Dès CH. DARWIN (1882) beaucoup de chercheurs ont fait des observations sur le travail mécanique énorme des Lombrics. On a essayé récemment de le mésurer quantitativement, mais c'est très difficile, car les vers de terre ne déposent qu'une partie de leurs excréments à la surface du sol. Le reste, dans les sols meubles même la plus grande partie, est accumulé à l'interieur de leurs galéries, produisant une structure grumuleuse spéciale de la terre. Certains auteurs comme EVANS (1947), A. FINK (1952) et STÖCKLI (1949) se sont borné de peser la quantité des excréments déposés à la surface d'un sol de prairie ou de champ au mètre carré au cours d'un an. Ils ont obtenu des valeurs extraordinaires et ont calculé que dans les sols habités d'une population nombreuse et active de Lombrics une quantité de terre correspondante à la couche supérieure de 20 cm du sol passe au cours de dix ans le tube digestif des vers. Tels sols sont formés par les vers de terre dans une telle mesure que l'on a raison de les nommer sols formés par les Lombrics (Regenwurmböden).

L'importance des vers de terre n'est pas la même dans toutes les parties du monde. La sous-famille Lumbricinae est selon MICHAELSEN (1917) d'origine paléarctique. Elle a été introduite par l'homme au cours de la colonisation européenne dans les autres continents sans y être reparti jusqu'à présent généralement. Les autres vers de terre réalisent un travail moins important, nous en parlerons encore. Les sols extrêmement secs ne sont pas habités par des vers.

Les Termites représentent dans les pays tropicaux une concurrence grave des vers de terre. J'ai constaté que les vers de terre sont peu nombreux ou manquent même complètement dans les biotopes habités par un grand nombre de Termites. Ceux-ci réalisent aussi un travail très remarquable dans les sols habités par eux. Ils construisent en partie des nids énormes, qui représentent des véritables collines et ils accumulent dans leurs galeries les argiles, dont ils forment ensemble avec la matière organique une sorte de ciment plus ou moins dure. Ce ciment consiste comme le Mull des Lombrics en complexes argilo-humeux, malheureusement encore peu étudiés du point de vue chimique. Du point de vue physique les galéries des Termites sont défavorables pour le sol, tandis que la formation du Mull des Lombrics et la structure grumuleuse qu'ils produisent représentent une amélioration du sol remarquable. Les galéries des Termites sont très stables et se conservent longtemps. On les trouve quelquefois dans un état plus ou moins fossilisé à des endroits qui actuellement ne sont pas habités par leurs constructeurs.

Il faut remarquer qu'il y a encore d'autres groupes d'animaux terricoles qui réalisent un travail mécanique remarquable. On doit mentionner par exemple les fourmis, surtout celles qui construisent leurs nids a l'intérieur du sol. Certaines espèces récoltent des plantes et les déposent dans leurs galéries pour y cultiver des champignons, autres sont carnivores et ont une très grande importance pour l'équilibre biocénotique. Un autre groupe important sont les Coléoptères coprophages. Ils creusent leurs galéries jusqu'à une profondeur de plus de 50 cm, pour y déposer une boule formée de la substance des excréments des grands mammifères. Les larves se développent dans cette boule. Quand les galéries sont abandonnées les Lombrics les remplissent avec leurs excréments en formant des microcrotovines. Beaucoup d'autres Insectes, de Myriopodes et Isopodes terrestres creusent aussi des galéries dans le sol et contribuent ainsi à mélanger le sol et le rendre meuble. On ne doit pas oublier finalement le travail énorme effectuée surtout dans les sols de steppe par les petits mammifères terricoles. Ils creusent leurs galéries jusqu'à une profondeur de plusieurs mètres. Les galéries abandonnées se remplissent avec les excréments des vers de terre et sont connues dans cet état sous le nom de Crotowines.

La contribution des animaux endogés à la transformation chimique de la matière organique est moins évidente que l'importance de leur travail mécanique. LAATSCH (1948) a exposé que les conditions pour la production d'humus sont extrêmement favorables dans le tube digestif des animaux détritophages, parce que l'accès de l'oxygène y est limité et l'azote nécessaire pour la formation des acides humiques est disponible en quantité et qualité favorable. C'est surtout le cas chez les animaux qui vivent en symbiose avec des microorganismes capables de fixer l'azote libre.

Il est malheureusement très difficile d'étudier les réactions chimiques qui jouent dans le tube digestif des petits animaux endogés, et encore plus difficile de décider si ces réactions sont causées par les organes digestifs des animaux ou par les microorganismes qui participent à la décomposition de la nourriture. Nous avons comparé (FRANZ et LEITENBERGER, 1948) du point de vue qualitatif et quantitatif le contenu de substances insolubles en Azetylbromid dans la matière organique de la nourriture et des excréments de différents animaux détritophages. Pour une comparaison exacte se posent des difficultés très grandes, même si l'on fait des expériences en conditions relativement bien déterminées. Nous présentions dans nos expériences une quantité pesée de feuilles mortes d'une seule espèce de plantes et d'une seule provenance à un nombre déterminé d'individus d'une seule espèce détritophage. Les petits animaux nécessitent malheureusement plusieurs semaines pour produire une quantité d'excréments suffisante pour une analyse chimique. Nous avons recueilli les excréments journellement et nous les avons sêché immédiatement pour éviter une attaque microbienne supplémentaire, mais il était impossible d'éviter que la nourriture pas encore mangée était attaquée par les microbes. Nous avons déterminé non seulement le poids des excréments, mais aussi celui du reste de nourriture non mangée. Bien qu'une partie de la matière organique a été minéralisée au cours de la digestion, plusieurs expériences ont donné le résultat que la quantité des substances organique non soluble en Azetylbromid était plus grande dans les excréments et les restes de nourriture ensemble qu'au commencement dans la nourriture entière présentée aux animaux. Cela permet la conclusion, qu'une production de substances humeuses a eu lieu. La question cependant, que cette production a été causée par les animaux eux mêmes ou par des microorganismes reste ouverte. Il n'y a pourtant aucune raison de supposer, que les réactions chimiques, qui jouent pendant la transformation des restes de plantes en humus, soient freinées pendant la digestion des animaux détritophages.

La digestion n'est pas de la même intensité chez les différents groupes d'animaux détritophages comme c'était déjà montré par KUBIENA (1945). On sait aussi que la qualité de la nourriture joue un très grand rôle. Les animaux mangent d'une nourriture favorable pour eux des quantités plus grandes et produisent des excréments, dans lesquelles les restes organiques sont plus decomposés. Ils préfèrent en outre une nourriture déjà attaquée par les microbes à une nourriture encore fraîche comme nous l'avons utilisé dans nos expériences. Toutes les observations faites sur la transformation de la matière organique dans le sol en conditions naturelles montrent, que cette transformation est jamais le résultat de l'activité d'une seule espèce. On observe toujours des chaînes de nourriture auxquelles appartiennent différentes espèces de microbes et d'animaux. Il est sûr en outre, approuvé aussi par des expériences faites par M. HENIN, qui est parmi nous, qu'une transformation de la matière organique causée seulement par des microbes donne un résultat différent de celui qui l'on obtient quand les animaux détritophages en participent. C'est surtout évident pour les vers de terre. Leurs excréments contiennent des complexes argilo-humiques, qui ne se forment que dans leur tube digestif et qui se forment même quand les animaux ne mangent que des restes de plantes encore peu decomposés ensemble avec un matériel argileux. Il faut ajouter que l'influence des animaux terricoles sur la transformation de la matière organique n'est pas limitée à la formation d'humus, elle comprend aussi la décomposition complète des substances organiques, inclu la minéralisation des acides organiques solubles en eau qui se forment au cours de la décomposition des résidus des plantes. Ces acides, qui ont une influence très défaborable sur l'evolution du sol, se décomposent rapidement par l'interaction des animaux terricoles tandis qu'ils se conservent quand cette interaction n'a pas lieu ou reste trop faible.

Nous avons parlé des chaînes de nourriture des organismes qui participent à la transformation des restes de plantes. Il est évident que l'effet de cette transformation dépend des organismes qui collaborent. Elle donnera un résultat autant plus différent que les membres des chaînes de nourriture changent. La composition des chaînes de nourriture dépend de la composition en espèces des biocénoses terricoles qui de sa côté dépend en grande mesure des conditions climatiques données. Chaque espèce est adaptée à des conditions climatiques plus ou moins étroitement limitées, elle doit mourir au moment, où ces conditions ne correspondent plus à elle. On peut facilement observer, que déjà les différences microclimatiques causées par une exposition différente au soleil ou par l'ombrage différente causée par une végétation de différente hauteur ou densité suffisent pour provoquer un changement de la composition des biocénoses terricoles. Un tel changement a une répercussion forte sur la transformation de la matière organique du sol, comme l'ont démontré les expériences interéssantes de Mme G. GISIN (1952). Elle instalait au même temps, en automne, deux tas de feuilles, l'un au côté nord, l'autre au côté sud d'un bâtiment. Au printemps suivant les deux tas étaient habités de populations différentes de Collemboles. On mettait alors les deux tas l'un à côté de l'autre à une distance de 20 cm seulement, ils se trouvaient par conséquence dès lors dans les mêmes conditions climatiques. Les populations de Collemboles qui les habitaient restaient pourtant différentes et même la transplantation d'un échantillon avec tous les Collemboles qui l'habitaient de l'un tas à l'autre ne pouvait pas provoquer un changement. Cette expérience fait voir, non seulement l'influence profonde du climat sur la composition des biocénoses terricoles mais aussi la répercussion d'un changement des biocénoses sur le milieu chimique. Les grandes différences, qui existent dans la composition des biocénoses en relation avec les conditions climatiques dans les différentes parties du monde doivent avoir par consequence une influence encore beaucoup plus profonde.

Je me bornerai selon l'objet de mon rapport à discuter l'influence des facteurs climatiques aux zoocénoses, mais l'interaction multiple entre animaux endogés et microorganismes le rendra nécessaire de tenir compte aussi un peu de l'influence climatique sur l'activité microbienne.

Deux facteurs climatiques ont une très grande influence sur l'activité biologique; la température et l'humidité. Discutons premièrement l'influence de différentes températures sur l'activité et composition des zoocénoses en conditions humides. En ce cas l'activité biologique est corrélée largement avec la température, elle diminue avec elle et augmente avec elle jusqu'au point optimum. Ce point n'est jamais surmonté en conditions humides naturelles, on trouve des températures plus hautes seulement dans des amas de résidus organiques en décomposition rapide. Les tas de fumier par exemple atteignent souvent dans les parties intérieures une température de 60°C et plus. Dans un tel milieu aucun animal peut exister. Les animaux participant à la décomposition du fumier se trouvent en ce cas seulement dans la couche superficielle et peuvent pénétrer à l'intérieur seulement à la mesure que la température diminue. C'est un ver de terre, Eisenia foetida Sav., un animal presque cosmopolite, qui domine les zoocénoses habitant les tas de fumier et de restes de plantes en décomposition rapide. Ce ver de terre se multiplie rapidement dans le milieu favorable pour lui. L'évolution de l'oeuf jusqu'à l'adulte nécessite trois mois. Les animaux sont androgynes, chaque individue ponde environ 100 oeufs qui donnent après trois mois 100 adultes (Graff, 1955), qui pondant du nouveau chacun 100 oeufs. Dans un tas de fumier qui était habité au début de 1000 vers d'un poids moyen de 0,5 g par individu, se trouvent par conséquence après trois mois 100.000 individues de différent âge avec un poids total de 23 kg. Ils mangent par jour approximativement la moitié de leur poids, ce sont 11,5 kg et transforment les restes organiques non digérés en excréments humeux. On voit que le travail réalisé par une population nombreuse d'Eisenia foetida au cours de la décomposition du fumier est énorme. L. MEYER (1943) a montré que le rapport Carbon-Azote des excréments que produisait une population d'Eisenia foetida dans un tas de paille était beaucoup plus étroit que celui de la paille même.

Entre les biotopes naturels les forêts tropicaux humides sont les plus favorables pour la faune terricole. La température et l'humidité des sols y sont presque constantes. La biocénose terricole peut être active toute l'année à un niveau très élèvé. La matière organique subit par conséquence une minéralisation rapide, excepté les sols qui ont une réaction très acide. La faune terricole des forêts tropicaux humides non dévastés est énormement riche en espèces, la population extrêmement dens. Tous les groupes d'êtres vivants importants pour la transformation de la matière organique du sol y sont présents en grand nombre et ils sont très actifs.

Le nombre d'espèces qui composent les biocénoses diminue quand on avance des régions tropicaux vers les régions plus sêche ou plus froides. L'activité biologique est freînée en hiver déjà dans les régions tempérées, comme en Europe centrale. La quantité de travail réalisée par les organismes détritophages diminue plus rapidement avec la température que la production des substances organiques par les plantes vertes. Les restes végétales s'accumulent par conséquence à la surface du sol et forment surtout dans les forêts subarctics une couche épaisse d'humus brut. La réaction extrêmement acide de cette couche conduit a la podsolisation du sol mineral. Dans un tel milieu beaucoup de microorganismes, surtout bactéries, mais aussi certains animaux terricoles ne peuvent plus vivre. Les vers de terre par exemple disparaissent presque complêtement, quoique l'influence directe des facteurs climatiques leur permetterait encore une certaine activité. Les Acariens et Collemboles dominent la zoocénose. Ils transforment les restes végétaux au cours d'années en excréments et débris de plantes très petits. Ce matériel forme enfin l'horizon H de HESSELMAN (1926) qui consiste chez les Podsols d'une substance organique peu structurée, riche en eau hygroscopique et très peu airée.

L'influence d'une humidité variable sur la composition et l'activité des biocénoses terricoles est encore plus marquée que celle de la température. Un défaut d'eau limite les activités biologiques pas moins brusquement qu'une température basse. La plupart des animaux endogés ne peut survivre dans une période sêche que dans un état anabiotique. Les animaux hygrophils meurent immédiatement quand la déssiccation du sol dépasse un certain degré. C'est pourquoi la destruction des forêts, qui protègent le sol contre la déssiccation, est tellement défavorable pour les biocénoses endogées. Elle est extrêmement dangereuse pour la fertilité des sols dans les zones avec un climat de transition ou les périodes sêches se repètent périodiquement.

A. ZICSI (1958) a observé en Hongrie que même les Lombrics habitant les tchernosems meurent, quand ils doivent subire une période sêche trop longue. Les vers de terre ont dans les régions de climat sémihumide et sémiarride tempéré comme la plupart des autres animaux terricoles une double periode d'inactivité. L'une est causée par la température basse en hiver, l'autre par la dessiccation du sol en été. L'activité de la faune terricole diminue dans les tchernosems russes du nord vers le sud et du même de l'ouest vers l'est avec la précipitation annuelle. Au même sens diminue aussi la profondeur des sols et la qualité de l'humus comme nous avons pu apprendre de nos collègues russes pendant l'excursion avant du congrès international de la science du sol à Bucareste en 1964.

Le type d'humus caractéristique pour les sols de steppe est Mull. L'humidité accumulée dans le sol pendant les periodes humides permet en général une activité suffisante des lombrics pour transformer les restes de plantes non minéralisés en Mull. J'ai trouvé en outre dans toutes les régions avec un climat de steppe des vers de terre spécialement adaptés à ce milieu. Les sols au climat relativement sec à l'est de l'Autriche et au sud de la Tchecoslovaquie sont en grande partie des tchernosems. Ils sont habités d'une espèce de vers de terre de 50 cm de longueur, Allolobophora hrabei Cern., qui est endémique dans cette région. Cet animal produit des quantités extraordinaires d'excréments qu'elle dépose en grande partie à la surface des sols.

Une espèce endémique dans les steppes de l'Espagne, Allolobophora haasei Čern., a la même coûtume, et j'ai trouvé aussi au Norte Chico de Chile une espèce d'activité enorme, sans connaître jusqu'au moment le nom de cet animal. Les sols de steppe sont en général des véritables sols de vers de terre. Il y a pourtant des endroits défavorables, trop secs, ou ne se forme plus Mull. Ces sols, on les trouve en extension limitée même en Autriche, ne sont pas habités de Lombrics. Le type d'humus, qui se forme en ce cas est Moder.

Les sols sémidésertiques sont habités d'une faune terricole pauvre en espèces et en individus. Même les forêts secs avec une végétation clairsemée d'arbres ou d'arbustes, comme on la trouve par exemple dans la région sahelienne au sud de la Sahara, ont une faune terricole pauvre. Le type d'humus qui se forme là est un Moder, qui consiste de debris de plantes et d'excréments d'Arthropodes. Des Julides et quelquefois aussi des Isopodes terrestres y jouent un rôle dominant. Ces animaux ne sont pas capables de mêler complètement la couche mince de litière avec le sol minéral, ainsi que presque tout d'humus reste superficiel. Les vers de terre y manquent complêtement. Au bord des déserts et dans la plupart des oasis ne manquent pas seulement les vers de terre mais aussi les Isopodes et Myriopodes. Au-dessous des plantes épineuses clairsemées des biotopes sémidésertiques ne s'accumule pas en général d'humus. Il y a trop peu de litière. La fauna que j'ai trouvé aux endroits d'humidité plus élevée dans les oasis au nord de la République du Tchad et au bord du grand désert au nord de Chile consistait de quelques Acariens, Coléoptères, Psocides, Lepismatides, Collemboles et fourmis. Même cette population pauvre était encore capable de décomposer la petite quantité de résidus de plantes et de la transformer en collaboration avec les microbes en Moder. Dans la partie sude de Ténériffe les bouses de vache sont transformées aux conditions sèches de ce territoire en humus coprogène par un seul animal, la larve d'un Microlepidoptère.

Si la dessication du sol dépasse la valeur de pF 5,5 la composition de la microflora du sol change selon DOMMERGUES (1964) profondément. Une partie des microorganismes disparaît complètement, une autre partie peut persister et reste même plus ou moins active. Les biocénoses des sols sémidésertiques sont autant plus incomplètes en animaux et microbes que leur dessication devient plus extrême. La transformation de la matière organique doit par conséquence rester incomplête elle aussi et donner comme résultat de substances organiques différentes de ceux qui se trouvent dans l'humus formé par une biocénose riche. Nous sommes au moment sur le point d'étudier chimiquement les formes d'humus formées en telles conditions extrêmes.

La plupart des animaux endogés n'est pas capable de faire de grandes migrations. Leur répartition géographique est par conséquence en general limitée. Même des régions voisines sont habitées fréquemment par une faune terricole différente, mais ce sont pourtant les mêmes groupes d'animaux détritophages qui se trouvent presque partout. Ils se rencontrent dans les sols des forêts tropicaux, dans les sols des forêts des régions tempérées et même dans les sols de steppe. Il y a cependant quelques exceptions, qui méritent un intérêt spécial.

De telles exceptions se trouvent sur quelques îles océaniques très isolées. Il y a quelques îles ou n'existent que très peu d'animaux terricoles. C'est le cas par exemple à Tristan de Cunha où l'on a trouvé seulement très peu d'espèces d'Arthropodes endogés. L'humus de tels endroits n'est pas malheureusement étudié du point de vue morphologique et chimique, mais les naturalistes, qu'ont visité Tristan de Cunha, y ont observé au-dessous de la végétation arbustive une couche d'humus épaisse et défavorable.

Des observations très intéressantes, ont été faites à Nouvelle-Zélande. Les îles de Nouvelle-Zélande ont une faune terricole riche, mais reliquataire à cause de la longue isolation. Beaucoup d'animaux modernes n'ont pas pu y immigrer. C'était aussi le cas pour les vers de terre de la famille Lumbricidae. Ceux-ci ont été introduits récemment et par hasard par les colonistes européens. Ils se sont reparti rapidement le long des côtes, mais ils pénètrent lentement dans l'intérieur des îles. Les vers de terre endémiques des îles sont beaucoup moins actifs et ils n'ont pas par conséquence la même importance pour l'évolution des sols que les vers européens. L'immigration des Lombrics européens, surtout d'Allolobophora caliginosa Sav., d'une espèce migratrice et extrèmement active, cause une transformation complête de la végétation et aussi des sols des prairies et pâtures nouvellezélandaises. On a introduit ces vers de terre avec des touffes d'herbe dans les pâtures pauvres à l'intérieur des îles et a observé que les herbes naturelles y était remplacé rapidement par des herbes bonnes, surtout par Lolium pérenne (Raygras anglais), une graminée introduite par les colonistes. On a répété l'introduction des Lombrics européens beaucoup de fois et obtenu toujours le même resultat qui correspond à une ammelioration considérable des pâtures. L'immigration des vers de terre européens ne causait pas seulement un changement de la végétation des pâtures mais aussi un changement de la dynamique du sol. Tandis que les prairies naturelles de Nouvelle-Zélande ont en général des sols à Moder, les pâtures intenses habitées des vers de terre européens ont des sols à Mull.

Cet exemple approuve une fois de plus le rôle important de la fauna terricole pour la fertilité des sols, mais elle démontre aussi que l'homme de notre époque technique et industrielle est en train de transformer profondément les équilibres écologiques naturelles. Les colonistes européens ont introduit dans toutes les régions tempérées et humides du monde pas seulement les Lombrics européens mais aussi beaucoup d'autres pétits animaux endogés. L'agriculture européenne y a créé presque les mêmes conditions écologiques inclu un microclimat artificiel ce qui permettait l'évolution d'une faune terricole artificielle et presque cosmopolite aux terrains cultivés. Cette faune peut être nombreuse et bien équilibrée, elle peut être de très grande importance pour la conservation de la fertilité du sol. C'est le cas quand il y a une production d'humus à un haut niveau et quand la production et la décomposition d'humus se trouvent en équilibre. Les actions de l'homme peuvent cependant aussi diminuer la fertilité du sol et même la détruire complètement. En ce cas diminue toujours l'activité biologique du sol, elle peut tomber presque à zero, et il est très difficile de la restituer dn nouveau.

La destruction de la faune terricole est beaucoup de fois la conséquence d'un changement artificiel du microclimat des endroits en question. La liaison étroite entre la transformation des substances organiques et l'activité biologique du sol avec les conditions climatiques le rende nécessaire de conserver un microclimat favorable pour les biocénoses terricoles des terrains cultivés. Les méthodes de technique agricole et forestière ne correspondent pas malheureusement toujours à ce devoir. Ils ne correspondent pas en grande mesure aux pays sous-dévelloppés, mais ils ne correspondent pas aussi quelquefois aux pays qui appliquent des methodes techniques modernes.

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DISCUSSION

Chairman: M. ALEXANDER

ALEXANDER

Clearly, little is known about this group of organisms. Prof. FRANZ has done an admirable job in presenting the topic, not an easy one to consider in a short period of time.

BAVER

I want to comment on one of your last points about the impact of man on earthworms. I cannot vouch for the truth of the newspaper article that the Columbus, Ohio, area has been the earthworm capital of America. However, there was a very long article in the newspaper during the past two weeks complaining about the decrease in the number of earthworms that people use for fish bait. They contribute this decline to the fact that the people have been using herbicides for the control of weeds on lawns - do you have any comment on that?

FRANZ

No.

BAVER

Weed control chemicals.

FRANZ

That is right.

I can say something about pesticides. These chemical materials are very dangerous for the whole community of animals in the soil, and probably also for the micro-organisms. It was observed in the Netherlands a few years ago that in the orchards where pesticides were applied continuously, the population of earthworms was destroyed completely. The worms degenerated first and then disappeared completely.

BRAMAO

Prof. FRANZ I enjoyed very much your lecture. I have two questions. The first is: I was under the impression that the earthworms needed a sufficient supply of calcium in the soil, and I would like to have this confirmed by you. The second question is: I am under the impression that termites live under completely different conditions from earthworms, and the result of their activity is the production of areas of rather low fertility. This is the experience of South America and I believe also from Australia, as reported by Dr. LEE. We understand that termites need a climate with a dry season. Is this your experience too? I would also like to ask you if you know the carbon nitrogen ratios of organic matter produced by termites? This I believe is probably different from those of earthworms.

FRANZ

The calcium content of soils has a very great importance on the earthworm population. In acid soils there are very few earthworms and only such worms which are not burrowing the earth. So for instance in podsols you have no activity of earthworms. It seems that earthworms need the calcium for respiration. If they have no calcium they cannot breathe. Another thing that they need also is humidity. In Hungary ZICSI made a very interesting observation a few years ago after a very dry summer. The soils dried out just one meter or more and the young worms died, and it needed three years for the population of earthworms to return to a normal level. The termites are not the same in open land (Steppe, Savana), and in forests. We find completely different species of termites in forests than in the open land like the Savanas - and so on. The termites which make big hills live only in places where sunshine can come to the soil surface. If you cut the forest this changes the fauna of the termites. The little termites which make little hills are substituted by the termites which make big bills or produce cementation of the surface of the soil. This is very important for the soil because after this work the soil is much less fertile than it was before, and this does not change for hundreds of years. About the influence of the soil animals on the carbon-nitrogen relation, I can say only something about the earthworms. The carbon-nitrogen relation is in the earthworms cements much lower than in the other humus of the same place. So it seems that there is a certain accumulation of nitrogen in the excrements. I have the impression that in the digestive tube of the worms nitrogen fixation take place. There is a very rich micro-flora and also of protozoa. I have no exact information about nitrogen fixation in the digestive tube of the worms, but it would be very interesting to study this question.

DHAR

Did you measure the acidity of your soils?

FRANZ

The pH is of very great importance for the animal communities of the soils not only for the bacteria which is very well known, but also for the animals - first for the earthworms but also for many other litter animals. There are animals that you find only in soils which are acid and others only in soils which have pH about 7, and others which you find only in alkaline soils. There are very strong relations, not between all, but between certain species.

SWABY

You have emphasized the very desirable properties of many of the animals in the soil and I would like to show the opposite side. There are a number of animals in Australia which help to preserve organic materials often in odd spots. For instance, it has been briefly mentioned by Dr. BRAMAO that termites in his area of the world will tie up organic matter. I can give a little more information about this because I think it is important. Dr. LEE has been working on termites in savannah woodland where the termite mounds here are distributed usually about 10 per acre. They are quite large being about three or four feet high and about something in the order of 10 feet around. Now he has dissected them and analysed them and has found enormous quantities of organic matter, nitrogen and phosphorus, tied up in these mounds. What is more, these mounds take 60 years to decompose, under natural conditions, but the bull-dozer takes only 60 minutes. The amazing thing is that the organic matter persists — particularly in the tunnels where breeding activity is taking place — yet this organic matter is moist, it is correct pH, about 6.5 to 7, it seems to have a suitable carbon-nitrogen ratio, wide enough for decomposition, and yet it does not decompose. So we have come to the conclusion that it possibly has some toxic materials in it that stop microbial growth. Here is one case where very often termites are working against farmers by tying up organic matter in quite large quantities from their pastures and from their forests. I also want to mention another case. Many of the native earthworms of Australia are subsurface feeding. They digest soil and they get what little nourishment they can from the organic plant debris in the soil. I doubt very much if they get anything at all from the humic acid. I think what is happening is that often they help to create more humic acid and the worst feature is that they so thoroughly mix this in their gizzards with clay that this humic acid is for ever locked up inside clay micro-aggregates. So here are two examples where sometimes the soil fauna does not seem to be working in favour of man.

FRANZ

This is certainly an observation which is correct. It is possible that part of the fauna consists of animals which are bad for the soil fertility. This fauna lives in natural soil communities, as seems to be the case with the termite colonies on arid terrains in Australia. But it can also be that animals become bad for the soil because the community of organisms was destroyed by man. I can give you an example of this in Europe, where earthworms behave very badly sometimes for fertility. Once I was called to the Arlberg in eastern Austria where the tourists come in winter to ski — but I went in summer, when there is grass on the meadows and people cut the grass for winter. But earthworms were multiplied in a terrible form and I had to study how this happened. We found in the meadows different houses which were occupied by tourists during summer and in winter, and the feces were collected in fecal pits which were made of wood and not completely impermeable. So a little of this material got into the soil and was utilized by the earthworms as food. They multiplied very rapidly in these places and as there was not enough room for them they began to emigrate in all directions. They had also much food in the soil of the meadows because they received manure every year. The numerous earthworm population produced so much excrements that they covered the grass in summer 10 centimeters thick, and so it was impossible to use the grass for food. We had to apply insecticides to kill the earthworms.

ALEXANDER

Have germ-free animal colonies been established with the soil invertebrates? I am thinking in terms of trying to resolve the problem of establishing what soil animals contribute to humus formation and what soil micro-organisms associated with the animals contribute.

FRANZ

I know no publication about germ-free soil living animals.

BAVER

I am very much interested in your comments with respect to the need for calcium for earthworms. The earthworm activity to which I referred yesterday was under the mulch in the cane fields of Hawaii occurring in the rainfall district of 180 inches per year — very wet. The pH in the soil was between 5 and 5.2 and the only calcium was from the superphosphate that was applied to the sugar cane. Would the increased humidity there help offset the need for calcium?

FRANZ

This would be the case. We have great experience in forests with acid soils in Central Europe. In these soils there are no earthworms, and if you give calcium carbonate or calcium oxide, then earthworms are to be found in a relatively short time and they multiply rapidly. The same is the case if you apply nitrogen fertilizers. If you apply nitrogen and calcium you have the most rapid multiplication of earthworms.

GENERAL DISCUSSION OF PAPERS PRESENTED ON 24 APRIL 1968

Chairman: M. ALEXANDER

HERNANDO

Because Prof. FRANZ was absent when we started this afternoon, I asked him which group he would prefer, and he decided for the microbiologists. This evening at 8.30 p.m. the microbiologists will meet with Prof. Waksman at the Hotel Reale, the others with Prof. Baver. Tomorrow we shall have dinner here; afterwards we will join in three different groups: 1) the agronomists and those mostly interested in the natural conditions of the soil with Prof. Jenny; 2) those concerned with physical and structural problems with Prof. BAVER; 3) the microbiologists with Prof. WAKSMAN. The idea is to have an exchange with regard to the conclusions for the general discussion on Friday with Prof. BRADFIELD. Now the discussion on the today's papers.

BRAMAO

You said that if one could maintain the level of organic matter in virgin soils it would be all right, and then you added that if the level increases as much as three times, that might be bad. Am I quoting you well? Now, what did you mean by the first sentence, if one can maintain the organic level of virgin soil all right? Some virgin soils have a very low organic matter content, some others have a very high organic matter content. For instance, we have in Asia some areas with a surface layer as deep as two meters with a very high organic matter content while soils in areas of the central plateau of South America may have a very low organic matter content.

SWABY

I was making a rather sweeping statement when I said you would be very lucky if you could keep the virgin level. We sometimes can do this by alternate grazing and cropping. Usually it is much below this because the cropping cycle is usually a little longer than the pasture cycle. But in the problem case that I was dealing with in Australia, where we have too much organic matter, more than the virgin level, this is not any great trouble to the soil animals as far as I can see. It injures the plants growth, and the pocket of the farmer, because it tends to tie up far too much fertilizer applied each year. And this is the problem. We want to save as much of the artificial fertilizers as possible, and if you tie them up in organic forms they take a long time to become available again. You would indeed be very lucky if over the whole of Australia you could maintain the virgin level, because it is usually a downgrade process. Now you say that in Asia you have got some jungle areas that have enormous quantities of organic matter, and you have arid soils where there is very little. We have the same too, and we would be very surprised if over our whole continent we could keep up this very high virgin level, but I think we ought to aim for something close to this. This is what we try to do by alternate pasture and cropping. If we have our cropping phase of the cycle too long it certainly goes down. Now there are two problems that we do not know how to solve in our country. The first is the problem of excessive stable organic matter under permanent pastures and forests. The second is the problem of the arid grazing areas because these are always going downhill, for many reasons. First of all the amount of plant life there is extremely variable depending on rainfall. We tend to overgraze in drought years and destroy a great deal of this plant life. So as a consequence we get much less organic matter returned to these soils. We have never yet, however, struck a case where we have depleted the organic matter so much that it can never be restored by weed growth, because usually when the rains come in these arid areas there is sufficient weed seed persisting to give you at least growth of ephemerals, and upon these many of the animals graze. What we are troubled about is restoring the original shrub and tree vegetation, that is extremely difficult, and we do not know how to do that, except by excluding grazing animals, including rabbits and perhaps kangaroos.

BROADBENT

In your paper, Dr. SWABY, you stress the difference in age as determined by radio-carbon dating of humic and fulvic extract of soil organic matter. In view of the rather arbitrary separation between those two components, do you have any explanation for the rather sizable difference in age which was reported?

SWABY

I look at it this way. If MAYAUDON and SIMONART are correct in saying that the more resistant plant constituents form the main body of the humic acid and humins, then it is likely that these will tend to accumulate at the expense of the more easily decomposable materials, and over centuries you will tend to find these resistant materials remaining while the decomposable materials will be lost as gaseous products. I would think that would be sufficient explanation; do you feel there is a defect in this argument?

BROADBENT

My question really should be phrased a little differently. Since humic and fulvic acids are essentially the same thing and the relative quantity of one or the other can be altered over a rather broad range simply by altering the conditions of extractions, how does one then account for these differences in age?

SWABY

I see the difficulty now. I for one do not believe that humic and fulvic acids are very similar. I think that in fulvic there are many substances that are very easily decomposed. In fact if you take fulvic acid and put it into a Warburg respirometer, you can very easily show CO_2 output, partly we think from the polysaccharides that are there. Also within fulvic there are the phenolic-protein complexes. However, these do not seem to be anything like as tangled up and as cross-linked as humic phenolic-protein complexes. They are usually much smaller molecules. I know there is a difference of opinion in the literature about this statement; some people say they are larger, some say they are smaller, but in our experience based on Sephadex separations, fulvic acid contains smaller molecules than we find in humic acid. So I think they are not nearly so cross-linked and therefore are more vulnerable to attack, and that is why perhaps they go and the humic and humins stay.

DHAR

Have you determined the pH of the soils showing the acidity and also the carbon and nitrogen contents?

SWABY

I suppose you are referring really to the pH of the soil in our forests and the pH of the soil in our permanent pastures. Well you see, these permanent pastures and forests stretch for 2,000 miles along the eastern border of our continent, and you can have pH's ranging from as low as 4.5 to as high as 8.2, so the pH range would be extremely variable. The carbon and nitrogen of many of our permanent pastures is very wide simply because the leafy mat that forms is frequently very carbonaceous material, and in the forests it is likewise very wide because it is largely mature leaf litter and twigs, but down below it is much narrower because I think a more normal decomposition is going on there. I do not know whether that is quite what you want; I cannot quote you figures because they are extremely numerous and variable, but I think these generalizations would be fair.

BROADBENT

I would like to make a comment on Prof. FRANZ's paper in relation to those soils of New Zealand which accumulate high levels of organic matter.

There is an abundant population of earthworms although these may not belong to the European species to which you refer; the resistance of the organic matter in these soils is associated with clay mineralogy primarily, rather than with the nature of the organisms which are there.

FRANZ

I am sorry I do not have the exact information about the soils where these observations were made, but I have the impression from the literature that very different soils have given the same results, because the first observations were made from Ashmore which had very bad pastures in the inner parts of the island. I do not know what soils were there but certainly the vegetation consisted of very bad grasses, and then with the European earthworms English rye grass was introduced, and this English rye-grass, of course, then multiplied in these places so that vegetation was in a few years completely changed. The same experience was later made also by scientific stations, and with the same result, and I think probably Dr. SWABY can say something about it because experiences like this were also made in Australia in completely different conditions certainly, and always with the same result. It seems that there is a certain correlation between the transformation of soil by earthworms and the evolution of English rye-grass, and we know that such relations between other animals and certain plants exist also. It was found in England that larves from Agriotes disappeared when English rye-grass was planted in a certain place. So that as there exists a negative correlation between English rye-grass and Agriotes, probably exists also a positive correlation between earthworms and this plant. I have no information that this problem was studied and anything published about this correlation between plant and animal.

HENIN

First of all I would like to make a short comment. You seem to be very much impressed by the high exchange capacity of the montmorillonite and its great surface but if you look at the kaolinite with its 20 square metre area, and a B.E.C. of 10 mill. equivalent per hundred grams, you will realise that the density of charge is greater in this case. Then if you have to consider some effect of fixation or of inactivation of some substances by fixation, kaolinite can be much more active than do the montmorillonite. Now I have a question for Dr. SWABY. In France when we have to bury some straw in the field, some farmers sow some plant to produce a green manure. After a few months the straw is easily pulverised and mixed with the soil by ploughing. Have you an explanation for this particular effect of the green plant on the straw?

SWABY

This is a case where a straw mulch is hastened into decomposition by the presence of a growing plant. The only thing I can think of is that a growing plant could reduce the soil temperature by shading and perhaps stop a little of the evaporation from the mulch so that you get more microbial decomposition. On the other hand, I am very well aware that a green manure crop will also transpire a great deal of moisture from the soil, so you have two opposing effects. I do not have any good explanation for this observation.

CHAMINADE

My question to Prof. SWABY is about phosphorus. First point, it has heen shown by some experiments that phosphorus of organic matter is very easily available by plants without decomposition of organic matter. I have seen experiments with incubated straw in which the phosphorus of the straw was taken by the plant more easily than phosphorus of mineral fertiliser. And the second point is that in soils with high fixing capacty for phosphorus (lateritic soils especially) the best means for improving the availability of phosphorus is to add organic matter to the soil; when the quantity of organic matter of the soil diminishes the availability of phosphorus in the soil diminished and not increases. What do you think, Dr. SWABY?

SWABY

I wonder if I might take the last question first? This question of organic matter preventing fixation of phosphates. I think it is well known where the phosporus is being fixed either as an iron complex or an aluminium complex, or perhaps even in some cases as a calcium complex. As you know, humic acid is anionic and it can combine with some of the positive charges of the iron and the aluminium, and thus phosphate is no longer fixed.

On the other question we have a different experience. We find that when straw containing phosphate is added to our soils it is not readily available. We have tried to analyse this by extracting from the straw inositol phosphates and looked at these to see if they were decomposing. We have been baulked in finding many other phosphates because the small quantities of sugar- and nucleic acid-phosphate which we can extract are so very easily decomposed we do not think that these are a problem. So we are bound to base our argument on inositol phosphates. When we put these into sand they become very easily available, but it is quite a different story if you put them into a soil containing active sesquioxides, for then I am pretty sure there is some sort of conflict between the iron oxide and the hydrolysis of the phosphate. I do not think it is necessary that the inositol phosphate is split into inositol and phosphate and then the phosphate becomes refixed on to the surface of the iron-oxide. I think it is something more complex than that. I think there is really no splitting of the inositol phosphate by the phosphatase because of the presence of the iron oxides and the aluminium oxides. So our experience is that in sandy soils lacking in sesquioxides we can get some of our organic phosphate back, but in clay soils and sesquioxidic soils we cannot get them all back.

HERNANDO

I shall first try to answer some of Prof. HENIN's questions. In Spain we observed that when we applied straw after the harvest of cereals, the cereal plants, not legumes, grew worse when leaving the straw on the soil. But the leguminous crop grew much better so that the yield sometimes increased by 40% and much more. It may be that by sowing leguminous, these fix nitrogen.

Now I should like to ask two questions to Dr. ALEXANDER. I think that the problem of biodegradation of the chemicals in the soil is obviously in relation with two aspects: range of effect and duration of action. For practical conditions it is interesting to have a long range and a long time of action, because certain products may have an effect on many things, and with longer time. But as concerns the generalization of the study of these problems, it might be interesting to inform the makers, that is, to tell them that it would be much better to pay higher prices than using more specific products. It is more convenient to use several chemicals and to get an easy biodegradation.

My second question is not directly connected with the paper. I meant to ask Prof. WAKSMAN, but maybe you can give me the answer. Actually, one notices an increase in the use of town-refuse for fermentation by using methods to force the aeration of the composting material. The technicians working on these methods say that after 15 days one can get the composted material with an average composition and with the final fermentation. We, on the contrary, experienced that the temperature of the compost remains, sometimes for two of three months, and even more, above 60°C, but this material is in a state of continuous fermentation; it never seems to get finished. I believe that the application of some inoculations to the material before composting it, is not useful, because one can be sure that only one thermophyllic type of flora can live therein. Now my question is: is it advisable to make the inoculation to the compost after the fermentation, i.e. before it is applied to the soil, or would it be better to make the inoculation directly to the soil?

ALEXANDER

It is very important to perform all final tests under field conditions, but in attempting to choose the right chemicals for use as pesticides, industry is forced to screen a large number of chemicals under greenhouse or in pot conditions. Likewise in trying to establish general principles on the effect of chemical structure on degradability, it is necessary to do extensive screening in small containers. It is assumed that the information obtained in laboratory or greenhouse conditions is applicable in nature. In the last analysis, the test has to be conducted in natural conditions. By and large, pesticides tested under controlled conditions behave the same way in the greenhouse and in the field.

I have no experience in the management of town refuse, but in my contacts with people in this area, I have heard strong statements that the appropriate type of fermentation should be aerobic, or anaerobic, or thermophyllic or at low temperatures. I have heard statements favouring short incubations and long-term incubations, and favouring inoculation and no inoculation. I can only draw the conclusion that there are no conclusions to be drawn at all.

HERNANDO

First of all I should like to say that I intended to put my question to Prof. WAKSMAN. I know you are not closely related with this subject, but I thought you might be able to answer my question in some way. Now I know that Prof. HAUSMANN too is working in this field, and because you have not followed the details on the disscusion, I will summarize my question for you, Prof. HAUSMANN: What do you think about the application of fauna or the inoculation of micro-organisms to town-refuse before fermentation or after fermentation? Or should the inoculation made ouly to the soil? This is my first question. Then, what is your idea about the time of fermentation with the aeration-forced method. The technicians in Spain say that 15 days are enough, because they maintain that after 15 days the compost has completely changed and the temperature is decreasing. This, however, is uncertain since we observed that sometimes the temperature of the composting material was above 60°C after two months and even more, which means that the fermentation continues under the action of the thermophyllic flora.

HAUSMANN

I understand that the first question was related to the inoculation of city residues. I suppose that every inoculation should be done after fermentation, when temperature is rather low, because it could impede the development of micro-organisms; but I have no direct demonstration of that. As for the compost, it is quite sure that the fermentation is a long one, and the population of microbes or earthworms begins to develop much later than the fermentation is finished; it comes afterwards. The compost is very rich of different species of animals or bacteria, but they increase in member surely after the fermentation is finished; you are quite right that high temperatures should be observed in the compost, but it depends naturally also on the organic matter you introduce in the compost. If it is farmyard manure already well fermented, then the temperature doesn't rise very much. At least it is only affected by some aerobic bacteria, but not very much. But if you introduce some leaves or some undercomposed material then the temperature can rise rather high: 50-60°C.

JENNY

I should like to comment on organic matter decomposition from a different point of view. The natural soils of the world vary enormously in organic matter content, and many factors account for it. Often it is assumed that soils high in organic matter, like many soils in the tropics, must be related to low rates of decomposition of organic matter, say lack of enzyme activity, presence of aluminium humus, or disturbed micro-fauna. No doubt the rate of decomposition is important, but so is the rate of addition of organic matter. At any time, the organic matter content is a balance between addition and loss. For instance, we have found in Colombia that the high organic matter soils occur in forests which are rich in legumes and we suspect a high N-fixation. In Ghana, it has been reported, nitrogen fixation reaches 100 pounds per acre per year. In other words, the level of organic matter in the soil has to be interpreted both as to the factors that affect the decomposition and the factors that affect the addition of organic matter.

NORMAN

I am inclined to pass now, except I would just like to make the comment that I'd hoped to engage Prof. REESE and Prof. SWABY in a discussion of adaptive enzyme systems and the utilization of the insoluble compounds in plant residues, leaf litter, roots and the like. Clearly there are physical barriers to complete accessibility in cellular material and tissues. There is a good deal of evidence in the literature that the lignin content of a tissue inversely affects the availability of the cellulose. I have always been troubled by the notion of adaptive enzyme production although it seems clear enough when one is dealing with a single substrate and a single organism. I am not quite so convinced of this when one is dealing with mixed cultures of organisms that have diverse characteristics. Presumably fungi also have adaptive systems and perhaps hyphal contact is only necessary in a certain number of places or a certain amount of the area of the mycelium in order to produce the exo-enzyme without which there cannot be resolution of the polysaccharides. I would go further and stretch your patience by commenting that in your paper Mr. Chairman, you were drawing our attention to the utilization or degradation of pesticides in soil and in general there I suspect there is irregular distribution at the very low rates that many of these potent compounds are applied. They are applied in a spray, often they are water insoluble, or insoluble to any significant extent, and so the utilization of the materials so applied would seem to be a highly localized phenomenon. One hopes then that there will be the same kind of adaptive system developed at many locations.

DHAR

Composting has been studied in India for nearly 40 years. HOWARD tried to compost plant residues and municipal waste and obtained a product with the nitrogen content about ½%, and if we apply 5 tons of this compost by the acre like he recommended you can get a good crop. We have improved on this by mixing organic matter with phosphate, both rock phosphate or bone as well as basic slag, and in this way we have been able to catch atmospheric nitrogen by fixation and a compost of 1 to 1.6% nitrogen has been obtained which gave a very good crop. Now in investigating the science of this process we have found that the oxidation of organic matter (we did it under aerobic conditions), the oxidation goes on not only for one month, two months, three months, even 120 days. We noted the temperature daily and we found that the temperature shot up as I said yesterday to 75°C, in some cases 73 and 74, especially in the presence of basic slag. But later on the temperature dropped but was higher than the air temperature for 150 days because the excess organic matter undergoes oxidation and produces heat. RICHARDS and HUTCHINSON started to prepare compost from straw after the first European war, they added superphosphate and ammonium sulphate and continued the composting for 100 days. That was the recommendation. But super-phosphate we have found is not so suitable because it is acidic. Basic phosphates are better and hence in Madrid with a temperature of 15°C, composting should continue for 100 days, this time can be shortened if aeration is strong.

FRANZ

I would like to explain two things. First, that the time needed for decomposition of straw depends for a large scale on the climate. In the climate of Western Europe you can complete this decomposition in one year. In the pannonian climate, in the Eastern part of Austria, and in Hungary, it is impossible because the decomposition of straw begins only in autumn when soil becomes wet in October, and then a few weeks later it is so cold that the decomposition cannot be finished. In Spring you have only two months humid soil and then the dry period begins, so that two years are needed for the decomposition. So it is not possible to put the same quantities of straw into the soil in pannonian climatic conditions as in humid conditions. Another thing I wish to explain is that for the compost of town refuses which are very difficult to decompose, it is very helpful to apply urine and excrements of man. Then using artificial aeration it is possible to have in three months a very good and complete decomposition of this refuse.

V

INFLUENCE DES MATIERES ORGANIQUES ET DES PRODUITS DERIVES ET CONNEXES SUR LA CROISSANCE DES PLANTES

ORGANIC MATTER AND SOIL PRODUCTIVITY IN THE TROPICS AND SUBTROPICS

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INTRODUCTION

For the colleagues of the temperate zones it is not easy to understand our problems. When a scientist researches on one of our soil factors, he recognises this factor to be different from the one in his country, but he never concludes that with the change of one factor all the others change automatically, because soil is not a storehouse of isolated pieces but a biodynamical balanced system. The results of such researches are given as if all the other soil factors would be as in the country of this scientist, and a wrong and curious conclusion provokes still more confusion as there was before. A French Nobel price wearer says: « We always believe, things we do not know do not exist ». And what is known about our soil problems, our pathway of organic matter, the biodynamic equilibrium of soil?

SOIL

Professor F. SCHEFFER (1964), high authority in Edaphology in Germany, says, in the preface of our 15th book « A Biocenose do Solo na Produção Vegetal »: « The most different actions of soil organisms have a decisive effect on the same. The soil isn't only the vital space of living beings, but a dynamic system which changes permanently, under the influence of the most different ecological factors. Particular to it is the biocenosis of the meso and microfauna and of the macro and microflora, which suffer permanent modification and transformation, that is to say, a permanent adaptation to the environment.

The soil isn't a static factor, but a dynamic organism, always in evolution and transformation. The fauna of the soil revolves and mixes the stratum, enabling the branching of roots and its development in more profound layers causing the mellowing and the fertilization of these layers. Thus, soil becomes active.

Even the most modern machines can't accomplish what soil micro and meso beings do. None of the modern technics is able to devolve the former prodnctivity to the soil, they only can explore it. »

The crop soil, in the modern conception, isn't the support of plants and fertilizers, nor the vital space of the micro and meso life, but it is really a living dynamical system, whose biodynamical factors mutually influence one another and, therefore can conserve and improve the productivity of the soil, as well as hinder or diminuish it. That changes, obligatorily, our concept of agriculture. The necessity of considering the straight interrelation of all the physical, chemical and biological processes of the soil therefore arises. (We must remember that each technic, injudiciously applied, causes a disequilibrium of all the other factors).

The soil is a biocenosis in its widest understanding where exists a close interrelation between the physical and chemical properties, the organic matter, microlife, the roots and the vegetation. It is a dynamical system where the modification of one of its factors result in the modification of all the other ones.

We know, soil formation depends on the vegetation, and this, on the soil, the climate and the microlife. The microlife depends on the vegetation, the organic matter and the other soil properties.

It was a fundamental error of the analytical era to treat in separately the various factors of crop production, since the real signification of the obtained results appears only in the union of reciprocal relations.

THE ACTIVE SOIL STRUCTURE DEPENDS ON ORGANIC MATTER

Soil organic matter is of extraordinary importance to the active soil structure and microlife behaviour. For a long time its colloidal action, as well as its importance in the mobilization of mineral salts has been recognized. They play an essential part in the clay-humic exchange compound. But, the organic matter, humificated or not, still has its greater importance as energy source of the micro and meso life, producing what we call soil productivity. In the organic matter of the « living » that is aerobe soil — we especially stress the term « living », because in the « dead » anaerobic soil the transformation of the organic matter in humus and its subproducts doesn't occur in the form we need, having only its mummification or transformation to turf — remains, in last analysis, the key for the conservation of the productivity of our crop soils. Carelessness with the organic matter of the soil, has especially been observed in regions with reduced demographical density. There we find a strong erosion and the smallest crops per hectare. These zones are situated in the tropics and subtropics, where violent rainbursts and intensive microbian activity occur during all the year. In the more habitated temperated regions, man became an attent observer of nature, subjecting himself to its eternal principles, thus obtaining the highest crops.

Salter and Haworth (1961), proved the « field capacity » improves by the application of stable manure, but only, if this has been incorporated in the soil superficially. Only thus it does promote the formation of a mellow tilth.

We must be aware, that the organic matter, useful to the soil productivity, must be transformed in an aerobic environment and in the presence of sufficient mineral salts. It must be predecomposed by the mesofauna and decomposed essencially by bacteria and actinomycetes and in a less scale by fungus. Organic matter buried under anaerobic soil layers, decomposed nearly exclusively by fungus and some bacteria of putrefaction, doesn't contribute to the improvement of soil productivity. Here arises the first dilemma in the tropics and subtropics. A well ventilated soil never forms humus and a badly aired one may form humus, but acidifies strongly by the activity of its fungous population and turns it improper for agricultural crops. The question for us was: may we aim at humus formation or soil improvement? We decided for soil improvement.

The quantity of organic substances doesn't matter, but the soil layer where it is to be found and the richness of this soil in minerals, since the micro and mesofauna, useful to soil productivity, don't feed on acid material, poor in calcium. Each organic fertilizer in very acid soil (pH 3.8 to 4.2) which shall improve soil tilth, has to be mixed superficially with the mineral soil substratum, together with limestone, although this speeds up mineralization and diminishes humification.

The pH theory made many harm to tropical and subtropical soil productivity. High cation concentrations always lower the humus content and it is not seldom that in spite of a still acid pH (6.5), cation concentration, especially of Mg, K and Ca, but also Fe and Al depleted the soil so completely of all organic material, that it hardens rapidly when drying up; and it dries up quickly in consequence of its highly floculated structure, like in lateritic soils, or it has a completely desfloculated structure like in deteriorated prairie soils; none can store water.

The balance between organic matter and cations is, therefore, very sensible: To little cations and humus will be of a low quality. To much cations and humus will disappear.

The green manure is, essencially, feed for the micro organisms, producing nitrogen and carbohydrates, that is, energy for the microlife (RUSSELL, 1961). It rarely forms humus due to the close relation of C:N, which is approx. 4:1.

The humus formation in the tropics depends on an excess of lignin, which only exists, when the relation C:N is greater than 10:1. In the tropics, where we have an explosive mineralization of organic matter, the problem is not that of humus, but the problem of microlife nutrition.

Therefore, all attention must be given not only to the formation of humus, but to the nutrition of the aerobic micro and mesolife, which promotes the mellowness of soil tilth.

Organic manuring is indispensable to maintain aerobic, heterotrophe microlife, and therefore, to the biostructure of crop soils; it is the basis of soil productivity. But it is a fundamental error to believe micro and mesolife are maintained exclusively by the organic matter. This depends as much on the mineral nutrition as our crops.

In poor and acid soils, organic matter doesn't improve the structure, because the microlife which utilizes it are nearly exclusively fungi.

The problem is, therefore, entirely a biological one.

The heterotrophic bacterias and the saprozoontic mesofauna which keep our soils permeable, need:

a) organic matter;

b) balanced mineral salts;

c) balanced air: water ratio;

d) shade, that is, protection against the sterilizing action of sun;

e) vitamines, enzymes and hormones excreted by plant roots.

In the formation of the crumbled and permeable soil structure autotrophic bacterias are of little interest as they serve only to oxidize metals or nitrogen, or to reduce nitrates and sulphates, a. s. o. But they need the crumbled, well-aired soil because the same bacteria which oxidize or fix nitrogen in an aerobic environment may reduce oxigenous compounds in an anaerobic one and harm plants not only by the products of reduction but also by the great quantities of antibiotics they excrete to defend their living space, like *Pseudomonas, Bact. subtilis*.

The parasitic and predatory mesofauna also are not interesting in relation to tilth formation although they are indispensable for the dynamical equilibrium of soil.

To obtain a crumbled soil surface in compact acid soils and to turn it stable against the action of rains, we need organic matter and limestone. These two factors form the basis of any micro or mesolife. The acid organic matter of poor soils is only populated by fungus. These soils need more than any other a stable structure by aerobic and heterotrophic life. Limestone is still more necessary in acid range land, where the mesofauna must take charge of the mixture of the organic matter, superficially deposited, with the mineralic soil phase. Acid organic matter is less habitated by mesofauna, permitting the proliferation of fungi and the formation of turf on the soil surface which contributes to the superficial swamping of these soils and the killing of all forage plants in the cool, moist winter season by fungi, which always causes the death of thousands and thousands of animals and great part of the new born calfs and lambs.

Mesofauna distributes the predigested organic matters throughout the soil, allowing the development of heterotrophic bacterias and actinomycetes which promote soil structure. Our problem is therefore:

Mobilize the soil micro and meso life, to recover the former productivity of our soils.

Many scientists believe that it is much more important to conserve humus in the soil than to mobilize soil micro and mesolife. But what for do they need this humus? Only to make up the clay-humus compound? To strengthen the exchange capacity? Our crops need as much minerals as bacteria, fungi and actinomycetes for their root development as well as for their health. Organic matter is an essential energy source for soil life, and humus may be considered as conserved energy; the energy reserve for bad times! The colloidal action of humates is an extra giving.

We are aware, that zymogenic life — as WINOGRADSKY (1949) called it — only develops in the superficial layer of the crop soil and this life causes a crumbled, water stable, active soil structure, necessary to:

1) water infiltration;

2) water can be stored beside sufficient air so that the soil doesn't turn swampy or dry up;

3) roots can develop profoundly and broadcast to absorb sufficient mineral salts;

4) hinder erosion, floods and droughts.

All our care must, therefore, be given to this micro and mesolife, which is the basis of soil productivity. We say productivity, because chemically fertile soils often don't produce well, as many scientists prove.

We already exposed in the First Latin-American Colloque of Soil Biology in Bahia Blanca in 1965, our experiencies improving a petrified soil in the tropics, completely unproductive, without bio-structure. In a large scale experience on 420 hectares during 9 years, we succeeded to prove the importance of micro and mesofauna on the bio-structure and soil productivity.

In these soils — with a revitalized superficial layer — we didn't notice gully erosion. Water flow was too little to form torrents. On the other hand, there was no decayed, peptized soil about, to be washed out to the deeper layers. It didn't form anymore hardpans, because the condition of compact layers is the disaggregation of the superficial soil and the wash out of the clayish and humus part to the subsoil.

Water infiltration depends especially on the active soil structure of the top soil. It does not interest if this soil is a sandy or clayish one, whilst biostructure is active. But it becomes extremely important when biostructure is lost. Texture is always important in the subsoil with its one-grain-structure. A detoriated biostructure always contributes to the accumulation of clay in the subsoil and therefore contributes to a bad draining.

Productive soils and, particularly, virgin land, that is, biologically sound and equilibrated soils, don't erode. Erosion is the sign of « dead » soils and therefore of those with reduced and decreased productivity. It may be understood, that the biological fight against the accelerated erosion doesn't only avoid the carrying of earth by water and wind, but also recuperates the former soil productivity. Nature is in an eternal dynamic equilibrium. Conservation of a « status quo » doesn't exist. There exists either destruction, with always lower equilibriums, or improvement, with always higher equilibriums bringing benefits for mankind. Everything that hinders destruction and the instalation of inferior equilibriums — desert is also an equilibrated system — promotes the recuperation.

ACTION OF THE ORGANIC MATTER IN THE FIGHT AGAINST HUNGER

It isn't only interesting to know in detail the action of the humus in the colloidal complex, its influence on the microlife, its composition and its reaction on soil, but what interests the world of today, is its importance in the fight against hunger, against the unproductivity of the crop soils and range land, its connection with erosion, droughts and floods, in short, the correlation of the various factors, which touch human life in a disastrous way.

In the tropical countries does not exist reserve humus in crop soils. In tropical countries agriculture is much more difficult than in temperate zones. Soils do not have the recuperative rest under a thick layer of snow. The estival sun is much hotter than in Europe or in the United States, sterilizing desprotected soils. The rain bursts are much violenter and heavier. But heat and humidity provoke a microlife of an intensity, unknown in countries with a temperate climate. Thus, in ventilated soils an explosive mineralization takes place and no organic matter remains to suffer this low and complicated process, which is the formation of reserve humus.

We know perfectly well that reserve humus is not plant food as THAER supposed it to be. We also know that it is not worthless as it was assumed at the beginning by LIEBIG.

What is humus? What is it used for? What is its role in the soil? We call humus only the reserve humus (Dauerhumus), because « Nährhumus » is not humus, it is organic matter immediately mineralized by microorganisms.

There is 10 to 12%, or more, of humus in virgin forest soils and up to 20% in prairies but only 0.8 to 1.2% in crop land. What is the difference of its soils?

The chemical difference of soil is not so revealing. In relation to the total of nutritive substances, one as well as the other, may be rich in minerals. In crop soils the balance of these minerals was disturbed and soil was aired.

The availability of these minerals varies widely. The soil, poor in humus, has a high fixing capacity in contrast to that containing humus. From the chemical point of view, this is due to the clay complex. But there are sandy soils with a minimum of clay content, where also any kind of fertilizer is unavailable when humus is lacking due to the high compacity of even these soils.

Why is there hardly any plant pest in virgin soils? Why are plants not affected by droughts in virgin land? Why don't they become chlorotic in long rainy seasons? Answering these questions, Sir A. HOWARD said it was the humus that made them withstand. How? This explanation didn't satisfy anybody and only a few could make anything out of it. Virgin and crop soils were analysed and we noticed a different structure in the top soil of ploughed land. The virgin land was crumbled with 36 to 48% of porosity, whereas the cultivated land was defloculated, compact with 9 to 15% porosity, and sometimes less, falling in rare cases to 6%.

THE BIO-STRUCTURE AND THE ORGANIC MATTER

Many authors have already made references about the active soil structure or bio-structure, as we call it, as it differs from the shape of structure given by the clay compound.

The root development is larger in porous soils. The infiltration rate and drainage is better, evaporation is less and field capacity is higher. Plants are better nourished due to the more abundant absorbtion by means of its broadcasted root system. The transpiration of these well fed plants is smaller because of the more viscous cellular plasma. No pathogens or pests attack this well fed plants and yields are high and of good quality. Soil bio-structure seems to be the magis key to many agricultural problems of today. Bacterias, harmful in compact soils are doing good to plants in mellow ones. Everything seems to be in harmoniously interaction.

What is the role humus plays in this biodynamic system of soil structure?

Is it as brittle brown material composed by quinones, melanines, humic, fulvic and crenic acids, as complex compound of aminoacides rich in minerals, and with colloid properties? If that is the case, nothing can be done to help tropical crop soils. Or must the tropics continue to be a poorly populated zone, where never more than 20% of the land can be cultivated, because only in rotation with forests humus can be accumulated?

What causes the bio-structure? It was not difficult to find it out. On range land it is mainly caused by actinomycetes, on crop land by heterotrophic bacterias. Fungus and autotrophic bacterias can be found all over abandoned land, deteriorated by erroneous agricultural practices or by extensive pasture management.

The maintenance of the autochton microflora on grassland and the zymogenic heterotrophic on crop soils is therefore the target for a rational soil use, because they conserve the active structure which enables high soil productivity. What is the basis for life of this microflora? Energy derived from organic complexes, in form of carbon, oxygen and mineral nutrients. The problem of the humus in tropical soil, condenses itself therefore, to provide the heterotrophic microlife with energy in form of organic matter. Humus is conserved energy. In temperate climate, when humus is carefully handled, we may enjoy more or less three years of carefree agriculture in relation to any organic manuring. In tropical climate where humus is not build up in crop soils, microlife requires organic manuring every year. There we have to look for microlife as for domestic animals, feeding it from time to time.

SOURCES OF HUMUS

In subtropical winter moist climates where the humus is formed even in crop soils, there persists the question: of what material it is made of?

Not all black soils are humous one. There are many soils in the tropics and subtropics that are black due to iron sulphate, manganese oxide, antimony oxide, etc. and which don't show any traces of humus, like the black cotton soils of India and our range land in south-east of Brazil. They are compact as bricks, with no biostructure at all and with large cracks after two or three weeks of drought, damaging seriously crops and grassland in spite of the richness of the soil in mineral salts.

The green manuring, so propagated by Sir HOWARD (1956), disappointed greatly the majority of the Latin American farmers. Because in Europe usual it is mixed deeply into the soil to fertilize the subsoil too. This is not possible in the tropics, where rain bursts easily desintegrate and compact soil structure. The bacterias are to be nourished and not the fungi. In the tropics and subtropics when the organic matter is thoroughly mixed into the soil only a rich flora of fungus is obtained. It increases soil acidity, causes a great number of plant diseases, doesn't improve the structure, and in many cases, the plants are poisoned by methane, nitrites and other phytotoxics. Frequently, organic matter when deeply incorporated into the soil, continues there indecomposed for years and becomes turfy and brings no benefit whatsoever. Soils, where green manure is used for improvement, are always compact, inactive, acid and usually poor ones. In the tropics and subtropics the organic matter has to be mixed superficially, a part still resting visible on the surface. Here it is at once attacked by bacteria. In the tropical zones, it is mineralized in 4 or 6 weeks; in the subtropical climate, a part can form humus, if the incorporated matter is lignous.

The green manure never accumulates humus in tropics, for it has a C:N ratio of 4:1 which is too narrow. It liberates much nitrogen and it may be considered a nitrogenous fertilization besides the nutrition of mesofauna and microorganisms.

In subtropical climates, the fertilization with straw and stubles enriches the soil in humus. In these countries, thinly populated, there exists no stable manure. The reasons are the following:

1) due to the climate there is no need to stable the cattle;

2) livestock husbandry is completely extensive, being 99% beef cattle and only 1% dairy cattle. Any pasture rotation system with beef cattle is unknown, and the dairy cattle, in most cases, are managed in the same way as beef cattle. Only a few dairy interprises keep the cattle in stables for some hours each day, being able to collect some manure. So stable manuring of soil in these countries is non-existent.

THE PLOWING

Therefore one of the most important problems in the maintenance of soil structure is the plowing. The deep plowing up of the soil, as used in Europe, is a calamity in the tropical and subtropical latitudes because:

1) the aerobic layer is buried and asphyxiated;

2) the production of antibiotics by microorganisms is very strong, being the latter accumulated especially in the layers between 15 to 30 centimeters.

We usually determine the depth of plowing according to the root development. We generally do not plow deeper than two centimeters beyond the well rooted layer to keep the active structure on the surface and never pass the lower boundary of 18 cm. The active structure depends on the aerobic microorganisms. We have been putting this into practice for 21 years and it has never failed and it has always proved well.

The production of antibiotics by our soil microflora is so strong, we never succeeded to grow one germ in a culture medium where soil extract was added. Therefore, plowing must always aim at the incorporation of the organic matter into the soil, in such a way that it will still continue in the ventilated layer. Epoch of application is also important. If, for instance, in the subtropics, with its hot dry weather in the summer and cold rainy weather in the winter, we bury the organic matter in the fall it will unfailingly produce fungi, acidify the soil and cause many problems and inconveniences. It is true that during this epoch humus formation takes place more easily for it is due to fungi and actinomycetes and not so much to bacteria, but the unilateral development of fungi, even forming humus, will always harm the next crop.

TRANSFORMATION AND UTILIZATION OF THE ORGANIC MATTER

In our country, which is as large as all of Europe and a part of Russia, we live the drama of acid soils (pH 3.8 to 5.1). In the subtropical zones, in acid range land, organic matter accumulates on the soil surface. But, proceeding from fibrous plants, poor in mineral salts and calcium, it is never attacked by mesofauna nor by bacteria, and seldom by some fungus. It remains there deposited, mummifying on the surface, forming a layer of fresh humus. The water stagnates because this humus closes the soil surface against the water infiltration, contributing to turn the land paddy. Thus we distinguish (PRIMAVESI, 1963) three zones of pH, according to which humus develops. The acid zone, below 5.2, where the humus, formed of poor plants, forms a substratum which depletes the range land, contributing to its stronger leaching. The zone from 5.2 to 7.5, humus is valuable and forms what is known all over the world as « reserve humus ». And finally the alkaline zone where little humus is formed, due generally to the scanty vegetation and the intensive combustion in the presence of salt accumulation.

Therefore, the humus problem is intimately connected with the pH, as we can see from the following experience:

pH CORRECTION BY BIOLOGICAL METHODS

INTRODUCTION

The extremely low pH values and the low productivity of many soils in the Brazilian subtropical zones, made research in this sector urgent.

The areas mentioned were generally crop soils or range land, without any fertilizer dressing.

In an area of 240,000 hectares a systematic study gave the characteristic of the soils as pH, exchangeable nutrients, organic matter, pore volume, permeability, crumb stability and draining.

It was possible to determine a straight correlation between the compactness and the pH of soil, which suggests a biological dependence of pH. The field and laboratory experiences proved this theory, and showed a new type of pH correction of alkaline and acid soils.

METHODS USED:

Ca^{++}	(Michigan test) with ammonium oxalate,
K^{+}	(Michigan test) with sodium cobaltinitrite,
Mg^{++}	(Michigan test) with titan yellow,
Na^{++}	Piper's method of uranyl acetate.

Organic matter: (WALKLEY and BLACK) with potassium dichromate.

Porous volume: To measure the pore volume we used a graded and sharped steel cylinder, 5 cm in diameter, 20 cm high and with a longitudinal split of 2 mm. This cylinder was introduced into the soil, till the 300 cc mark and then removed. Then the soil was carefully crushed upon a steel plate. The difference of volume made possible the calculation of the pore volume.

Infiltration capacity: A sharp steel cylinder, 5 cm of diameter and 25 cm in height, was introduced into the soil, 3 cm deep, and then filled with water. The time this volume of water needed for complete infiltration was stopped.

Crumb stability: Samples of fresh soil were carefully screened by a 3 mm size sieve. 5 crumbs were placed upon a 5 cm large filter-paper strip which rests upon a thin screen to permit the draining of the water. The crumbs were rained, 46 drops per minute, falling from 45 cm height. After half an hour, the destruction of crumbs was classified according to SEKERA's chart (6: is a well hydric stability; 1: is a total destruction).

Base saturation: Percolation with 1 N ammonium acetate according to PEECH, pH: electrometricaly; soil water relation 1:2.5.

The results of the raising were the following:

TABLE I

pH	S meq. %	Ca meq. %	Organic matter %	Crumbs stability	Pore volume %	Infiltration cap. (minutes)	Crops
3.2	3.23	1.81	2.1	5	24.1	43	potatoes in virgin soil
4.2	0.65	0.50	1.2	5	19.1	under water	rice - rice
4.4	0.31	0.01	1.2	3	16.8	108	corn - wheat
4.4	0.43	0.01	2.1	5	35.2	30	corn - wheat - soybeans
4.6	0.39	0.01	1.8	2	13.0	145	range land
4.6	0.28	0.01	1.7	4	21.7	110	corn-mandioc
4.6	0.91	0.008	2.5	3	31.0	75	corn - corn
5.1	0.18	0.10	6.9	3	33.0	130	range land
5.2	0.26	0.01	5.5	4	23.1	68	range land
5.2	0.67	0.01	5.2	2	40.3	20	vegetables
5.2	0.63	0.001	4.2	5	42.0	92	range land
5.2	0.32	0.01	5.5	5	23.7	71	fallow
5.4	0.64	0.005	2.6	4	40.1	44	oats - corn
5.6	2.92	0.8	1.2	3	18.1	92	potatoes - pot. (well fertiliz.)
6.0	0.75	0.3	6.6	3	24.6	57	vegetables (well fertiliz.)
7.0	8.61	0.1	1.7	1	17.0	82	orchard (Na-accumulation)
7.2	2.17	1.3	3.6	3	46.2	23	vegetables (well fertiliz.)

Each number is the average of 100.

RESULTS

A straight correlation between the organic matter and the pH was found. In soils with a pH below 4.6 the humus induces a stronger acidification of the soil and does not act as a factor for soil improvement.

The quantity of exchangeable calcium and the saturation or dissaturation of bases in soils of low pH did not justify its variations. The base saturation is generally low in acid soils, however, according to the results obtained, the low base saturation cannot be considered the reason of low pH.

It is not possible to see a direct dependence of pH and the saturation of exchangeable bases in the areas of pH above 7.0 and below 5.2.

Therefore the saturation of bases seems to have less influence upon the soil pH than soil compactness. There seems to be a principle according to it, the compactness decreases with rising pH. This law does not exist in a pH below 5.1 or above 6.8. In soils with extremely low pH (pH 3.2) or an extremely high one (8.7), the relation between the pH and the pore volume suffers alteration.

In alkaline soils, the hydric resistance of crumbs is nil, in fairly acid soils it may be rather high, in spite of very little pore volume in both cases. This means that the resistance of crumbs and the pore volume, in alkaline soils, are exactly the contrary of what one should expect of soils with high saturation of bases. In fairly acid soils the hydric resistance of soil aggregations may be high, due to the rich fungus flora, however, the pore volume is very low (about 6%).

If only the base saturation (which is, doubtless, a factor of soil floculation as we saw at the beginning) is responsible for the pH and the pore volume, the facts mentioned above can no longer be understood. There is only one factor that can explain these phenomena: the microlife of soil.

EXPERIMENTS (tests)

METHODS

A) *Field teses*

We selected test parcels of 3×3 m (in 6 blocks) for field tests, during the dry summer months. The experimental parcels were watered twice a week.

a) The first group of test parcels (8) was an acid gley, pH 4.5.

b) The second group of test parcels (8) was located in an alkalinized gley, pH 8.7 (alkalinized with MgO, KCl and NaCl).

In the upper surface (8 cm deep) manure and chemical fertilizers were mixed.

The dressing of the Test parcels was as follows:

1. Manure 4.0 kg/m^2
2. Limestone (dolomite $CaCO_3$, 42%) 100 g/m^2
3. Manure + limestone 4.0 kg/m^2 + 100 g/m^2
4. NPK 1.4 : 5.2 : 3.6 g/m^2 ($NaNO_3$, superphosphate triple, KCl)
5. Limestone 100 g/m^2 + NPK - 1.4 : 5.2 : 3.6 g/m^2
6. Manure + limestone + NPK 4.0 kg/m^2 + 100 g/m^2 + + 1.4 : 5.2 : 3.6 g/m^2
7. Manure + limestone + NPK + rare elements 4 kg/m^2 + + 100 g/m^2 + 1.4 : 5.2 : 3.6 g/m^2 + 500 mg of borax, 500 mg $CuSO_4$, 1.2 g $MgSO_4$, 600 mg $MnCl_2$, 300 mg $ZnSO_4$ for each square meter.

After 12 weeks, the pH was as follows:

TABLE 2 — *pH correction by manuring.*

Manuring	Acid soil (pH 4.5) pH	Alkaline soil (pH 8.7) pH
0. Test	4.5	8.7
1. Manure	5.8	7.6
2. Limestone	5.4	8.1
3. Manure + limestone	6.3	7.5
4. NPK	4.4	8.2
5. NPK + limestone	4.9	8.1
6. Manure + limestone + NPK	6.2	7.4
7. Manure + limestone + NPK + trace elem.	6.8	6.8

It is surprising that even limestone ($Ca\ Co_3$) is able to lower a highly alkaline pH. The final accomodation of pH on 6.8 as in acid soils as well as in alkaline ones, is indeed interesting. The tests show that the base saturation cannot be exclusively responsible for the increase or decrease of pH; on the contrary, an increase or decrease of pH permits a less or more concentration of exchangeable bases.

B) *Laboratory tests in non cultivated soils*

The sandy top soil of a pseudogley (sand 87%) was distributed in one kilo cans and then mixed with different quantities of manure and limestone (six repetitions).

After 10 weeks of incubation, 35°C, the pH was measured with an electrical potentiometer with 1 glass electrode. The soil-water relation was 1: 2.5.

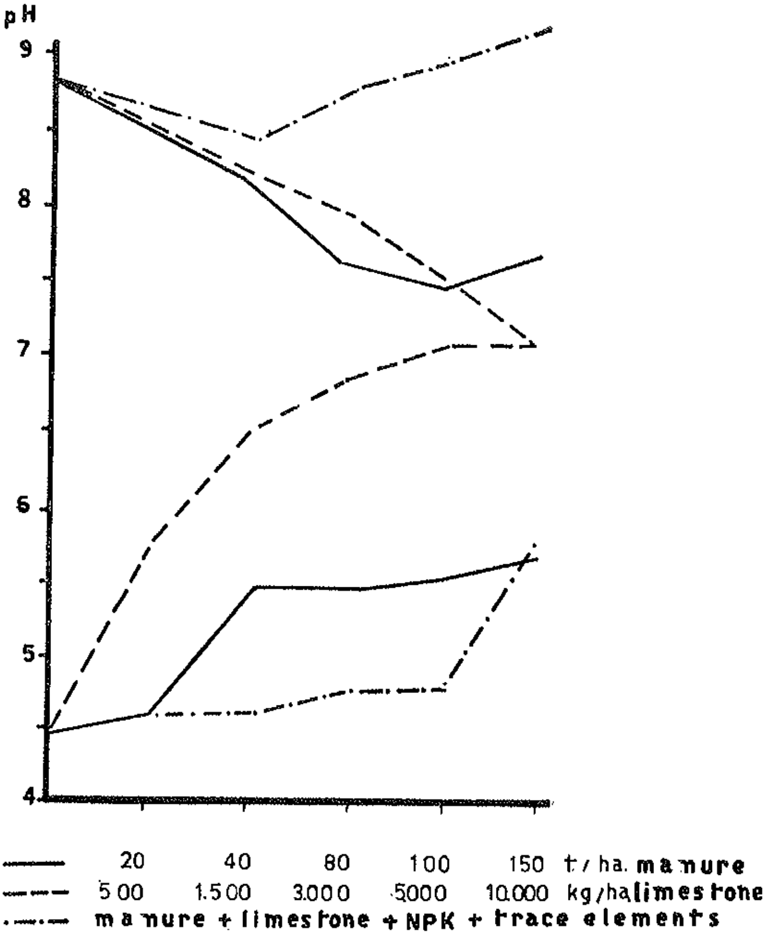

pH
9
8
7
6
5
4
—— 20 40 80 100 150 t/ha. manure
– – – 500 1.500 3.000 5000 10.000 kg/ha limestone
·—·— manure + limestone + NPK + trace elements

FIG. 1

TABLE 3 — *pH correction by limestone and manure.*

Quantity of manure	pH/manure	pH/lime	Quantity of lime
0 test	4.4	4.4	0 test
10 g/kg	4.6	4.6	0.5 g/kg
20 g/kg	4.8	4.6	1.0 g/kg
40 g/kg	4.8	4.7	1.5 g/kg
80 g/kg	4.9	4.7	3.0 g/kg
100 g/kg	5.1	5.2	5.0 g/kg

This table shows the pH correction can be induced as well as by an increased base saturation as by an increased biological activity.

C) *Laboratory tests in cans, planted with different crops*

a) Red podsolic soil, sandy phase (90% sand, 9% silt and 1% clay).

b) Pseudogley (81% sand, 9.6% clay).

c) Fluvial sand (96.8% sand, 3.2% silt and 0.8% clay).

d) Garden earth (well fertilized) (95.2% sand, 4% silt and 0.8 clay).

The tests were repeated six times. Half of them were dressed with 80 grams of manure and the other part received nothing. The garden earth was not dressed. In all the cans wheat and an other crop were planted, as shown below: *a*) wheat + wheat; *b*) wheat + corn; *c*) wheat + alfalfa; *d*) wheat + red clover; *e*) wheat + *Chloris gayana*; f) wheat + perennial soy bean; *g*) wheat + *Lolium multiflorum* (see Figure 2).

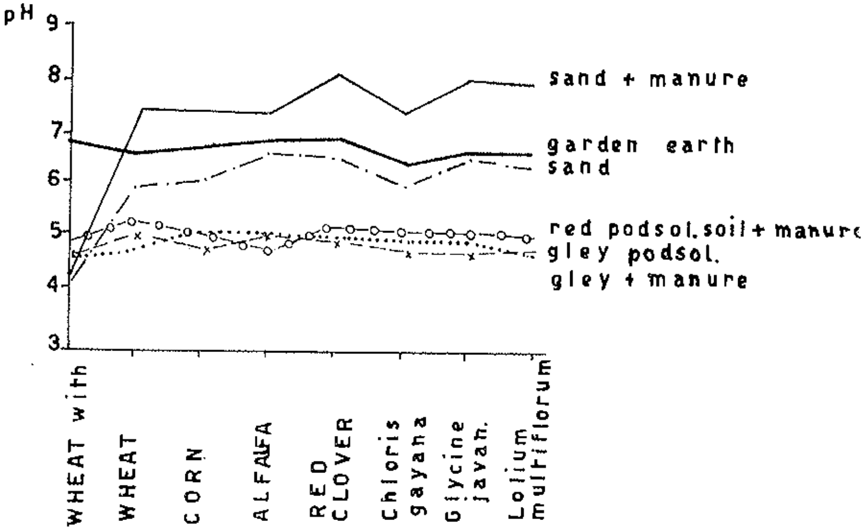


FIG. 2

The association with clover increased the pH in all soil, with alfalfa increased it only in highly sandy soils (sand and garden earth). On the other hand, *Chloris gayana* provoked a decrease of pH in all soils. This fact can not be attributed only to root excretions, but also to the microlife stimulated by them.

RESULTS

Manure as well as limestone can correct an acid pH. A slight liming is in condition to lower an alkaline pH. The acid pH as well as the alkaline one, can be adjusted to 6.8 by manuring, liming and a poliform commercial dressing.

CONCLUSIONS

1. The strict correlation of the pH, between 5.1 and 6.8, and the pore volume suggest a biological dependence.
2. The pH cannot only be the consequence of base saturation because its increase by liming decreases soil alkalinity.
3. Organic matter as well as limestone can neutralize an acid pH.
4. A balanced fertilization, the addition of organic matter, can neutralize an acid pH as well as an alkaline one.
5. The accomodation of pH at 6.8 can be explained by the biological neutral point. We know that the plasma of cells of soil microorganisms has a pH 6.8 and thus, it is supposed that the bacteria tend to establish their own reaction, in their environment.

Therefore, we may admit that the pH is primarily the product of the biological soil activity. Its durable correction is possible by methods which tend to establish a more active microflora and poliform meso-fauna in the soil.

The saturation of exchangeable disposable bases, also of trace elements, is a consequence of soil reaction.

* * *

The matter formed from poor vegetation does not sustain most of the microbes nor the mesofauna. In acid crop soils, a green manuring does little good. Mineral salts are necessary for profitable use by micro and mesolife. Therefore, we have not only to take care of the enrichment of the soil with organic matter, but, first of all, to supply the necessary nutrients. Acid soils rich in organic matter are always poor in nitrogen, and trace elements.

Soil poor or rich in bases may be compact and unproductive because both have something in common: the lack of organic matter and of microorganisms. Acid soils generally have high mineral reserves, though they are not available. Why did it acidify? It acidified because of the lack of a good structure, this deficiency being due to the inexistence of bacterian microlife. For its turn, the microlife needs organic matter. So we see the way clearly. As soon as the energy source of heterotrophic microlife runs short, the biostructure of the soil declines, resulting in an anaerobic environment. This only permits some fungi to prosper. It acidifies the soil, contributing to its sterilization. In this environment, there are chemical processes which let the clay compound deteriorate releasing aluminium and iron which combine with calcium, magnesium, phosphorus, and others. The soil becomes depleted not in minerals themselves, but in disposable minerals.

The plants that now appear are poor, woody, robust, nourishing, when dead, at most some fungus, but never bacteria. No mesofauna touches this organic material. The normal decomposition process remains incomplete and different.

The soil, then isn't acid by dessaturation of bases. It lacks the disposable bases which are fixed in insoluble compounds. The problem of acid soils in the tropics and sub-tropics is, no doubt, to mobilize the soil again. The first step is to treat with lime. It is not in order to correct the pH, but to animate the mesofauna and with it the microlife, which need the nutrient calcium.

Experiences of pH correction showed the pH may be neutralized, by lime, as well as by neutral organic matter and that the acid pH as well as the alkaline adjust itself at pH 6.8, the proper pH of the plasma of soil microbes. The pH corrected with lime is unstable, it lacks a water stable floculated structure. Furthermore the other nutrients are unbalanced in such a way, that it provokes the unproductivity of the soil for a definite time; that is in the tropics about one or two years.

The pH corrected by rich organic material is more stable. Besides this, it is the only method to recuperate as alkaline as saline soils.

As our experience shows, the salinity must not be leached out only from soil by irrigation. What we need is also to hinder the strong evaporation. What's important in saline and alkaline soils is an infiltration bigger then the evaporation and this may be obtained by increasing the infiltration or by decreasing the evaporation. There is no salt in the soil if the evaporation does not dominate the infiltration. Thus, a decreased evaporation is equivalent to an increased infiltration and we reach this by the biostructure of the topsoil. We made an experiment about this subject to verify the evaporation and the infiltration rate, as well as, the hydric power of Brazilian soils:

INFLUENCE OF SOIL BIOSTRUCTURE ON INFILTRATION AND WATER EVAPORATION

INTRODUCTION

The problem of droughts, on the pastures of the frontier of Rio Grande do Sul, becomes more and more dramatic, in spite of yearly precipitation of 1,350 mm to 1,700 mm. (In the semidesert of Karvo, Capland, zones have 2,500 to 2,900 mm of rain by year, but 95% run off and evaporate!).

The soils, generally, are shallow due to the fact that basalt presents itself in horizontal diaclasse, reaching sometimes only 12 cm of depth. Generally, they reach 30 cm or more of depth, and in very favorable cases, up to 60 cm. The soils are prairie-soils: dark colored although poor in humus and of a more or less clayish to sandy texture (30 to 91% of sand).

During the spring-rains, water stagnates on the surface of these soils. At this time there is an exuberant vegetation, which, when rain fall shortens, begins to diminish, and to dry up completely when there is a drought of 3 or 4 weeks, duration which are very common in summer. When dry, these soils are almost petrified, due to the exiguous pore volume, which varies between 6 to 9%.

It would be interesting to know if the drought may only be attributed to the climate, this means, to the bad rain distribution, or if it also depends on the soil and its deficient hydric regime. This problem is becoming worse, despite an unchanged pluviometric regime.

The soils of this region have a pH between 5.3 to 6.0, due to high magnesium content (150 to 400 ppm) and a good calcium content (1,000 to 1,750 ppm), what disagrees with its moderate to low disponible phosphorus, potash and copper content.

Dreibelbis and Post (1941), pointed out the importance of the difference between the possible water content of soil and the quantity of it present in this soil during the driest period of the year.

Salter and Williams (1963) verified, that soils, even very sandy, were retaining more water in proportion to the quantity of humus they contained.

Bol'Shakov et al. (1966), and Primavesi (1966), pointed out, that the compact superficial layers, as of sandy as clayish soils, hinder the infiltration of pluvial water, causing a very great flowing. The infiltration of these soils is deficient, the field capacity poor, but transpiration high.

With the improvement of bio-structure, the hydric regime of the soil changes radically.

PAULO SOUZA (1966), observed the little importance of soil texture, and the very insecure relation among the soil types and the water behaviour, which is in conformity with observations made in Rio Grande do Sul. The gradual loss of the field capacity by use was proved.

JUNKER and MADISON (1967), added turf to compact sandy soils and verified, with the decrease of soil density, an increase of water disponibility. The same was observed by KIJNE (1967), who treated compact soils with the polymer « Krilium », increasing by this way the soil floculation and water diffusion, which percentage, in this case, reached 100%.

KÖHNLEIN and OEHRING (1965), observed in sandy, compact soils, the damming of the rain water on the soil surface. They attribute this phenomenon to the tension free water (« spannungsfreies Wasser ») in consequence of the formation of sustaining meniscus. The damming was as greater as less clay and humus the soil contained. The infiltration of water was hindered and substituted by a lateral movement, permitting its ready evaporation.

GUREWITSCH (1961), states little relation between the distribution of precipitations and crop production, the crop production depending specially on the hydric regime of the soil.

Our experience should verify the influence of the biostructure and the vegetation about the hydric regime of the soil.

We denominate biostructure the structure of the upmost soil layer, floculated and animated by microlife, differences of the pedologic structure of soil, typical to clays and the genetic soil development, which is not caused directly by biological processes.

METHODS

On a plain plot with range soil, poor and decayed, we selected parcels of 5,000 square meters.

Parcel I — There remained the native grassland, receiving only a liming, being cleaned from time to time, to remove the vegetation rejected by cattle, pasturing here permanently, according to the extensive system, in use at this region.

Parcel II and III — Were ploughed and submitted to a recovery-treatment, in economic terms, which consisted of the following:

First year:

Oats (*Avena sativa*) for green fodder, twice mown.
The third cutting was used as green manure.
Corn (*Zea mays*) associated with soy-bean (*Glycine max.*) (*L. Merrill*), remaining the soy-beans as green manure.

Second year:

Wheat (*Triticum sativum*) followed by hybrid sorghum.

Third year:

Ornithopus sativus associated with oats for fodder and for green manure.
Corn associated with soy-beans, remaining the soy-beans as green-manure.

The soil of two parcels so treated, had a floculated tilth till 12 cm, and from 12 to 30 cm a cloddy structure (clods of approx. 3 cm in diameter (Photo 1), whereas the range land was thoroughly compact and above 18 cm it had a sheety structure (Photo 2).

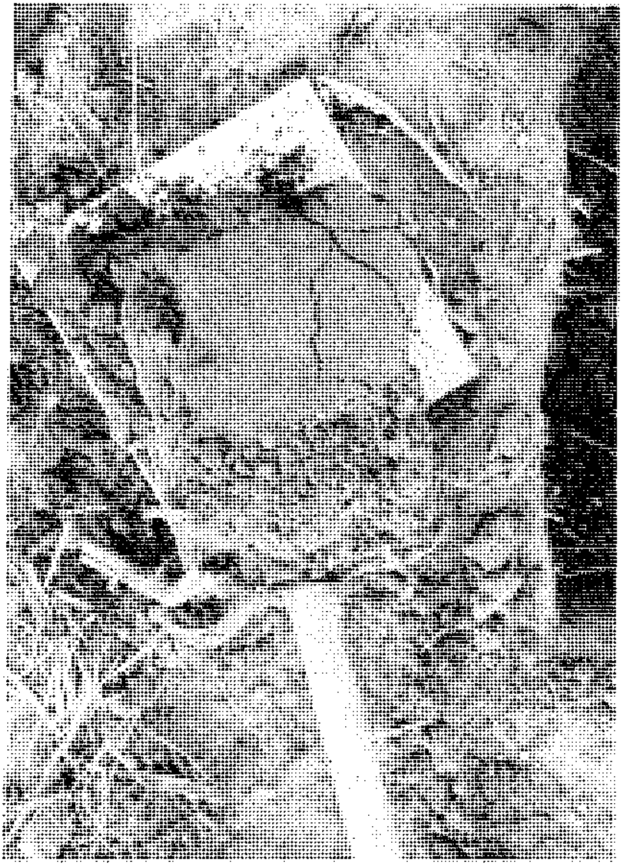


Photo 1

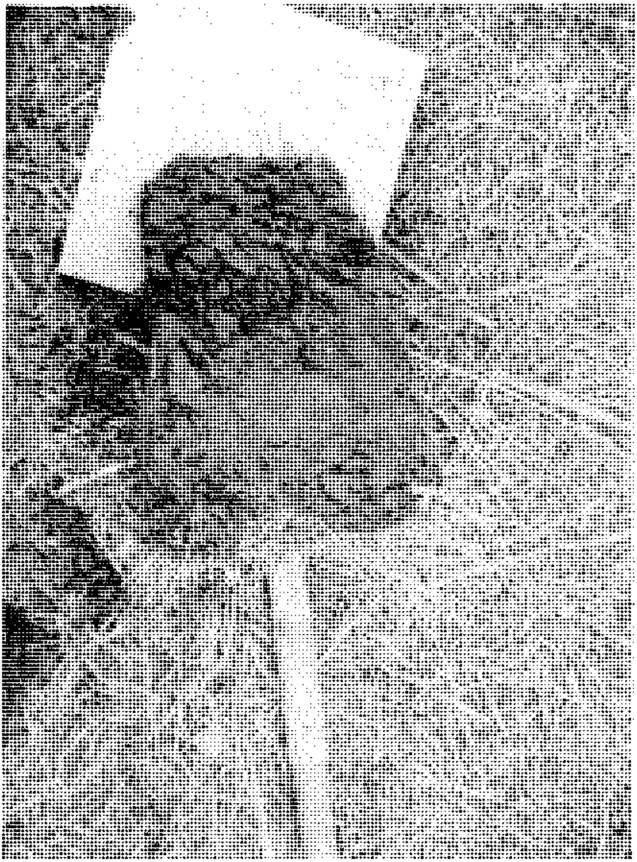
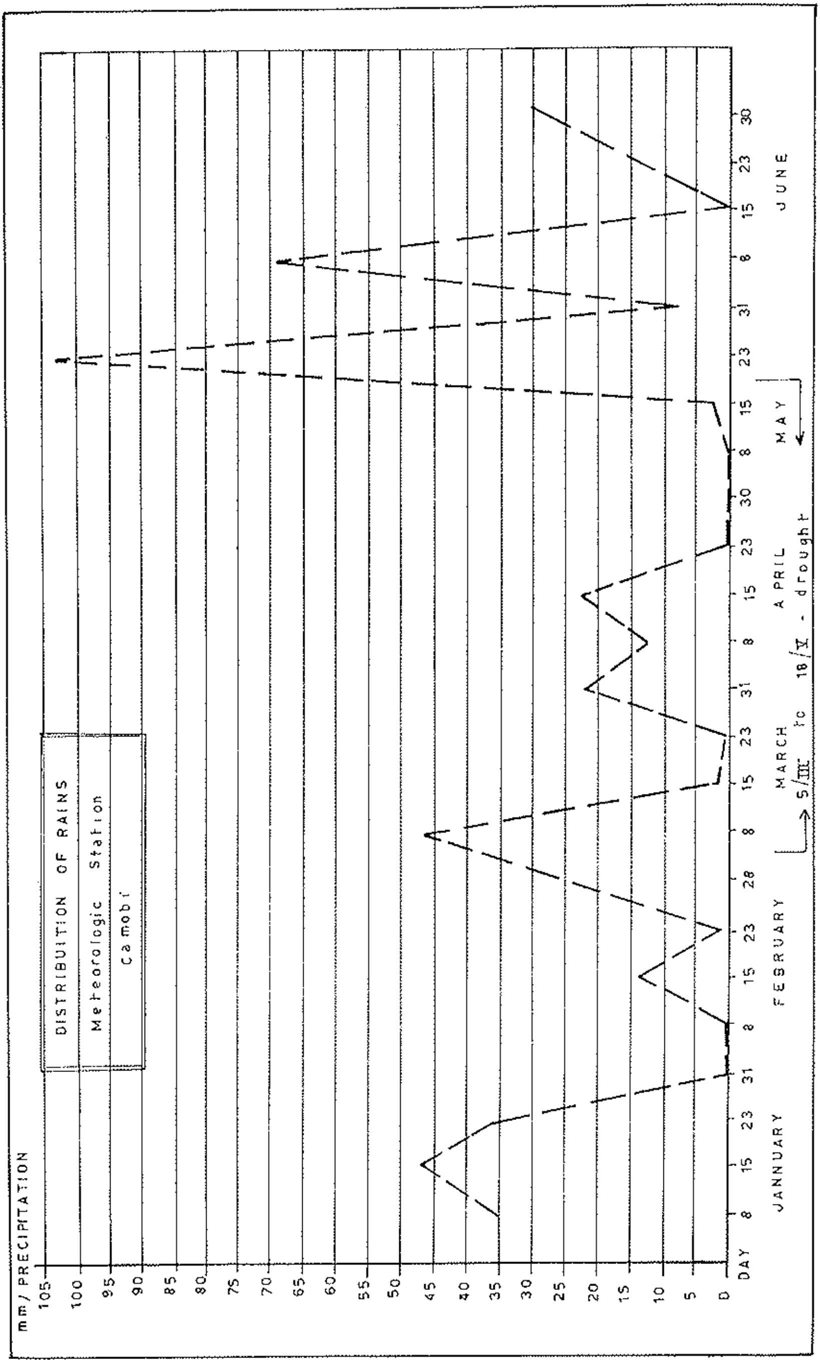


PHOTO 2


DISTRIBUITION OF RAINS
Meteorologic Station
Camobi
mm/PRECIPITATION
105
100
95
90
85
80
75
70
65
60
55
50
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DAY
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23
30
JANNUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
5/III to 18/V - drought

FIG. 3

Parcel III — Was planted in March, with lupine (*Lupinus albus*).

Parcel IV — Was only ploughed in March, and didn't receive any crop, in consideration to the dry-farming, where the soil rests every second year, without any vegetation, being eliminated the native herbage which germinates, in order to economize water for the next crop.

However, FUEHRING (1966) says, the minor fertilizers, in this particular case zinc and boron, regulate the vegetal population per area.

In 1962, VIETS, Jr. found out well nourished plants transpire less and use less water per kilogram of dry substance formed than poorly nourished ones. LATZKO (1966), accused the diminished plasma viscosity, in pottash deficient plants, as being responsible for the higher transpiration rate. GIFFORD and JENSEN (1967), verified on compact soils a lower production of dry substance per hectare and a higher water consumption per kg of dry substance as compared to floculated soils. This was the reason because we fertilized the lupine of parcel III with trace elements B: Mn: Cu = 1 : 0.5 : 0.7.

It was also interesting to know the water consumption on plots planted with fodder plants, because it is believed, that grassland has a greater water consumption than crop land, due to its permanent high production of green mass.

The granulometric analysis of the soil (according to BOUYOUCOS, 1939) was identical for all parcels:

Sand: 70% Silt.: 6% Clay: 23%

The moisture was determined in unalterated samples, becanse, according to YOUNG and DIXON (1966), screened samples present more water than natural grown samples. SOKOLOVSKAYA (1966), attests also the micro aggregates differ from the macro aggregates by the accentuated increase of water content which may arise up to 20%.

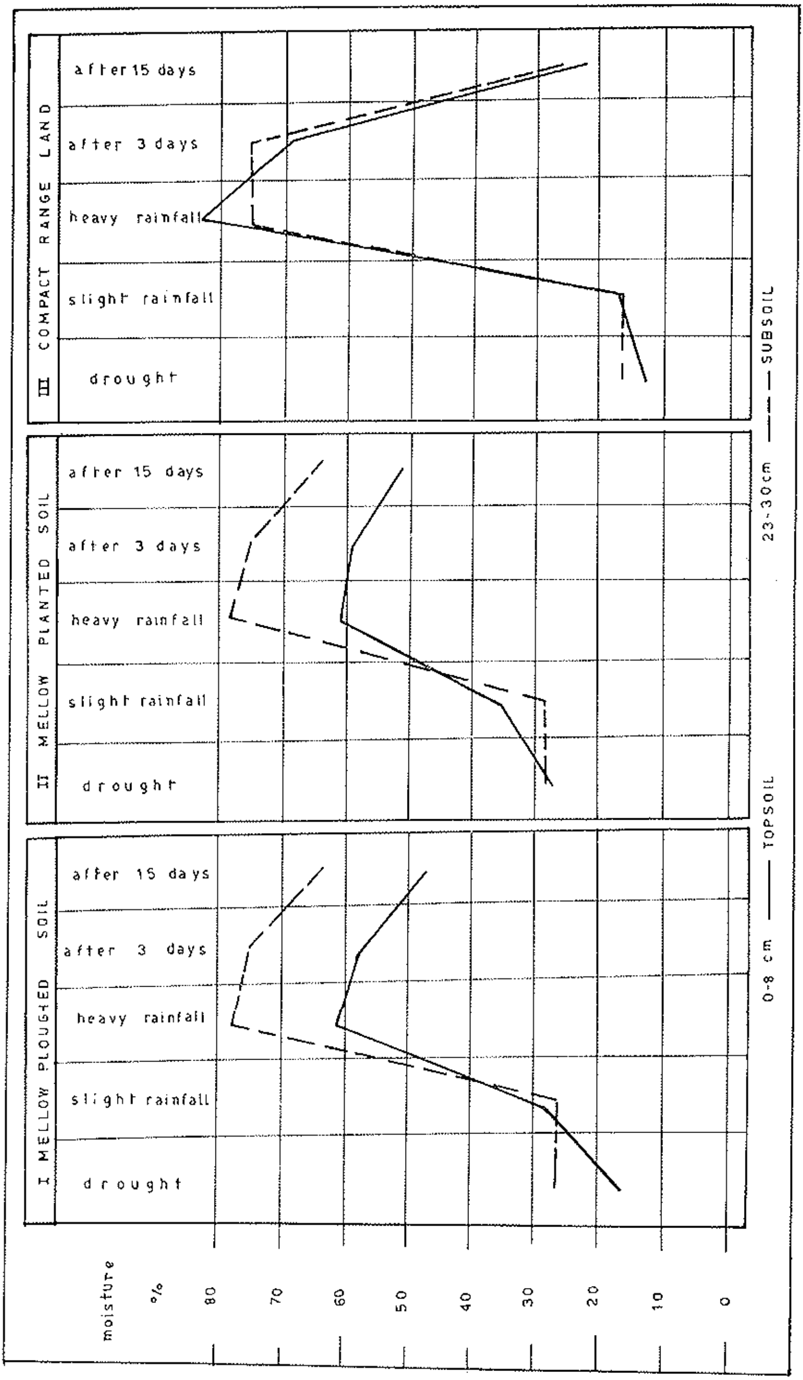
I MELLOW PLOUGHED SOIL
II MELLOW PLANTED SOIL
III COMPACT RANGE LAND
drought
slight rainfall
heavy rainfall
after 3 days
after 15 days
0-8 cm —— TOPSOIL
23-30 cm — — SUBSOIL
moisture %
80
70
60
50
40
30
20
10
0

FIG. 4

There were taken samples of natural grown soil, with a sharp cut away sampling tube and put in borrel flasks, with registered weight. The openings of the flasks were shut immediately with plastics. In the laboratory, the weight of soil was adjusted to 100 gram and dried in a stove of 105°C during 24 hours, being shut again and weighed once more. The difference of weight gave directly the percentage of water.

THE OPTIMUM OF WATER (FIELD CAPACITY)

METHOD

The soil was spread out in a layer of 1.5 cm and air dried in the laboratory during 4 days; the moisture was determined aside.

Of each soil, 5 samples (of 50 gram each), were weighed, and put in beakers of 125 ml. There was added respectively, 4, 5, 6, 7, 5-10 ml of water, well mixed with the soil, which was pressed with a spatula covered and let rest during 12 hours. After this time, the soil was stirred again and mixed. If it broke into loose clots, the water content was at the optimum. If it was sticky, moisture passed the optimum.

		Initial moisture	Water added	Optimum moisture
I Range land	topsoil	14 %	10%	24 %
	subsoil	13.5%	8%	21.5%
II Ploughed soil	topsoil	18 %	12%	30 %
	subsoil	16 %	10%	26 %
III Crop soil	topsoil	21 %	15%	36 %
	subsoil	20 %	12%	32 %

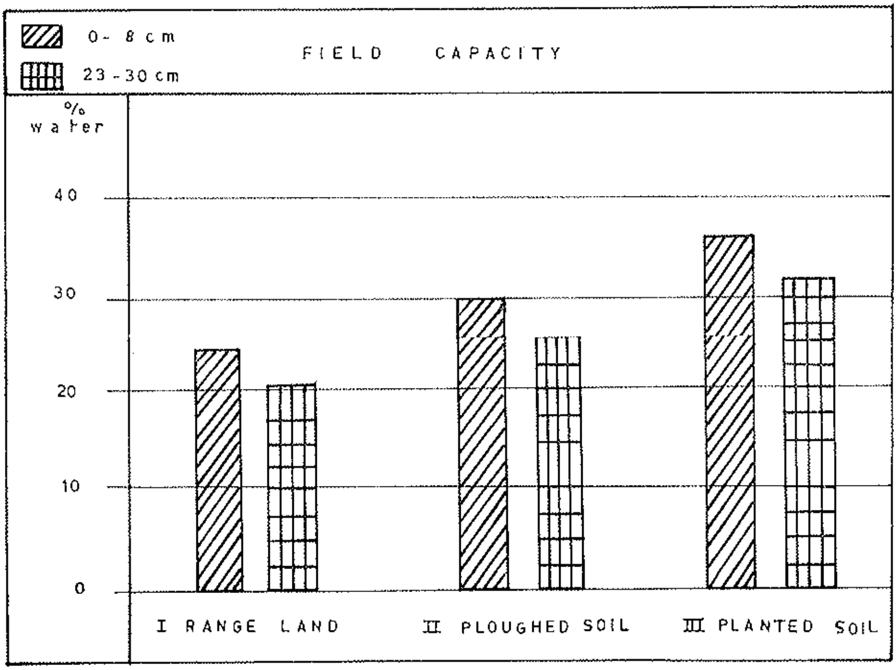

Fig. 5

Passing this moisture level, the soil becomes sticky, being susceptible to any pressure (be it caused by cattle or by agricultural machines which compact it).

Results and Discussion

By any means the obtained results were surprising. The soil without vegetation was dryer than the planted one, in spite of the fact that the latter had produced all its vegetation, with water reserves out of its field capacity, plus 61.6 mm of rain which it received during the period of 72 days. It may be attributed to the shading of the soil, which avoided the direct insolation and, consequently, the evaporation of soil moisture.

The transpiration by the leaves of lupines, which was calculated on 28 to/ha, was less than the loss by direct evaporation of moisture by the soil exposed to sun and wind.

The parcel with poor pasture, principally formed by: *Aristida pallens, Sporobulus poiretti, Carex spp.* (Capim cabelo-de-porco) and *Eragrostis sp.* all plants with little transpiration, calculated to have at this time a green-mass production of 6 to/ha, had a compact soil, with a minimum of water (13.31%). But, 104 mm of rain in 4 days turned the soil surface swampy with nearly no infiltration and, consequently, with a very rapid direct evaporation. As most of the roots reached only a depth down to 4 cm, we can believe water loss was not by the vegetation, but directly from the soil. The subsoil of the range land was less moist than the surface. The results of water-optimum and of total soil moisture are in good correlation.

CONCLUSION

The rapid loss of water of our range land must be attributed principally to the compact soil structure.

The water logging of soils in humid seasons, is due to the decayed biostructure, damming the tensionless water. Field-capacity of the soil is little. The evaporation is rapid and processes directly by the soil and probably through the poorly nourished vegetation.

It may be concluded that in compact and poor soils the drought-effect is much more pronounced than in soils with active biostructure and equilibrated mineral content. Even the shallow soils of our south-western frontier, could resist better to summer droughts, if their compact structure would be transformed into a floculated and active biostructure, through a suitable management.

* * *

The bio-structure is the only known method to:

1) guarantee a favorable pH to our crops;
2) avoid the soil leaching and podzolisation under a water regime where infiltration dominates;
3) avoid the soil salinization under a water regime where evaporation dominates;
4) avoid erosion, floods and the droughts following.

We verify the humus problem is not the problem of plant nutrition as THAER believed, or to serve only as a colloidal factor. The role of Organic Matter in the soil is: to serve as an energy source to the heterotrophic microorganisms, which depends on the floculated soil bio-structure.

This mellow bio-structure of the tilth is essential:

1. To good plant development for it:
    - *a*) permits the largest root development;
    - *b*) maintains the available nutrients;
    - *c*) conserves enough soil moisture for the nutrient absorption.
2. The good infiltration, avoiding erosion, flood and drought.

Little permeable soils do not permit rain water infiltration. The water run off immediately and forms a large superficial water sheet which flows in torrents, forms rills and finally

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promotes water erosion that devastates all the tropical and subtropical countries.

The merely mechanical fight of erosion is little efficient because the reason for the erosion is the water flow as the consequence of the little soil permeability. The « wadis » in Asia Minor and Africa are typical for this development.

On the other hand we may avoid the soil leaching by water infiltration, because water stable aggregates do not desintegrate, nor permit the colloidal complex decomposition.

Plants in compact soils have less water at their disposition and waste more in consequence of their bad nutrition. Therefore they suffer strongly the effects of the drought, while the plants in mellow soils still have a normal growth, enduring well the adverse climatic conditions.

We can find a lot of references in the world literature from which here are some:

FEODOROFF (1962) indicates the organic matter as the principal factor in the formation of rain stable aggregates, essential to the water regime of soil. SALTER and HAWORTH (1961) increased the field capacity by using stable manure. BUEHRER and DEMING (1961) attribute the bad infiltration and the deficient root development to the deficient soil floculation, which they improve by using organic matter and gypsum. BLACK and POWER (1965) prove that the biggest crops are produced in soils with better moisture conservation which depends on an adequate treatment; in this case the « stubble mulch fallow ».

ROSENBERG (1964) emphasizes the unfavourable influence of soil compactness relative to soil water and root development. COHEN and STRICKLING (1962) determine the aggregate stability by the permeability factor, because aggregate dispersion decreases soil permeability. GROVER and CAHOON (1964) verify great differences in the velocity of the moistening and drying of the soil, according to its texture and structure. BISHOP (1962) shows a close relation between the nutrient availability and organic matter content that is equivalent to an active structure. SCHULZE (1957) and also BECKER (1961) one independent from the other, establish a very important relation saying: « The water consumption per kg of dry matter is greater the smaller becomes the plant production in consequence of mineral lacking. » This means plants with « full » sap, that is a more viscous one, transpire less water than those of « empty » sap poor in minerals.

3. *Poor evaporation avoids salinisation*

There are saline soils even in Alaska, U.S.A., where evaporation predominates thanks to the compactness of soil surface not allowing infiltration. Compact soils heat much more than floculated ones. This provokes a strong evaporation accumulating salt even in artic soils. The eminent Professor E. W. RUSSELL (1967) says: « There is a desert in Africa not because of the absence of rain, but because rain water is not preserved in the soil. »

The whole problem of erosion, droughts and floods, belongs to the chapter of defloculated soils, compacted, in humid environment acidifying, principating water erosion or, in semiarid environment, alkalizing, giving origin to wind erosion.

FINAL CONSIDERATIONS

All these problems mentioned, whose solution is tried in the many different ways, have a solution:

The recuperation of the bio-structure through the aerobic and heterotrophic micro-life.

And this micro-life needs:

1) an energy source which is organic matter and, in favourable cases, humus;

2) mineral nutrients in sufficient and balanced form;
3) shade against direct insolation, which is given in pastures and may be easily obtained in well managed crop soils;
4) protection against splashing of the top soil by the impact of rain drops.

The organic matter alone cannot do miracles. The miracle is operated only, when our whole attention is turned to the soil micro-life to which it serves.

Poor humus of poor soils, therefore, must not be considered. There should be considered only the organic matter of soils which also offer nutrients to the micro-life.

We believe that the value of organic matter for the soil and for the survival of men never can be overestimated, because the whole life of the terrestrial globe depends on it.

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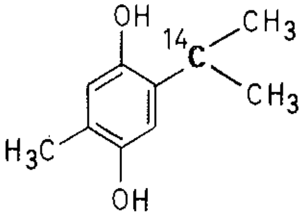
as the dependence of this effect from environmental conditions will be reported later on.

2.2.2.2. *Thymohydroquinone as model substance of oxidized lignin degradation products.*

It has been mentioned that phenols or quinones are formed by oxidative decarboxylation of 4-hydroxybenzene carboxylic acids. ^{14}C-labeled thymohydroquinone (SCHMID 1962, 1963, 1964) was used as model substance, because we had experiences (summaries: FLAIG and SÖCHTIG 1962, FLAIG 1965) about the effects of this substance on plant metabolism, growth and yield depending on environmental conditions.



thymohydroquinone

Thymohydroquinone was labeled in the secondary carbon atom of the isopropyl group and only small amount of labeled carbon dioxide is split off during experiments with plants.

The behaviour during the uptake by plants is principally the same as in the case of phenol carboxylic acids (KASTORI, SÖCHTIG and HAIDER 1968, in press). But only the inhibition

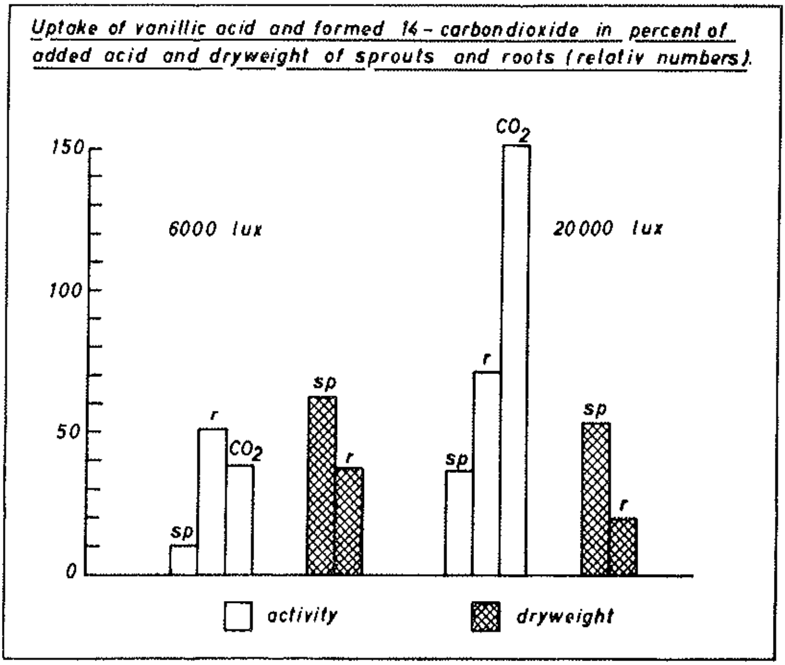


FIG. 9 — Influence of light on the uptake of vanillic acid.

The differences of dry weights of sprouts were not significant, whilst the dry weight of roots was only half in the experiment with higher illumination. This may be due to the fact, that the concentration of vanillic acid of about 10^{-3} molar may inhibit the growth (FLAIG and SAALBACH 1958, SÖCHTIG 1964). The uptake of vanillic acid increased by illumination with 20,000 lux may have effected the significant inhibition of root growth.

The relation between the used concentration of physiologically active substances and their effect on plant growth as well

Furthermore we studied the influence of environmental conditions on the uptake of phenol carboxylic acids. The uptake of vanillic acid in the sprout depends upon the pH-value of the nutrient solution and is therefore differently large. The uptake in the root and the quantity of liberated labeled carbon dioxide increases with decreasing hydrogen ion concentration. The increase of the uptake in the root is presumably caused by the increase of its negative charge by the increasing hydrogen ion concentration and the decrease of the dissociation of cationic groups. The migration of vanillic acid into the sprout is the most when the pH-value of nutrient solution corresponds to the pK-value of vanillic acid, which is 4.4. Similar observations were made in other cases of physiologically active substances.

Another dependence of the uptake from environmental conditions was observed in experiments with differently relative humidity. The dependence of uptake of vanillic acid from pH-value is larger in the case of a humidity of 50% than in this of 98%. The quantity of vanillic acid uptaken by the plant was measured by its decrease in the nutrient solution.

Light intensity as an environmental factor has also an influence on uptake of vanillic acid and its transformation (Fig. 9). Experiments have been made under nearly the same conditions by illumination with 6,000 and 20,000 lux. Only the specific activity of the added vanillic acid was different. It was 6.84×10^{-4} ipm/min in the case of 6,000 lux and 2.4 times higher in the case of 20,000 lux. But according to SAUERBECK and FÜHR (1966b) the higher activity in the sprout (0.6 μc/g) and the root (3.4 μc/g) should not damage the wheat seedlings; however the habitus of the plants showed some features, which may be caused by the higher activity.

The higher illumination increased the uptake in sprout and root. Especially the quantity of liberated carbon dioxide was enhanced whereby an increased respiration of the more than threefold quantity of activity in the sprout may play a role.

thoxy-p-benzoquinone occurs in wheat germs as glucoside. ZENK (1964) explains the formation of arbutin, the diglucoside of hydroquinone, in the plant by oxidative decarboxylation of p-hydroxybenzoic acid as its precursor.

Furthermore we demonstrated that the effect of vanillic acid on the increase of dry weight of wheat seedlings is larger than this of p-hydroxybenzoic acid, although the latter is more resistant against chemical oxidation (MORRISON 1963) or against enzymatic oxidation (LIM 1965) than vanillic acid. The effect of protocatechuic acid is somewhat less than this of vanillic acid; the lowest effect is caused by syringic and gallic acid. The reason for this may be, that these two acids are altered oxidatively very easily and decomposed.

Further investigations have shown, that the largest effect of phenol carboxylic acids on the increase of drymatter weight of seedlings of cereales can be observed by an addition of about 10^{-3} mol/liter, whilst the favourable concentrations of phenols or quinones are between 10^{-4} to 10^{-6} molar.

The experiments of oxidative decarboxylation of carboxylic acids as well as the higher physiologically activity of phenols or quinones and — as mentioned now — the fact that a larger quantity of phenols or quinones are present in the plants in free form and can be extracted in a higher yield than in the case of phenol carboxylic acids, let assume, that not the phenol carboxylic acids but presumably phenols and quinones as oxidation products may lead to alterations of the metabolism, whereby an increase of dry matter occurs under certain environmental conditions. This assumption must be proved by further investigations.

According to OXFORD (1942a, b) and OXFORD and RAISTRICK (1942) the substitution of quinones with methyl groups increases the effect against microorganisms. This result may be explained by either physiological activity or chemical stability of quinones.

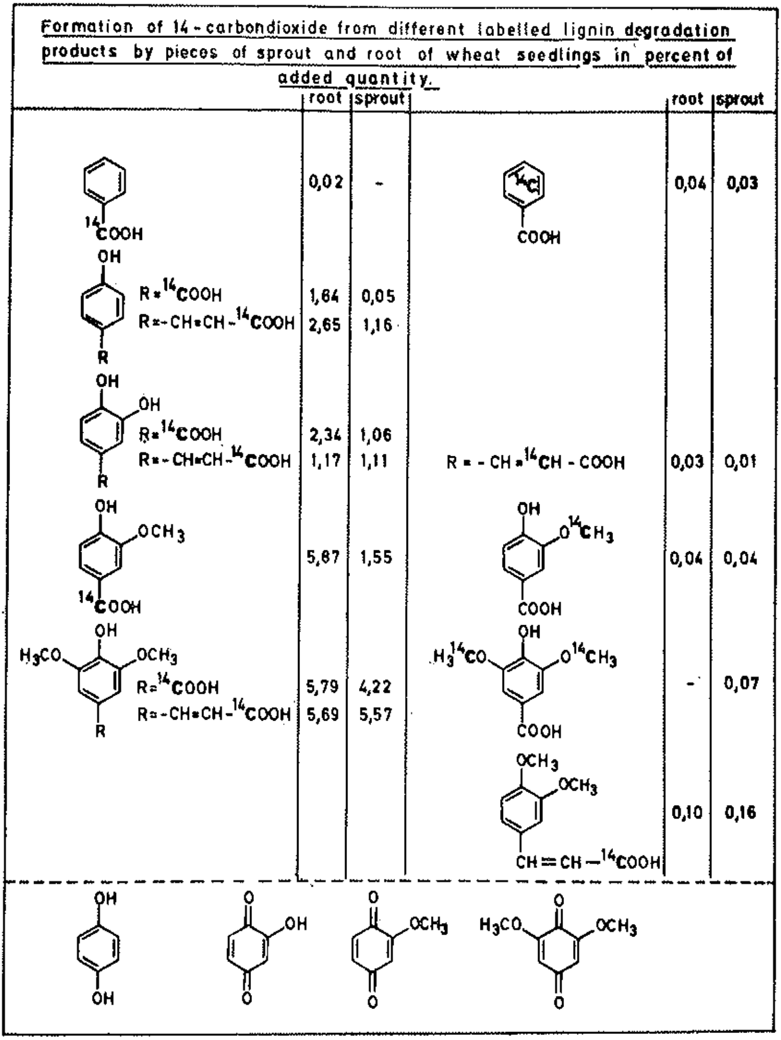


FIG. 8 — Formation of ^{14}carbon dioxide from different labeled lignin degradation products by pieces of sprouts or roots of wheat seedlings in percent of the added quantity.

In further experiments we studied the decarboxylation of phenol carboxylic acids in the presence of pieces of sprouts or roots with the Warburg technique (HARMS, SÖCHTIG and HAIDER 1968, in press). The oxygen absorption was not different in all cases (Fig. 8).

The table shows that benzoic acid as the fundamental substance of these compounds is not decarboxylated. No cleavage of the ring was observed as it could be proved with ring labeled benzoic acid. It seems to be that the formation of hydroxy benzoic acids does not occur during the time of the experiment, because the cleavage of the ring mainly occurs after hydroxylation and no active carbon dioxide could be found.

No remarkable amount of carbon dioxide is formed in the presence in the pieces of roots or sprouts after addition of caffeic acid labeled in carbon atom 2 of the side chain or after addition of vanillic and syringic acid, both labeled in the methoxyl group.

No decarboxylation is observed after etherification of the hydroxyl group in 4-position, for instance in the case of 3,4-dimethoxycinnamic acid. We suggest that the decarboxylation is due to the action of a phenol oxidase, because only compounds with hydroxyl groups in 4-position are decarboxylated. The decarboxylation occurs in a similar way — presumably through semiquinones — as it is also the case during the decarboxylation of phenol carboxylic acids in the presence of phenol oxidases from white rot fungi (FLAIG and HAIDER 1961a, b, HAIDER, LIM and FLAIG 1962, 1964, HAIDER, FREDERICK and FLAIG 1965, LIM 1965). During these reactions phenols or quinones could be identified as decarboxylation products (FLAIG, HAIDER 1961a, b) as it has been reported before. In this connection it is also mentioned that COSGROVE et al. (1952) isolated methoxy- and 2,6-dimethoxy-p-benzoquinones from fermented wheat germs. According to the work of BUNGENBERG DE JONG, KLAAR and VLIEGENHART (1953) me-

1964, Hutchinson, Roy and Towers 1958); also glucose esters of phenol carboxylic acids are known (Harborne and Corner 1961).

At the moment only assumption can be made about the importance of the reactions between glucose and phenol carboxylic acids to the corresponding derivatives as well as about the cleavage into the initial compounds for the plant metabolism. It seems to us not sufficient to explain the formation of glucosides and/or esters only as a reaction to detoxicate the phenolic compounds.

The activity found in the water extracts and in the residues of extraction is explained with the endogenous fixation of carbon dioxide which is split off from the phenol carboxylic acids.

The activity of the residues of extraction of sprouts was mostly higher than that of the roots and was mainly fixed in the holo-cellulose or α-cellulose respectively.

Jackson and Coleman (1959) have established the fixation of carbon dioxide in plant roots through phospho-enol-pyruvic-acid-carboxylase. Recently Kick, Sauerbeck and Führ (1964, 1965a, b) published a summary about the uptake of labeled carbon dioxide by plant roots and its fixation in plant constituents.

We investigated the remaining activity in the residues of extraction after hydrolysis with 6 n hydrochloric acid and found (Harms, Söchtig and Haider 1968, in press) that it is fixed in amino acids, soluble proteins and sugars. By further investigation of the amino acids we found, that the main part of activity was in the amino acids, aspartic and glutamic acid, which are formed by amination of oxalo-acetic acid and α-ketoglutaric acid from the citric acid cycle.

According to investigations of Dannenberg (1959) with seedlings of summer rye and with carboxyl-labeled protocatechuic acid also a part of the activity was found in the lignin fraction which has been isolated with 72% sulfuric acid and with 2% of dry matter.

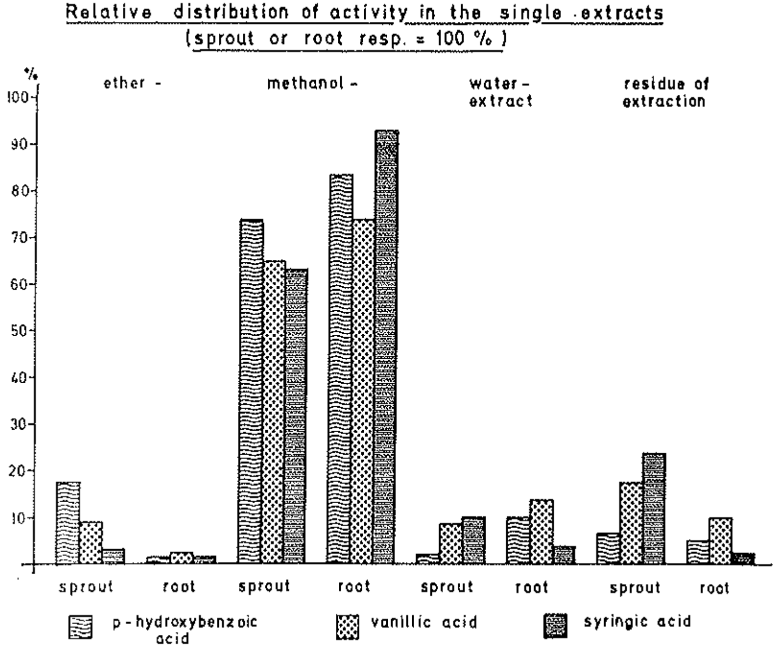


FIG. 7 — Distribution of activities of different extracts and residues of extraction from roots and sprouts in percent (Activity of root or sprout = 100).

The firstly sorptive bound acids were found by means of thinlayer chromatography in all cases of added phenol carboxylic acids. Furthermore it could be demonstrated by hydrolysis with diluted sulfuric acid or by a β-glucosidase, by following thinlayer chromatography as well as by means of UV-spectra and measuring of activity of the single compounds that the phenolcarboxylic acids are present in the plant partly as glucose esters, glucosides or as glucose esters of glucosides. The formation of phenol-mono-β-D-glucosides in plants was described already (PRIDHAM and SALTMARSH 1963, PRIDHAM

Therefore the extent of decarboxylation increases with increasing number of methoxyl groups in o-position of OH-groups in 4-position.

At the end of the experiment it was established by analysis, that besides the added phenol carboxylic acids no other labeled phenolic compounds are present in the nutrient solution. The sum of the remaining activity in the nutrient solution, the uptaken and the respirated activity corresponds nearly to the added.

The measured activity in the plant organs indicated only an accumulation of activity derived from phenol carboxylic acids, but without further investigations no statements can be made, in which form the activity was present.

Above all the large part of activity in the roots was noticeable. This could not be decreased by rinsing of the roots with diluted sodium hydroxide solution. The investigations made hitherto cannot explain the type of binding. BRIAN (1966) has reported in a detailed summary about the uptake and the transport of differently charged and neutral fungicides and bactericides. First of all we suppose, that the accumulation is a sorption effect.

The immediately deep-freezed, lyophylized and than pulverized plant organs have been extracted with ether, than with methanol and finally with water for separation of activities which were in roots and sprouts.

The determination of the radio activity in the extracts and in the residues of extraction resulted, that there exists a certain differentiation of uptake and distribution of the three acids. In the following only the principal differences are mentioned.

A part of acid is only found in the ether extract of sprout after addition of p-hydroxybenzoic acid.

The sorptively bound and the transformed phenol carboxylic acids are extracted with methanol. These extracts contain by far the largest part of activity.

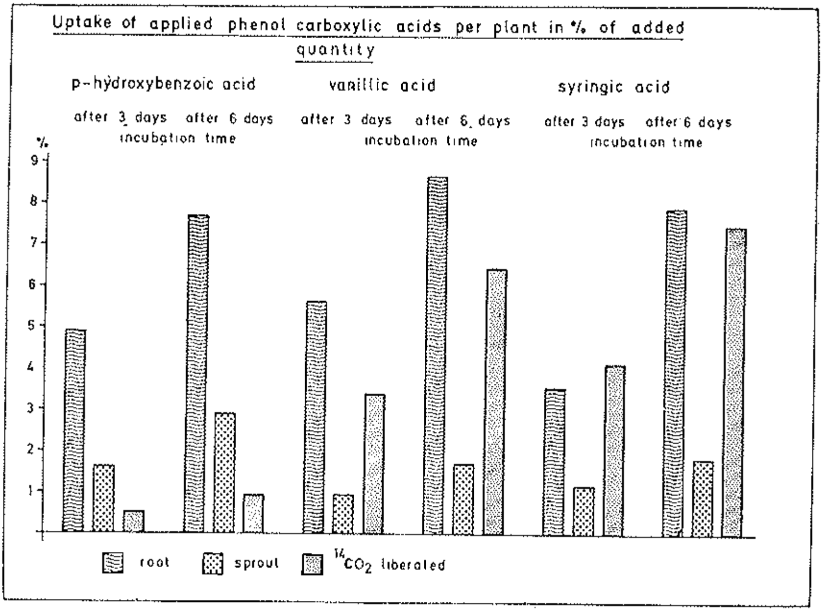
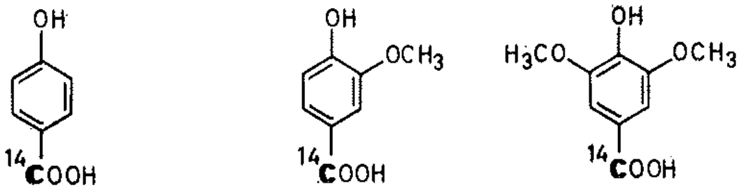


FIG. 6 — Uptake of phenol carboxylic acids in percent of the added quantity.

3) the activity measured in the sprouts is about 1 to 3% of the activity which has been added in form of phenol carboxylic acids; the differences of uptaken activity in sprouts are therefore not large,

4) the amount of liberated carbon dioxide differs remarkably; in the case of p-hydroxybenzoic acid it was the smallest (about 8% of the added quantity), in the case of vanillic acid it increases largely (about 35% of added quantity) and in the case of syringic acid it was the highest (about 45% of the added quantity).

addition of carefully isolated lignin to cultures of microorganisms (BÖRNER 1955, 1956, COLLISON 1925, FLAIG and MAEDER 1962, GUENZI and MCCALLA 1966, HENDERSON 1955, HIGUSHI, KAWAMURA and HAYASHI 1956, ISHIKAWA, SCHUBERT and NORD 1963a, b, c, JACQUIN 1963, SHOREY 1913, SKINNER and NOLL 1916, WAHNSCHAFFE 1955, WALTERS 1917, WHITEHEAD 1964). We made extensive studies (HARMS 1967, HARMS, SÖCHTIG and HAIDER (1968, in press) about the uptake of carboxylic labeled p-hydroxybenzoic, vanillic and syringic acid by the roots of wheat seedlings in sterile nutrient solutions according to KNOP.



p-hydroxybenzoic

vanillic

syringic acid

FIG. 5 — Labeled phenol carboxylic acids.

The distribution of the activity was determined in roots, in sprouts and in liberated carbon dioxide. The numbers of the activity in percent of the quantity of phenol carboxylic acids added to nutrient solution after an incubation time of 3 and 6 days are depicted in Fig. 6.

It can be concluded that:

1) the largest quantity of activity is in every case in the roots,

2) the quantity of activities increase in the roots, in the sprouts and in the liberated carbon dioxide with incubation time,

They found also in experiments with sunflowers that the addition of fulvic acids effects a significant increase of the yield of dryweight. In a further paper they demonstrated that only the low molecular weight parts of humic substances migrate in the sprout and that the high molecular weight substances are sorbed at the surface of roots (FÜHR and SAUERBECK, 1967). Therefore only the low molecular weight parts of soil organic matter seem to effect an increase of the dryweight of sprouts by their participation on metabolic processes.

2.2.2. *Defined compounds.*

The use of chemically defined and labeled compounds has the advantage, that their uptake and distribution in the plants can be investigated very exactly. After extraction of plants with corresponding solvents, after separation of the extracted compounds by thinlayer chromatography and by determination of specific activity of the single compounds the uptake can not only be determined in their order of magnitude, but also the transformations of the added compounds can be followed as long as the group with the labeled atom is not split off.

2.2.2.1. *Lignin degradation products such as phenol carboxylic acids.*

To support findings and to enlarge statements phenolic lignin degradation products such as phenol carboxylic acids have been labeled in different carbon atoms. Thereby the transformation of added compounds could not only be determined more exactly, but also their participation in reactions in the metabolism could be followed in a better way.

By a number of papers it was known, that the phenol carboxylic acids were isolated from soils, composts or also by

2.2. *Investigated substances and compounds.*

In the following it will only be recorded about a selection of substances which have been used for the studies of the uptake by plants.

I. Fractions of humic substances.

II. Phenol carboxylic acids as lignin degradation products.

III. Thymohydroquinone as model substances for oxidized lignin degradation products.

IV. Amino acids.

Whilst in the cases (I) to (III) the effect of the uptaken substance is considered as a « biocatalyst » in its function, in the case (IV) the uptaken substance can also serve as building blocks for the production of protein.

2.2.1. *Fractions of humic substances.*

FÜHR and SAUERBECK (1966) separated humic substances isolated from rotted and labeled barley straw in different fractions. They established in experiments with the mentioned setup, that sunflowers as experimental plants contained 4 till to 10% of the added carbon. The largest quantity was found in the roots. Only about 0.3-0.4% of the water soluble part of humic substances or about 0.1% of humic acids have been transported into the sprout. The authors explained the accumulation of the labeled compounds in the roots by sorption at their surface. They made similar establishments in experiments with radish (Raphanus sativus) (FÜHR and SAUERBECK, 1964) and carotts (Daucus carota) (FÜHR and SAUERBECK, 1965) by autoradiography of slices.

transform the added compounds. Therefore in this connection a setup is briefly described which was developed by us and used for our investigations (HARMS 1967).

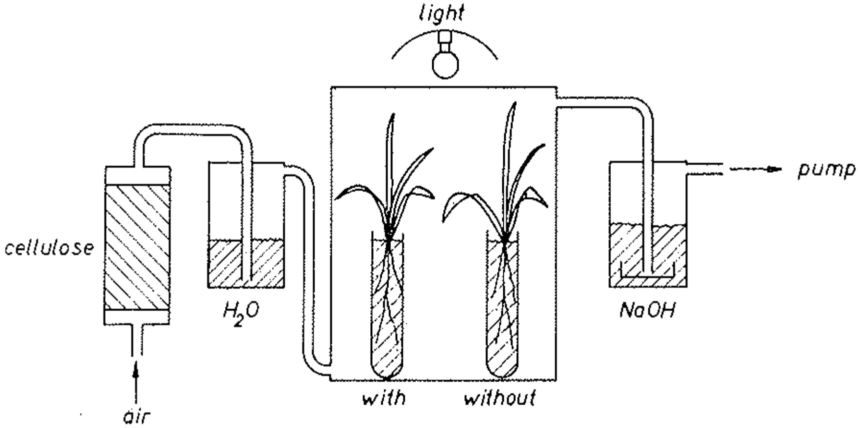


FIG. 4 — Scheme of apparatus according to HARMS (1967)

An airstream has been sucked by a pump througb a cotton-wool strainer and a safety trap, which has been filled with water or differently concentrated sulfuric acid for the regulation of hnmidity in a vitreous vessel. The vitreous vessel has dimensions that the quantity of air has been as small as possible. In this vessel the singular plants are in smaller test tubes to avoid infections. One part of the plants are in nutrient solution according to KNOP which contains the labeled phenol carboxylic acids, the others were used as check-plants. The sucked air passed than a safety trap with sodium hydroxide in which the liberated carbon dioxide was absorbed. The activity in the sodium hydroxide solution was measured. The rate of the air stream was about 60 liter per hour.

A stream of air purified from carbon dioxide by sodalime is sucked by a pump and passes through two bottles with nutrient solution according to CRONE. The bottles are closed with a stopper perforated several times. In the stopper were

two glas tubes for areation,

a dropping funnel by which the solution of the labeled humic substances could be given into nutrient solution,

and

the plants, which were fixed with a non hardening and physiologically inert plastic material (« Prestik », Bostik G.m.b.H., 637 Oberursel/Ts. West-Germany).

The airstream was 25 liter per hour. The carbon dioxide formed from the labeled humic substances was transported with the airstream from the vessel with the experimental plant into the vessel of the check-plant. In this way the quantity of the labeled carbon dioxide could be estimated which is uptaken by the plants through the roots. The non absorbed carbon dioxide was fixed in a trap with sodium hydroxide. The activity of the formed sodium carbonate was measured. In between the two bottles, in which the experimental and the check-plant were fixed, there was a safety trap with glasswool, to avoid contamination of nutrient solution of checkplant by aerosol of the active solution of experimental plant.

It seems to us absolutely necessary to work in sterile medium for investigations about uptake of defined compounds, in order that no microbially caused transformation products penetrate into the plants and simulate an uptake of the added compounds by means of measured activity of roots and sprouts or other plant organs. The determination of the formed carbon dioxide as in the case of addition of phenol carboxylic acids allows to draw conclusions about the occurring reactions which not know which transformation of these fractions occurs, when it is sterilized.

Substances degraded by activity of microorganisms may penetrate into the plant not only faster but it is also possible that degradation products from which the atoms are labeled, simulate an uptake of originally added compounds by participation on metabolic processes and therefore by the formation of labeled metabolites. This is especially the case, when the measured activity of plant organs such as roots or sprouts etc. is the only measnre for the value of uptake.

Remarkable quantities of carbon dioxide occur as degradation product, when overall labeled fulvic acids are used. By this reason FÜHR and SAUERBECK (1966) used a special experimental setup for their investigations of different extracts of labeled humic substances. With this equipment carbon dioxide, which is formed by the decomposition of the labeled humic fractions should be especially removed from the nutrient solution to avoid a reassimilation of $C^{14}O_2$.

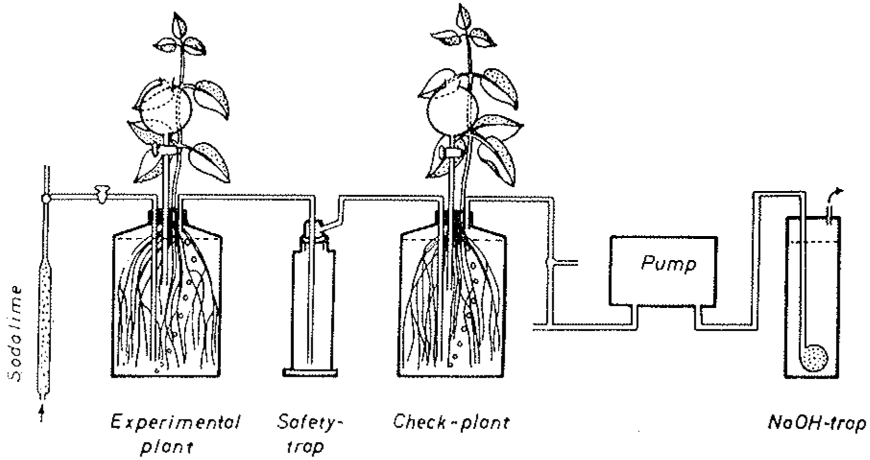


FIG. 3 — Scheme of the setup of SAUERBECK and FÜHR (1966a).

up to 1000 or 1500. These findings go back to the work of Winter (1952), who added physiologically active substances such as antibiotics to nutrient solution of plants and identified the added substances again in the guttation drops by means of their effect against microorganisms. In other cases the substances have been extracted frrom the upper organs of wheat or bean plants (e.g. Winter, Preuss and Schönbeck, 1959). Quantitative statements cannot be made in this way.

Recently different authors (Buvat and Lance 1957, Policard and Bessis 1958, Weilinger 1961*a*,*b*, Wittekind 1963) describe that the plant is able to uptake high molecular weight protein such as enzymes. A special mechanism of uptake (Pinocytosis) is supposed. This differs from the uptake of ions thereby, that plant proteins go through the membrane in the surrounding solution and include the foreign proteins. The included proteins are uptaken by the plant proteins which go back inside the plant.

The labeling of compounds with isotopes is indispensable for quantitative measurements of uptake of compounds through the roots of plants. Furthermore by labeling also a transformation of compounds can be detected which occurs inside the plant. The use of isotopes has the further advantage, that the compounds can be labeled in different carbon atoms of the molecule and therefore also details can be established during transformation.

2.1. *Experimental prerequisite for the proof of uptake.*

Experimental prerequisites must be provided for the use of labeled compounds, in order that actually the effect of added compounds and not this of transformation products is observed.

The investigations of fractions of humic substances are connected with some difficulties, because their constituents are not yet chemically identified in detail. By this reason one does

Epicoccum nigrum synthesizes orsellinic and cresorcellinic acid. Both are transformed into methyl resorcinols by decarboxylation. Different polyphenols, which have hydroxyl groups in 1,3- or 1,3,5-position as well as in 1,2,3- or 1,2,4-position are formed by oxidation of methyl groups to carboxylic groups, by following decarboxylation and by hydroxylation. Phenolic derivatives with hydroxyl groups in 1,2,3- or in 1,2,4-position can be oxidized to quinones and are responsible for the formation of the dark, humic acid like substances in the cultures of microorganisms.

By the microbial synthesis also p-hydroxy-benzoic, protocatechuic or gallic acid are formed. As mentioned before these substances occur also during the degradation of lignin and can be oxidized to quinones.

Other species of microorganisms synthesize different other phenolic or quinonoid compounds. From these only spinolusin and fumigatin are mentioned.

1.3. *Other physiologically active compounds.*

Furthermore indole-3-acetic acid has been found in soil organic matter or in different organic fertilizers (Hamence 1948, Seiler-Kelbitsch and Rademacher 1964). Finally it is mentioned that antihiotics also occur in soil organic matter which are dominantly of microbial origin. It is not yet known, to which extent this is the case singularly. Further compounds will not be mentioned.

2. UPTAKE, TRANSPORT AND TRANSFORMATION INSIDE THE PLANT

At first it shall be reported that only such substances are uptaken without difficulties, which have a molecular weight their chemical constitution and their behaviour during reactions will be mentioned.

1.2.2. *By microbial synthesis.*

Recently HAIDER and MARTIN (1967) made extensive studies about phenols as initial materials during the formation of humic acids in cultures of microorganisms.

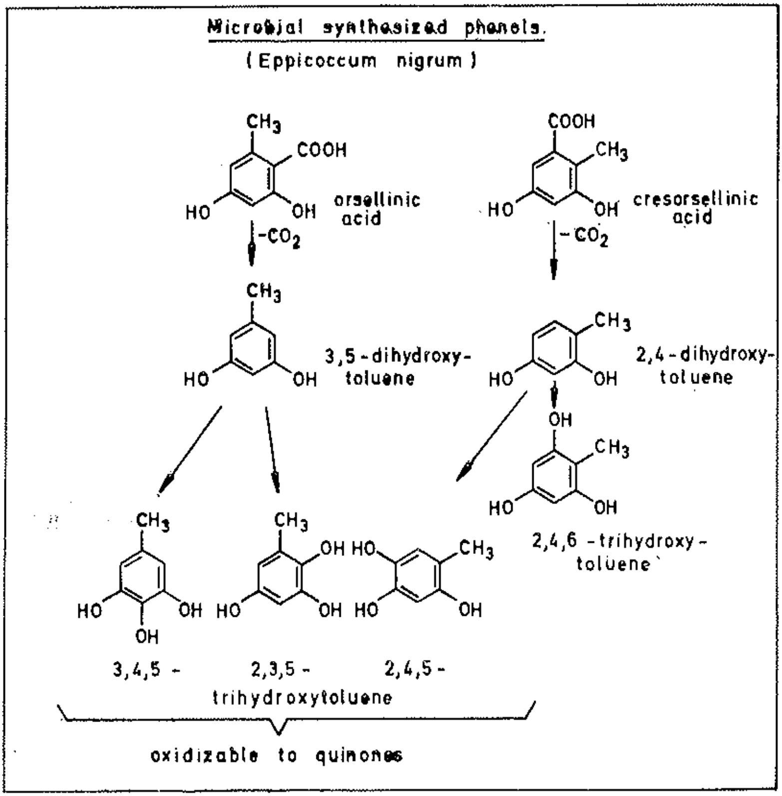


FIG. 2 — Synthesis of phenols by microorganisms and their transformations.

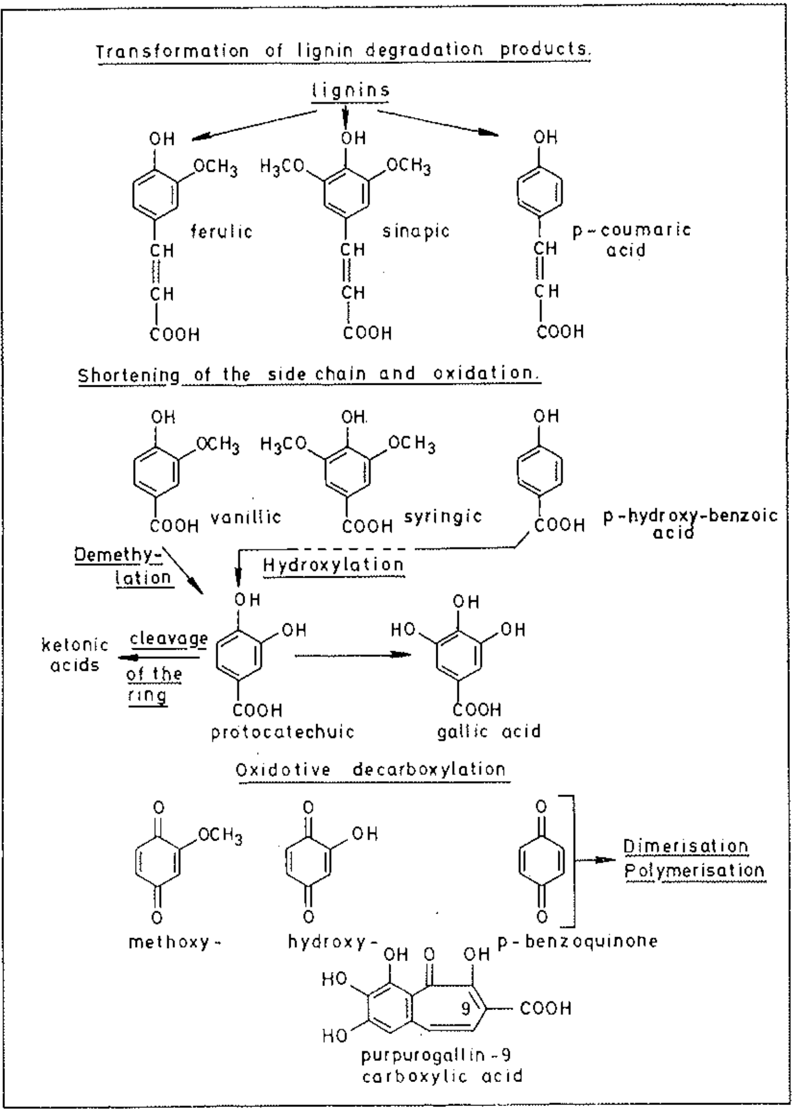


FIG. 1 — Reactions of lignin degradation products.

From the established reactions only these will be mentioned which seem to be important for the discussion of the uptake of organic compounds from soil organic matter by plants (Fig. 1).

Lignin degradation products are formed by biological reactions; they have an aldehyde- but mostly a carboxyl group and are phenol derivatives with a different number of methoxyl groups in o-position to the hydroxyl group and have side chains with one or three carbon atoms in p-position to the hydroxyl group. The shortening of the side chain of phenolacrylic acids occurs mainly at the double bound.

Demethylation is a further important reaction, whereby gallic acid is formed from syringic acid and protocatechuic acid from vanillic acid. Protocatechuic acid seems to have an important position for the transformation of aromatic to aliphatic compounds during humification. The aliphatic keto-carboxylic acids formed by the cleavage of the ring can be utilized by microorganisms as carbon sources.

Hydroxylation is a further reaction, which occurs during transformation of lignin degradation products. p-Hydroxybenzoic acid is hydroxylated to protocatechuic acid and this to gallic acid (HAIDER and MARTIN, 1967).

Quinones are formed in the course of oxidative decarboxylation catalized by phenoloxidases. Methoxy-p-quinone (FLAIG and HAIDER, 1961a) could be identified in cultures of microorganisms. According to ZENK (1964) hydroquinone is formed by oxidative decarboxylation of p-hydroxybenzoic acid and is present in the plant as the glucoside, arbutin.

All the mentioned compounds are transformed to dimers or polymers of different types by dehydrogenation. The formation of purpurogallin-9-carboxylic acid from the oxidation products of gallic acid is mentioned as a special example of dimerisation reactions (SALFELD 1957, SALFELD and BAUME 1964). Later several other transformations of phenol carboxylic acids in the plant, a certain dependence of their physiological activity as well as this of the formed phenols or quinones from

1.2. *Phenols and their oxidation products.*

For the detection of physiologically active substances from soil organic matter at first we studied 1,2- or 1,4-diphenols and the corresponding quinones, because larger quantities of polymeric phenols are present in soils in form of lignin as initial material for the formation of low molecular weight phenols during the humification.

Furthermore we found that phenols with hydroxyl groups in 1,3-position are synthesized by microorganisms and are transformed by hydroxylation and some further reactions in hydroxyhydroquinone derivatives. These can be considered as intermediary products for the formation of « microorganism-humic acids » (HAIDER and MARTIN, 1967).

1.2.1. *By degradation of lignin.*

The lignins of the different plant species are polymers of coniferyl alcohol or mixed polymers with sinapyl alcohol. In some cases p-coumaryl alcohol occurs as a third building block.

The knowledge about the microbial degradation of lignin has been remarkably increased by experiments with labeled monomers of lignin with carbon-14 in the benzene ring or at the carbon atoms of the substituents or by experiments with specifically labeled polymers of synthetic lignins (HAIDER and LIM 1965, HAIDER 1966). Also degradation products of lignins, which can be isolated from soils, or such which are possibly formed and not yet found, have been labeled specifically with carbon-14. We investigated their biological degradation, their polymerisation as well as the degradation of their polymers (FLAIG 1964, FLAIG and HAIDER 1961b, HAIDER 1965, HAIDER, LIM and FLAIG 1962, 1964).

substances, such which are usually formed by biological reactions in the soil, and such which get into the soil as herbicides, pesticides or other compounds by agricultural use of the soil.

An increase of the last mentioned physiologically active components in the soil may possibly happen by accumulation in consequence of the yearly use, when the chemical reactions, which effect the decomposition to inactive components or the biochemical degradation by soil microorganisms occur too slowly on account of the environmental conditions.

In the following different substances are mentioned, from which one knows or from which one can suppose, that they get into the plant from soil organic matter through the roots.

1.1. *Fractions of humic substances.*

In numerous experiments (CHAMINADE 1956, 1966, CHRISTEWA 1958, 1963, FLAIG 1958, GUMINSKI and GUMINSKA 1953, HUMUSDÜNGEMITTEL 1957, KONONOWA 1966, SCHEFFER and ULRICH 1960, Studies about Humus, 1962) a more or less large effect of fulvic acids or humic acids on the growth of plants or their organs is described. The effect of humic acids is next not comprehensible, because these as high molecular weight substances cannot penetrate through the cell membrane into the plants. SÖCHTIG (1967) could show that predialysed humic acids enclosed in a tube for dialysis and added to a nutrient solution had nearly the same effect on growth like such humic acids which have been added to the nutrient solution as a suspension directly. The humic acids have been partly degraded to low molecular components during 18 days, the time of experiment. The degradation products diffuse through the membrane of the tube. Therefore only the low molecular weight parts of humic substances have an effect on the metabolism of plants after their uptake.

UPTAKE OF ORGANIC SUBSTANCES FROM SOIL ORGANIC MATTER BY PLANT AND THEIR INFLUENCE ON METABOLISM

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For more than hundred years the importance of inorganic nutrients is aknowledged for nutrition of plants and therewith for the production of food. But the farmers know also, that soil organic matter is an important factor for the yield. They observe an « humus effect », which does not only deal with chemical or physical properties of soils, but also with biochemical processes in the plant.

Physiologically active substances have an effect on metabolism in small traces, and their investigation was therefore difficult in the past. But an elucidation of the action of organic substances of soil organic matter on plant metabolism can be anticipated, because of the availability of more sensitive experimental techniques and the progress of knowledge made thereby.

1. OCCURRENCE OF PHYSIOLOGICALLY ACTIVE COMPOUNDS IN SOIL ORGANIC MATTER

Investigations of occurrence of physiologically active substances in soil organic matter are concerned with two types of

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[19] *Khristeva* - pag. 20

method, and the cultures giving the best effect are the solanaceae plants, requiring great doses of nitrogen.

All these are some of the possible aspects of the use of physiologically active substances for the noble task — the increasing of the crop and the prosperity of mankind.

The problem laboratory of humic fertilizers by the chair of plant physiology and botany of the Dniepropetrovsk Agricultural Institue.

TABLE 9 — *Comparative effectiveness of humic fertilizers and the equivalent NRA set in the Ukraine.*

(According to the experiments of the Problem Laboratory for humic fertilizers at the Dniepropetrovsk Agricultural Institute during the years 1961-1965).

Sum total of experiments	From them:		The quantity of experiments which gave an addition, exceeding the addition from NRA, to the control		
	There is no effectiveness in comparison with NRA	There is effectiveness in comparison with NRA	under 10%	from 10%-20%	from 20% and more
General quantity of experiments 200	19	181	62	53	66
in % - 100 . .	10	90	34	29	37

The obligatory condition for the obtaining of organic-mineral fertilizers is the creation of conditions for the permanent dissolution of humic acids and the generation in the surroundings of the root nutrition of stimulating concentrations of physiologically active forms of humic acids.

As it is seen from table 9, these fertilizers give in the most cases an effect, exceeding the effect from equivalent set of mineral fertilizers.

The size of the increase of the crop in comparison with the mineral control fluctuate, first of all, according to soil and climate conditions — increasing to the north-west and to the south-east and it attains the minimum in the Central Steppes of the Ukraine.

The best means of applying such fertilizers is the local (table 8) while the worse the outward conditions were, the greater was the effect of the stimulation. Therefore, on the one hand, to raise the stability to the unfavourable conditions, and on the other hand, to reduce the cost of the application of dissoluble humates by means of out-of-root nutrition, we began to test the combination of herbicides with sodium humates and we received an average stable rise of the maize crop in comparison with the herbicide alone by 7-9%.

The next possible trend of the use can be their combination with mineral fertilizers. In this case we have the right to expect a rise of the coefficient of their use. It is easier to solve this problem if we take as a basis peat, brown coal or oxidized coal and combine them with mineral fertilizers, and not the contrary, though the last is more tempting.

TABLE 8 — *The effectiveness of out-of-root nutrition with sodium humates in the south of the Ukraine.*

(According to the experiments of the Problem Scientific-Research Laboratory for humic fertilizers at the Dniepropetrovsk Agricultural Institute during the years 1961-1965).

Deviation of the crop in the versions with humates in comparison with the control in %	Quantity of cases	% from the general quantity of cases
+ 5	26	25.5
from + 5 to + 10 . .	20	19.6
from + 10 to + 20 . .	28	27.4
> + 20	27	26.5
from — 5 to — 10 . .	1	1.0
Sum total	102	100.0

Unfortunately, this question is almost entirely unexplored in conformity with different soil types, and was considered by nobody from this standpoint. But we ought to do it!

It is not occasionally that the sodic soils certainly within definite limits, that is the soils containing a moderate quantity of sodium humat give the best wheat in the world from the standpoint of containing albumen.

It is known, that in many regions the strong wheat evidently degenerate. Perhaps we must look at this fact from the point of view of accumulation in the soil of inhibitors of synthesis of nucleic acids and that of albumen and look for means of struggle against this occurrence among the physiologically active substances, which can be used in different ways.

It is well-known, that the systematic use of toxic chemicals for the struggle against the pests and the illnesses leads to the suppression of the genetic organs both of the microflora and of the plants and animals.

As the physiologically active substances eliminate in some measure the inhibiting action of substances, operating on these organs, and it is so that most of antibiotics operate, the question arises if it is possible to eliminate or diminish the toxic action of usual toxics, which are used to struggle against the pests by means of physiologically active substances. Special experiments, while which tomato and cucumber seeds were wetted in toxics — in azurine and thiophos and were transplanted on physiologically active forms of humic acids confirmed this supposition. Other experiments in hothouses, where cucumbers were sprinkled with a mixture of thiophos and sodium humates, showed an increase of the crop from 13% to 30% in comparison with sprinkling by means of thiophos alone. We tested also the combination of physiologically active substances with herbicides.

The test of pure humates as stimulators of growth by the out-of-root nutritions gave an unstandard addition of the crop

TABLE 7 — *Action and after-action of humic fertilizers on the harvest of Tomato, fruits, yield of seeds and their quality.*

Scheme of the experiment	Action of fertilizers				After-action of fertilizers on the seeds					
	Average harvest of fruits for 4 years		Average yield of seeds for 4 years		Average harvest of fruits for 2 years		Average yield of seeds for 2 years		General mitotic index of the root meristem of tomatos	
	metric cent./ha	% to the control	% to the control	Coefficient of the yield of seeds in % to weight of fruits	metric cent./ha	% to the control	% to the control	Coefficient of the yield of seeds in % to the weight of fruits	1 generation	2 generation
1. Control-without fertilizers	403	100	100	0.46	254	100	100	0.47	29.8±3.3	25±3.2
2. Humophos 1 t/ha (local)	495	122	115	0.41	292	115	119	0.48	44.4±3.1	41±4.1
3. Mineral fertilizers equivalently to 1 t/ha of humophos .	432	107	107	0.46	262	103	108	0.48	37.0±4.4	32±3.8
4. Manure - 15 t/ha .	454	112	113	0.46	261	102	107	0.48	36.5±4.4	26.6±3.2

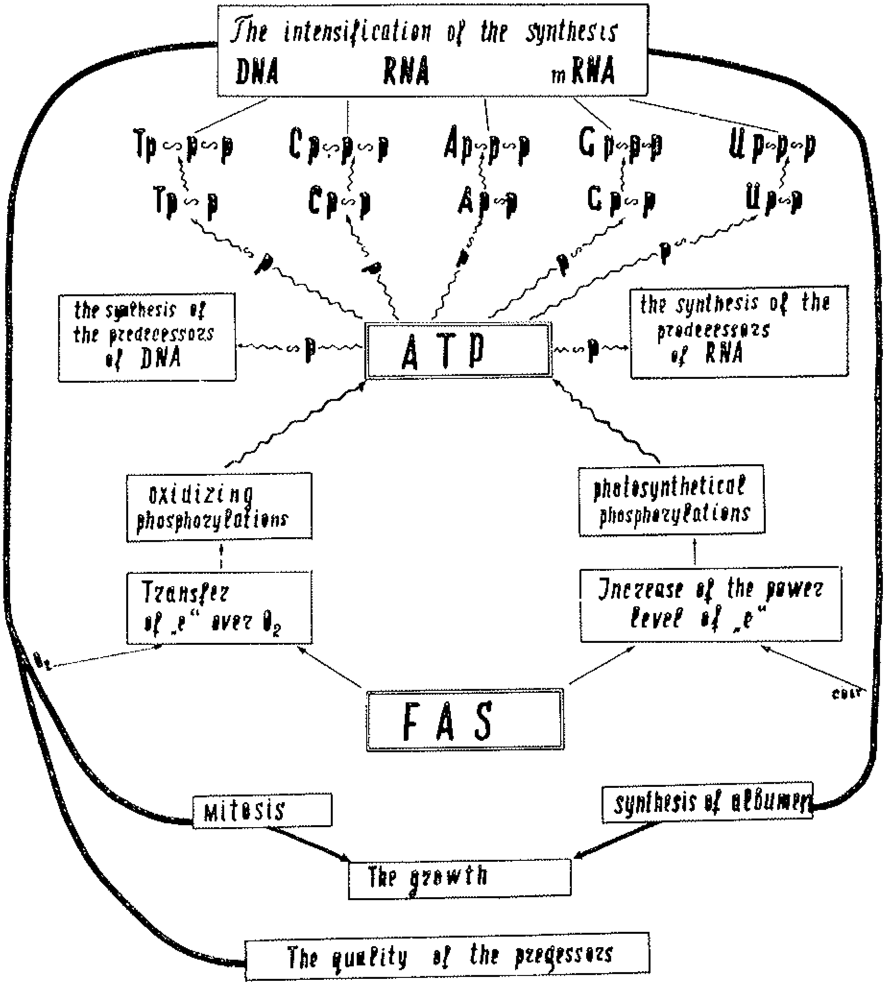
TABLE 6 — *The influence of sodium humate, applied in fallow (ordinary black earth) over the nuclein exchange, the crop, the albumen contents in winter wheat labelled bezostaya* - 1.

Versions of the experiment	Experiment of the year 1966					Addition of raw protein harvest from 1 hect.	Experiment of the year 1967					
	Paternal forms						The first generation					
	Grain			Addition of the crop in grain			Grain			Addition of the crop in grain		Addition of raw protein harvest from 1 hectare
	Milk-wax ripeness		Absolute ripeness				Milk-wax ripeness		Absolute ripeness			
	Sum of nucleic acids includ. RNA		% of raw protein				Sum of nucleic acids includ. RNA		% of raw protein			
	mg. % of absolut. dry weight		absolutely dry weight	metric cent./ha	to the control	% to the control	mg % of absolut. dry weight			metric cent./ /ha	% to the contr.	% to the control
1. Control	422	275	12.0	(37.3)	—	—	526	400	10.9	(23.2)	—	—
2. N 60	407	288	12.4	2.4	6.4	10.0	578	439	11.4	—0.6	—2.5	—2.1
3. Sodium humate . .	496	325	12.5	2.7	7.2	11.8	670	525	11.7	1.6	6.9	16.9
4. Sodium humate N 60	485	321	12.6	5.2	13.9	19.6	630	484	12.0	2.3	10.0	19.3

The sodium humate is prepared from brown coal by means of treating it with caustic soda; it is applied in the soil at a rate of 20 kg/ha of water soluble humic acid.

Diagram

of the influence of physiologically active substances of the soil humus and of the fertilizers over the plants



Footnote: FAS humic acides, vitamines B_2, PP, amber acide

Conventional disignations: energy 〰
management —

The determination of the mitotic activity of cells of maize root meristem of the first two generations showed the aftereffect of physiologically active substances over this index.

The determination of the DNA mass in the cells of the same tissues shows, that under the influence of physiologically active substances the quantity of cells with a great DNA quantity, preserves in two generations. In the third generation this effect disappears already.

Analogical results about the after effect of physiologically active substances in two generations are received by the applying of humic fertilizers in the soil under wheat (table 6) and tomatoes (table 7). In the last case it turned out that the sprouts, received from the seeds, the paternal forms of which were fertilized, have a larger germinating power and resist more actively to inhibitors of nucleic acids synthesis.

It is important to note that the chromatographical researches testify the invariability of the amino acid composition of albumen under the influence of sodium humat neither in the first nor in the second generation.

All this material permits to propose the following diagram of the influence of physiologically active substances over the vital activity of plants (diagram).

ABOUT THE AGRICULTURAL IMPORTANCE OF PHYSIOLOGICALLY ACTIVE SUBSTANCES

In the light of the above-stated, first of all, one must draw the conclusion, that by the appreciation of the soil fertility we must take into consideration the presence of physiologically active substances in their composition. This is important both from the point of view of the stimulation factor and from the point of view of eliminating the toxic action of those inhibitors, which accumulate in the soil, especially by a monoculture.

ment of the seeds with physiologically active substances told on the plant growth, partially on the crop, and especially on the albumen contents both in the year of the treatment and in the next two years (table 4).

TABLE 4 — *The influence of wetting maize seeds in different physiologically active substances over the crop and the albumen contents of the paternal forms and their after-effect on the first and the second generations.*

(According to the data of the field experiments on the chernozem [black earth] soil).

The seeds were wetted in:	Paternal forms 1964		First generation 1965		Second generation 1966	
	Addition to the control in %					
	Crop of grain	Raw prot.	Crop of grain	Raw prot.	Crop of grain	Raw prot.
1. Water (control) .	(39.5)	(—)	(41.6)	—	(35.2)	—
2. Sodium humat 6.10^{-5} M . . .	17.2	23.6	5.6	15.7	5.1	16.2
3. Vitamin B_1 $1,7.10^{-5}$ M	2.3	8.5	1.7	3.4	2.2	8.4
4. Vitamin B_2 $1,5.10^{-5}$ M	3.8	3.7	3.1	13.1	5.9	13.4
5. Vitamin C $2,9.10^{-5}$ M	5.1	18.9	3.3	2.1	2.8	4.2
6. Vitamin PP 4.10^{-5} M	10.6	32.0	10.3	17.4	3.4	12.6
7. ATP $1,4.10^{-5}$ M	5.8	17.6	5.4	9.1	7.1	21.9
8. Amber acid $8,3.10^{-5}$ M	6.1	18.5	1.4	19.6	3.4	26.8

azoquanine, RNA - nucleases and DNA nucleases, and also chloramphenicol and in the lesser degree 2.4 dinitrophenol on the growth processes is eliminated.

The results of general typological and citochemical investigations of the root meristem of maize showed, that under the influence of Na humat and ATP considerably increases the mitotic activity of the meristem cells and somewhat enlarge the dimensions of their nuclei on the number of interphase nuclei with a great quantity of DNA. All this shows the reinforcement of the nucleic acids synthesis.

This is confirmed by the autographs obtained from the inclusion of thimidine H^3 into the cell DNA. The analysis showed, that by the maize sprouts, grown on the solution of sodium humat and ATP, the thimidine H^3 actively includes itself into the DNA of interphase cells, while by the version with 2.4 dinitrophenol there was no mark. A lowering of the intensity of the inclusion of the mark in the DNA of the cell was observed under the influence of chloramphenicol. The investigation of the RNA synthesis in the meristem cells showed the reinforcement of the inclusion of uridine H^3, especially in the nucleus and nucleolus zones. This says about the enforcement of synthesis namely of the RNA-messenger.

Thus one may consider as established, that under the influence of physiologically active substances the cell organs, dealing with the transmission of information by the albumen synthesis, gain strength; here the observations showed that this tells not only on the cell growth, but also on the tissues differentiation and development acceleration. By this probably one can explain the fact established by CHAMINADE [5] and others, that the plants utilize better large nitrogen doses under the influence of dissoluble humats.

As the DNA - RNA system codes and communicates the genetic information, the question arises if the physiologically active substances can influence the posterity. This idea found its confirmation in the experiments with maize, where the treat-with radioactive isotopes showed the high mobility of this RNA - form. Therefore we supposed, that under the influence of physiologically active substances the synthesis speed of labile RNA - forms increases, and, first of all, of RNA messenger.

But the synthesis of all the forms of RNA, as well as those of DNA, is going on enzymably (KORENBERG [8], WEIP [2]) by means of condensation of nucleoside-triphosphates with the secretion of pyrophosphate, the nucleosidetriphosphates being generated here from nucleosidemonophosphates or from nucleosidediphosphates by means of their reaction with ATP. Therefore one could suppose that the physiologically active substances, which in the initial stage modulate in the cells an additional quantity of macroergs in the form of ATP, accelerate the regeneration of nucleosidediphosphates in nucleosidetriphosphates and must influence over the synthesis speed of the whole system DNA - RNA.

In order to verify this supposition, basing on the works of GRO and KHART [3], and also of CHANTRENNE [16], we experimented with specific inhibitors of this reactions and physiologically active substances, accompanying them with observations over the growth of the plants, the mitotic activity of the cells of the meristem tissues, with the study of the state of nucleic acids by histochemical methods, with cytophotometric determination of the DNA quantity and with the radioautographic investigation of the including of the predecessors of the DNA - RNA synthesis-thymidine and uridine, labelled tritium.

The influence of inhibitors and of physiologically active substances was realized by means of wetting the seeds in one solution with the following transplantation into another solution.

The results of this experiment show, that, if one suppresses the DNA or RNA synthesis, the speed of the growth processes reduces. Here it was determined that under the action of physiologically active substances the suppressing action of a number of inhibitors of nucleic acids synthesis - pyrophosphate, 8 -

It should be indicated that the academician of the Czechoslovak Academy of Sciences S. PRAT had suggested before as the influence of humic acid over the maintenance of free radicals in the plant.

So the basis of the influence of physiologically active substances over the biochemical processes of the plants seems to us to be their influence over the thermodynamics and the increase of the power potential of the cells, tissues, organism, though the mechanism of this phenomenon is not yet clear.

THE PRINCIPAL IN THE NATURE OF ACTION OF PHYSIOLOGICALLY ACTIVE SUBSTANCES OVER THE PLANT GROWTH PROCESSES

The growth processes are the main manifestation of life, because it is in this process that the cell reproduces itself.

But the cell reproduces itself in the mitosis processes, where the main is the DNA duplication and the synthesis of proteins-ferments and proteins-constituents. The intensity of this synthesis defines in a considerable degree the growth of the cells, tissues and organism. Therefore, trying to find out some chief and general things in the nature of the physiological action of growth activating substances, we must suppose, that this chief thing should be in the regulation of protein synthesis. Lately there are great achievements in the study of protein chemistry and in the understanding of its synthesis. Of these achievements we must put on the first place the discovery of cybernetical functions of nucleic acids, which realize the information by the protein construction. Therefore we should suppose, that the growth acceleration of the plants must be accompanied by the acceleration of nucleic acids synthesis. « The difference of the synthesis speed of protein accounts for the quality of parallelly working matrices » - Academician BRASLER says [1]. The matrix, as it is known, is a special form of RNA - messenger, brilliantly postulated by JACOB and MONOD. The work were grown by a different spectral composition of light, and here it turned out that the reaction of the plants on the physiologically active substances, in general, coincides with the spectrum of the absorption of light by chlorophyll.

The calculation of the concentration of paramagnetical centres, according to the data of the determination of the BEP signal in the sprouts of phaseolus aurens Piper after the lyophil drying (table 3) shows directly on the increase of the quantity of free radicals under the influence of physiologically active substances and the connections of this phenomenon with the oxidizing phosphorylation.

TABLE 3 — *The influence of physiologically active substance over leaves and roots EPR of the phaseolus aurens Piper sprouts.*

Properties	The seeds are germinated on: Water The sprouts are transplanted on: Water	Na humate Na humate	ATP ATP	2,4-DNP 2,4-DNP
A. EPR of the leaves of phaseolus aurens Piper				
Herstad	15.9	18.2	19.0	16.3
g-factor	2,0028	2,0024	2,0024	2,0030
N. 10^{14} spin/gramme	18.9	32.3	58.0	19.4
B. EPR of the roots of phaseolus aurens Piper				
Herstad	11.2	14.1	15.7	9.7
g-factor	2.0046	2.0044	2.0047	2.0038
N. 10^{14} spin/gramme	11.5	17.8	27.6	10.3

K = 7

The composition of physiologically active substances on which the sprouts were germinated 10^{-5} m/l.

The experiments of our collaborator N. V. LUKYANENKO showed the sprinkling of maize with humates in spring and in summer gives different effectiveness, and that phenomenon correlates more with the composition of light, than with the temperature.

TABLE 2 — *The influence of sodium humate over the catalase activity of sprouts of 4 days.*

Indices	Maize		Barley		Wheat	
	on water	on Na humate	on water	on Na humate	on water	on Na humate
Secreted O_2 in mm in 1 minute						
by 15°C . . .	0.9	1.2	1.1	1.6	1.7	2.2
by 25°C . . .	1.4	1.7	2.3	3.1	3.0	3.6
Coefficient Q_1 10 of Want-Hoff .	1.56	1.42	2.09	1.94	1.76	1.64
E active in calorie/mole	7624	6013	12637	11362	9692	8480
P^N active . . .	17.48	18.67	13.72	14.75	15.92	16.88

The experiments, carried out in Kirghizia [9] showed in their turn that the higher up the mountains, the greater the effect of humic fertilizers. This suggested the idea to us, that perhaps under the influence of physiologically active substances an increase of absorption of quanta of light by the chloroplast takes place, which, thanks to the tuning of power level of the dislocalized electrons may change and the power potential of the plants increases also in that way. We find the confirmation of this idea in the experiments, where the sprouts of maize substances over BEP, on the background of using O_2, we shall give table 1. The increase of the power potential is confirmed by table 2, from which it appears, that under the influence of physiologically active substances not only the activity of the ferments increases, in the case of the peroxidase, but the threshold of activation decreases, about which the Soviet scientist BLAGOVESCHENSKY [19] spoke in his time.

TABLE 1 — *The influence of physiologically active substances over the absorption of O_2 and BEP by sprouts of 4-5 days.*

Scheme of the Experiment Indices	The seeds were germinated on			
	Water	Sodium humat	amber acid	ATP
	Wheat			
BEP in mv . . .	96	123	196	160
Absorbed O_2 in mm^3/g . . .	85	142	223	324
	Barley			
BEP in mv . . .	88	119	122	127
Absorbed O_2 in mm^3/g . . .	79	190	216	287
	Maize			
BEP in mv . . .	88	137	167	138
Absorbed O_2 in mm^3/g . . .	147	178	213	310

The concentration of physiologically active substances — 10^{-5} m/l. Platinum electrodes.

[19] *Khristeva* - pag. 5

Now Prof. FLAIG suggests the idea, that the humic acids and other physiologically active substances separate the respiration and the oxidizing phosphorylation, thanks to which the generating inorganic phosphate induces the glycolysis and as a result the metabolism of the plants grows sharply.

However, remaining on the point of view expressed above about the biochemical function of humic acids, we included into our subsequent investigations a number of vitamins (B_2, PP and C), which immediately participate in the electron transfer (of hydrogen) in the reaction of oxidoreduction, and also some acids from cycle Krebs.

In all the cases we received an activation of the respiration and a physiological effect. Therefore we expressed the idea (KHRISTEVA, 1962 [12]) that the plant cells under certain, and mainly unfavourable outward conditions, and when the rhythm of respiration is heightened by some causes, do not cope with the synthesis of a number of complex combinations, executing the role of a carrier by the transmission of hydrogen on oxygen in the reactions of oxydoreduction, thanks to which they find themselves not prepared for the perception of the quantity of oxygen they need. As a result an oxygen insufficiency arises in the tissues and the sufferings of the plants resemble the avitaminosis of animals. The introduction of physiologically active substances to the plant at this period eliminates this insufficiency, and the plant raises its power potential.

So long as the main accumulator and giver of power for the biochemical processes in the cell is the ATP, we paid great attention to the determination of those forms of phosporus that have macropower connections. And really, we succeeded more then once in stating their increase. But this index by the total analysis proved to be so mobile, that we declined it. Later on, trying to characterize the power potential, we began determining BEP and introducing into all the physiological experiments ATP as an additional control.

As an example of the influence of the physiologically active

The decision of this problem seems to us expedient to be divided into two parts, and then we shall try to determine: firstly, what factors are the leading in the influence of physiologically active substances over the general course of the metabolism, and secondly, what is the basis of the growth reactions of the plant on these substances.

Considering that a review paper is not my task, I shall pass to the account of the experimental material, received in our laboratory, and to its analysis from the above mentioned standpoint.

THE PRINCIPAL IN THE INFLUENCE OF PHISIOLOGICALLY ACTIVE SUBSTANCES OVER THE BIOCHEMICAL PROCESSES

We worked mostly with humic acids of the organic fossils. Therefore I shall begin with these substances. First of all, it is necessary to say, that the humic acids have their physiologically active property only in their highly dispersed state.

Connecting at one time the influence of physiologically active forms of humic acids over the plant respiration with the presence in their composition of polyphenol and chinoid groups, and basing on the doctrine of BACH and PALLADIN about the oxidizing processes, we considered them as a factor of activation of the oxygen and of transfering hydrogen on other acceptors.

This scheme was confirmed by the fact, that when the phenolase oxidizing system was depressed by a specific inhibitor, the action of humic acid slumped. Therefore we considered the humic acid as an intensifier, first of all, of the phenolase system (L. A. KHRISTEVA [14].

A similar point of view was expressed then by Prof. GUMINSKI [4] and Prof. FLAIG, who worked with polyphenols and their derivatives, considering them as predecessors of humic acids.

ulating effect of these substances becomes especially apparent, and namely:

1) The specific concentration of the stimulator;

2) The importance of the early phase development of the plant;

3) The unfavourable outward conditions, and, first of all, heightened temperature, high doses of nitrogen, the insufficiency of phosphorus, lack of oxygen in the medium of root nutrition and others.

The works of many scientists (they are rather completely generalized in KONONOVA's monograph « The organic substance of the soil, its nature, its properties and the methods of its study », 1963, and that of PRAT « Humus and its importance » (Prague, 1964) in the collections « The humic fertilizers, theory and practice of their application » volumes 1, 2 and 3 (published in 1957, 1962, 1968) and also in the papers of professor FLAIG « About the influence of humic substances on the metabolism of the plants » at the International Peat Congress in Leningrad (1963) and those of Professor GUMILEVSKY « The influence of humic substances over some physiological processes », at the IVth symposium « Humus and Plant » in 1967 in Prague showed the great influence of physiologically active substances of the soil humus and of the fertilizers over the general metabolism in the plant, that is manifested by the intensification of absorption of oxygen, by activation of the ferments, and first of all, of the respiratory cycle, the reinforcement of the formation of chlorophyll, the change of phosphorus forms, the increase of the quantity of mono-and disugars, and the contents of the albumen in the crop.

But all this is only the statement of facts, and not the disclosure of the phenomenon nature, and here a part of the established facts must be the cause, the other part must be the effect.

ABOUT THE NATURE OF PHYSIOLOGICALLY ACTIVE SUBSTANCES OF THE SOIL HUMUS AND OF ORGANIC FERTILIZERS AND THEIR AGRICULTURAL IMPORTANCE

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The role of humus for the fertility of soils is vast and many-sided. Therefore this problem is very intensively studied in different aspects. One of the comparatively new aspects is the study of the humus as a system of physiologically active substances.

The works of Czechoslovak scientists (academician PRAT, professor RYPACEK and their collaborators), of Polish scientists (professors GUMINSKI, GUMINSKA, WOJCIECOWSKI, NIKLEWSKI B., NIKLEWSKI M. with their collaborators), of the scientists of the FRG (professor FLAIG with collaborators), of Scottish scientists (professor DE-KOCK), of French scientists (professor CHAMINADE and others) and of Soviet scientists (professors BLAGOVESCHENSKY, KHRISTEVA, KONONOVA, RAKOVSKY, KURBATOV, LARINA, ZABRAMNY, ZEMLANUKHIN, DAGIS, BLUZMANIS and many others) permitted to establish firmly, that the dissoluble humates, a number of vitamins and acids of the cycle Krebs, the polyphenols and their derivatives, that are a part of the soil humus and of the organic fertilizers, have the capability to stimulate the growth of the plants. And here a number of conditions were brought to light, by which the stim-

We have treated the soil with leguminous. Our experiences with straw are made only in small areas. The experiments with leguminous are made in greater areas. Straw does not exist in great quantity in Brazil. The leguminous experiences give very good results. For example, soil treated with leguminous and planted with wheat, a culture very difficult in São Paulo, because it is planted in the dry period, has given a good yield with 85 hectoliter-weight. The other soils, not treated with organic matter, only with fertilizers, gave no yield in 1958, which was a dry year. I think the soil structure is of great importance.

FRANZ

I think in connection with Prof. FLAIG's remark we must distinguish between the different influences of organic matter in heavy and sandy soils. In the heavy soil, the physical properties of humus have much more importance than the sandy soils. In the sandy soils the importance of chemical properties of humus is much bigger and I think this is the same in temperate climates and also in the tropical climates. Probably in the tropical climates the differences are more important than in temperate ones. I would ask Prof. PRIMAVESI for his comments.

PRIMAVESI

You are right Prof. FRANZ.

In my paper I refer to the organic matter like alimentation for meso and microlife. I think this point of view, the organic matter has always importance in sandy and clayish soils.

these matters. In all countries interested in this, I think, in the temperate zones there are none of these problems of soil productivity: in the States, in Austria, in Germany, in France, in Italy etc., here we have a very high crop and grassland production, but in the main part of Latin American countries, we have very small crop and grassland production. It is necessary to increase this production.

We have verified, in the same zone in the same soils, great differences in the relation between soil recuperated and the non-recuperated one. Biologically recuperated soils have given a high yield, the unrecuperated ones with only fertilizer application, low yields. This shows the importance of the biological recuperation of these soils. One point of view is, that the organic matter is alimentation for the micro- and mesolife.

We verified also on several occasions that soils without biostructure and treated with fertilizers only, do not produce well. I think we will ask Dr. BRAMAO to study this question with FAO to organize a program in many countries of the tropics and sub-tropics.

BRAMAO

I would like to congratulate you on your presentation. Concerning a possible participation of FAO in the study of OM throughout the world, your question could be discussed at another opportunity at your convenience, or, perhaps, tomorrow in the general discussion.

You refered in your lecture to the importance of moisture conservation in soils. I believe that organic matter, under tropical conditions, can preserve moisture in certain soils. I would like to ask you if you have experience on conservation of moisture in soils through organic matter.

PRIMAVESI

We have experiences in the State of São Paulo, the State of Minas Gerais, and in the State of Rio Grande do Sul in this matter.

DISCUSSION

Chairman: R. J. SWABY

HERNANDO

I am in complete agreement with your interesting talk regarding the experience we have had in Spain with the use of organic matter and the cultivation of the soil to get better conditions for crop plants.

FLAIG

One can divide the effect of soil organic matter for plant growth in three functions. The first function is the change of different physical properties of the soil; the second would be the influence on chemical reactions in the soil; and the third would be a direct effect, a biological effect, after the uptake of some compounds of soil organic matter on plant growth. You have many experiences under very extreme conditions. In which case would the effect one, two or three be more important than the other. Or is it not possible to say nowadays which of these three types of effect is the most important in the one or the other case.

PRIMAVESI

Really our experiences are realized in determinated conditions. I think this is a good occasion having a specialist from FAO, Prof. BRAMAO, to expedite a world Program of experiences in of growth of root or sprout occurs in concentrations, which are lower one or two power of ten.

The concentration of thymohydroquinone increases in the plants with increasing concentration in the nutrient solution. The activity in the roots is also much higher than in the sprouts. The extraction of roots or sprouts with ether, methanol and finally with water gave the same results as in the case of phenol carboxylic acids.

The highest amount of activity/g dry weight was also in the methanol extract. Free thymohydroquinone was found only in several cases. The main quantity of the activity was fixed in the glucoside of thymohydroquinone, as it could be ascertained by hydrolysis with sulfuric acid or with a glucosidose, thinlayer chromatography and determination of the activity of the separated substances.

Further experiments resulted, that labeled thymohydroquinone is distributed in the whole plant after application of different organs.

The transport follows in acropetal, basipetal and transversal direction in the case of monocotyledones (wheat seedlings) or dicotyledones (mustard seedlings). Furthermore it could be demonstrated, that thymohydroquinone is separated in the nutrient solution by the root (Fig. 10).

2.2.3. *Amino acids.*

Investigations with ^{14}C-labeled amino acids have shown, that these are uptaken as intact molecules and participate in protein metabolism. Mietinen (1959) demonstrated the uptake of labeled alanine, glutamic acid, glycine, serine, valine and leucin from nutrient solution by pea plants. He exposed the roots briefly to nutrient solution with the added amino acids

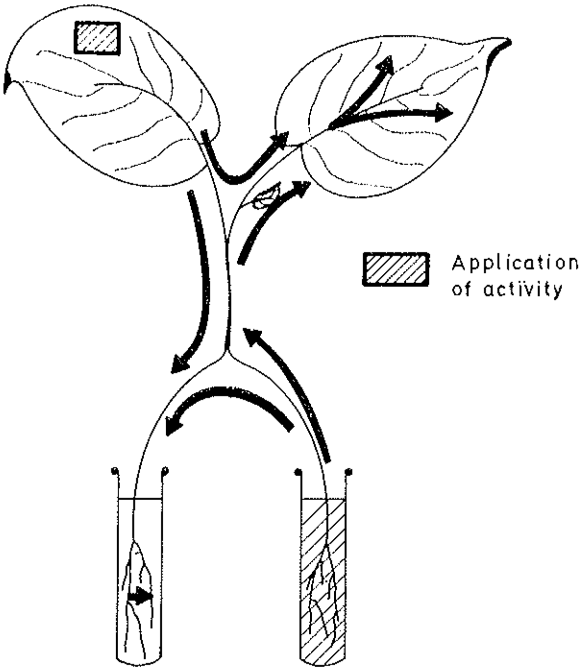

FIG. 10 — Distribution of labeled thymohydroquinone in plants.

and determined the distribution pattern of amino acids of each amino acid in ethanol extracts and hydrolysates of the extracted plant material. MILLER and SCHMIDT (1965) investigated the uptake and the assimilation of glycin-2-C_{14} and β-alanine-1-C_{14} by bean plants from sterile soil: root environments to exclude the effect of microorganisms.

The percentage of the activity of the basic fraction (free amino acid pool) of an extract of the aerial portions with 80% ethanol and that of the unsoluble residue (crude protein) after hydrolysis was as follows:

TABLE 1 — *Distribution of amino acids in the basic fraction of ethanol extract (free amino acid pool) and in the insoluble residues (crude protein) of bean plants treated with labeled amino-acids* (MILLER and SCHMIDT, 1965).

	Glycine-2-C_{14}		β-Alanine-1-C_{14}	
	Basic fraction	Hydrolyzates	Basic fraction	Hydrolyzates
1. Glycine	2.3%	27.9%	0.1%	13.8%
2. Serine	76.1%	30.5%	2.7%	7.6%
3. Glutamic acid	5.4%	7.9%	1.2%	8.1%
4. Theonine	1.6%	6.7%	0.9%	(—)
5. Alanine	2.4%	5.1%	0.9%	8.4%
6. Phenylalanine	0.4%	4.8%	0.3%	8.8%
7. Leucine	0.3%	4.5%	0.1%	3.8%
8. Asparatic acid	7.5%	3.5%	1.0%	5.0%
9. Proline	—	2.3%	—	1.5%
10. Thyrosine	0.4%	1.7%	0.5%	40.9%
11. Methionine	1.4%	1.3%	0.2%	0.2%
12. Asparagine	1.1%	—	—	(—)
13. β-Alanine	—	—	84.9%	(—)
14. others below 1%	ca. 1.1%	ca. 1.8%	ca. 7.2%	ca. 1.9%
Total	100.0%	100.0%	100.0%	100.0%
	Normal plants		Morphological changes	

The assimilated glycine-2-C_{14} was rapidly converted to serine, as it follows from the activity in percent of the basic fraction of ethanol extract. The relative specific activity of glycine-2-C_{14} was also high. More than 50% of the activity in the crude protein was in the amino acids glycine and serine. The growth of plants was normal in this case after 21 days. The dry weight was a little larger than this of the control plant with no N-additions. β-Alanine normally is present in only small quantities in the free amino acid pool of plants and participates in a limited number of cell reactions. Its high relative activity in the basic fraction of the ethanol extract demonstrates its uptake, but none assimilation occurs. The high relative activity of tyrosine in the hydrolysate cannot be interpreted, since only little information is available on the transformation to other amino acids. The effect on morphological changes by the uptake of β-alanine may be explained in different ways, binding of essential metallic ions (McKEE 1962), as antimetabolite (MIETINEN 1959, WOLTZ 1963) or by effect on synthesis of nucleic acids and proteins (WARIS 1962).

Morphological effects on plants have been observed by the action of different physiologically active substances, growth substances and even by the action of fractions of humic substances (e.g. RYPACEK 1962). In the following it will be discussed the mechanism of physiologically active substances only on increase or decrease of the yield of dry matter of plants.

2.3. *About mechanism of uptake and transport.*

Also some preliminary experiments have been made to elucidate the mechanism of uptake (KASTORI, SÖCHTIG and HAIDER 1968, in press). Measurements in the Warburg apparatus have indicated, that respiration of pieces of roots or sprouts is increased by concentrations of thymohydroquinone between 10^{-3} to 10^{-5} molar. The phosphorylation in the sprout was not much influenced, but it was inhibited in the root. According to the P/O-quotients the oxidative phosphorylation was stronger uncoupled in the root, than in the sprout.

Thymohydroquinone shows the same behaviour like 2,4-dinitrophenol (DNP) in concentrations between 10^{-5} and 10^{-6} molar, whereby respiration is more enhanced by DNP than by thymohydroquinone.

Other experiments for elucidation of the mechanism of uptake have shown, that transpiration is decreased by thymohydroquinone. Thymohydroquinone in concentration of 2×10^{-4} molar, which increases drymatter of wheat seedlings, decreases transpiration in mg H_2O/mg dry weight/hour about 25%. Transpiration is inhibited about 15% by addition of DNP in concentration of 10^{-6} molar, and about 35% in the presence of both, thymohydroquinone and DNP.

Experiments with thymohydroquinone at different humidity have shown, that transpiration is decreased with increasing humidity. The transport of thymohydroquinone in the sprout was larger and the content in the root was lower in the case of higher humidity. The transpiration may not effect the process, which determines the rate of thymohydroquinone transport in the sprout, because the amount of activity was larger in the case of higher humidity.

The dry weight of sprout was also increased in the experiment with high humidity; similar results have been established by MICHAEL and MARSCHNER (1962) with oat plants.

Plants treated with thymohydroquinone have a higher percentage of chlorophyll than untreated. If uptake and transport of thymohydroquinone is an active process, which needs energy, it would be possible, that photosynthetic activity is increased by higher production of plant mass, and more energy rich compounds such as adenosin-triphosphate (ATP) are formed by photophosphorylation. To clarify these problems it is necessary to study the influence of humidity on percentage of chlorophyll of plants treated with thymohydroquinone.

In pot experiments it could be shown that the effect of thymohydroquinone results a higher wilting resistance. These experiments have been made by comparison of the addition of different quantities of water to the pots or by growing the plants in different high humidity (SAALBACH 1957). Also some field experiments have shown that the effect of thymohydroquinone on the yield of crop plants depends upon climatic factors. In the case of relatively high rainfall the effect of thymohydroquinone was less than in dry years in humide climate. Similar observations were made with organic nitrogen fertilizers, which have been produced by oxidative ammonification of lignin residues of paper industry (FLAIG and SÖCHTIG 1967).

Furthermore we established that the transpiration of oat and rye seedlings is diminished by addition of thymohydroquinone in concentrations between 10^{-3} to 10^{-5} molar to sand or water cultures (FLAIG and SCHOLL 1960).

Some further experiments have been made to explain the mechanism of uptake by addition of DNPP as an uncoupling substance. DNP in concentrations of 10^{-5} to 10^{-6} molar decreases the uptake of thymohydroquinone in the roots. This may be explained by the lack of ATP as a consequence of the uncoupling of oxidative phosphorylation. Also the dry-matter of the total plants was decreased. While uptake of thymohydroquinone in the root is diminished by increased concentrations of DNP, the transport in the sprout is not much influenced. These findings may be explained by the stronger uncoupling of oxidative phosphorylation in the root than in the sprout.

Addition of ATP increases the uptake of thymohydroquinone in root pieces in nitrogen atmosphere and in the presence of DNP.

The calculation of the concentration in the root results values about 1.5×10^{-2} molar, while the concentration in the nutrient solution is 10^{-4} molar. Therefore the concentration of thymohydroquinone is higher in the root volume than outside in the nutrient solution. Thereby one may conclude, that the uptake of thymohydroquinone in the root occurs against a higher concentration and not only by osmosis.

It can be suggested by the mentioned results, that the uptake in the root and the transport in the sprout are at least partly active processes, which need energy, and depend upon the metabolism of the plant. The mechanism would be computable with the uptake and transport of ions and is also discussed in this sense by AUDUS (1966) in a summary of uptake and transport of other physiologically active substances.

3. POSSIBLE MODES OF ACTION OF PHYSIOLOGICALLY ACTIVE SUBSTANCES ON PRODUCTION OF PLANT MATERIAL

Elucidation of the mechanisms of action of physiologically active substances at the cellular and molecular level needs much more work in several basic disciplines because the different assumption do not explain all observed effects. Also MORELAND (1967) comes to this conclusion in a review about « Mechanisms of action of herbicides ».

3.1. *Influence on RNA and protein synthesis.*

Some authors believe, that growth substances, such as indole-3-acetic acid, have an effect on protein synthesis. ENGELSMA (1967) described the protein synthesis in a simplified form.

$$\begin{tikzcd} \text{DNA} \arrow[r, "\text{transcription}"] \arrow[d, "\text{replication}"'] & \text{RNA} \arrow[r, "\text{translation}"] & \text{proteins (enzymes)} \\ \text{DNA} & & \end{tikzcd}$$

The genetic information is located in the nucleus of each cell in the form of very long chains of desoxyribonucleic acid (DNA). Its role is twofold. By replication a centre of information for a new cell is formed. Furthermore DNA transmits parts of information by transcription to ribonucleic acid (RNA) as a new code. RNA serves now partly as a matrix, for the polymerisation of amino acids in particular sequence, whereby different proteins such as enzymes and others are formed. Formation of DNA, RNA and enzymes determine the speed, at which other metabolic processes occur, and therefore also the concentration of metabolites in the cell. Indole-3-acetic has an influence on these processes by interaction with RNA.

KEY, BARNETT and LIN (1967), MASUDA (1967) and CHERRY (1967) reported at a meeting about « Plant growth regulators » of the New York Academy of Science about the involvement of indole-3-acetic acid or 2,4-dichloro-phenoxy-acetic acid (2,4-D) in the regulation of RNA and/or of protein synthesis to the enhancement of growth; they conclude, that the role played by auxin and other plant hormones is not yet fully to understand. KAUR-SAWHNEY, BARA and GALSTON (1967) demonstrate by their studies with ^{14}C-carboxyl-labeled indole-3-acetic acid, that this is converted to a metabolite, which is bound firmly into the RNA molecule.

The growth is influenced by the concentration of indole-3-acetic acid. The concentration of latter is regulated by the activity of the enzyme indole-3-acetic acid oxidase (HILLMAN and GALSTON, 1957). Monophenols such as p-coumaric acid activate this enzyme, while o-diphenols and closely related substances have an inhibiting effect; therefore e.g. p-coumaric acid inhibits cell elongation and ferulic acid promotes growth (NITSCH and NITSCH 1962).

Otherwise SHANNON et al. (1964) report, that 2,4-D applied to intact corn plants promotes or inhibits growth depending upon the concentrations, but RNase activity, nucleic acid and protein contents increase with a concentration of 2,4-D applied even into the herbicidal range. The authors postulate « that the excessive nucleic acid and protein synthesis induced by 2,4-D would preclude normal cell development and function, and hence might serve as the biochemical basis for herbicidal action ».

In his summarizing paper MORELAND (1967) concludes that the lethality and phytotoxicity are only implied as resultant actions, if one explains the effect of physiologically active substance as an action on nucleic acid metabolism and protein synthesis. No author could explain lethality by implication of a specific interference. In the case of growth substances known as uncouplers of oxidative phosphorylation MORELAND suggests that the observed effects of interference are more related to the unavailability of ATP rather then to direct influence on nucleic acid metabolism and protein synthesis.

According to our experience (FLAIG and SCHMID 1962, 1966, SCHMID and FLAIG, 1962) the dependence of the growth promoting and inhibiting action or especially the lethal effect of physiologically active substances can be explained in the best possible way by the effect on oxidative phosphorylation, which is differently strong uncoupled by the added substance. The extent of uncoupling depends upon the chemical constitution and concentration of the added substances.

The alteration of plant constituents and activities of enzymes are then only secondary reactions in consequence of the uncoupling of oxidative phosphorylation.

3.2. *Influence on oxidative phosphorylation.*

In our studies we were interested to explain the effect of physiologically active substances on the increase of drymatter of seedlings or on the yield of agricultural products. The increase of dry weight is less connected with cell elongation than with a more often cell division per unit of time to produce a higher amount of plant material. Our experiments were not related to morphological alterations of plants. Sometimes effects of physiological active substances on vegetative and generative phase of growth were also observed. We tried to find a working hypothesis to explain the increase of yield of plant by the effect of organic substances which are in soils in form of natural occuring compounds or synthetical added compounds.

During our experiment with different physiologically active substances we observed in the case of seedlings of mono- and dicotyledons that the concentration of metabolites and the activities of enzymes varied, when these substances have been added to nutrient solutions or sand cultures. The alterations depended upon the chemical constitution and the concentration of the added compounds and also upon the environmental conditions. The results are summarized in the next table.

TABLE 2 — *Effect of physiologically active substances on content of plant constituents and enzyme activities.*

Sugar metabolism	
Decrease of starch Increase of soluble sugars	Increased activity of enzymes of sugar metabolism
Increase of pyruvic acid	
Citric acid cycle	
Increase or decrease of some acids	Decreased activity of succinodehydrogenase
Endoxidation	
Increased activity of oxidizing enzymes (SMIDOVA, 1961)	
Transamination	
Partly increased activity of transaminases (CINCEROVA, 1964)	
Increase of respiration and inorganic phosphate	
Decrease of transpiration	
Sometimes increased uptake of K, P and Fe.	

The higher the concentration the stronger were the alterations. But nevertheless an increase of drymatter of seedlings could be observed with each investigated substance at a certain concentration. We used low molecular weight fraction of humic substances, lignin degradation products, their oxidation products such as phenols or quinones, natural and synthetic growth substances and substances from which it is known, that they uncouple oxidative phosphorylation such as 2,4-dinitro-phenol, 2,6-dinitrocresol (Review: FLAIG and SÖCHTIG 1962).

By these experiments with plants and those with yeast we concluded, that physiologically active substances interfere at a central point of the metabolism. Since the glycolysis is less sensible than citric acid cycle, this less sensible than phosphorylation against the action of physiologically active substances, we came to the conclusion, that a weak uncoupling of oxidative phosphorylation may cause the increase of drymatter under certain environmental conditions.

Experiments with mitochondria of rat liver or cabbage (Brassica olera) SCHMID and FLAIG (1962), REINHARDT (1961) have indicated, that these substances, which uncouple oxidative phosphorylation increase the yield of drymatter and sometimes, in the case of cereales also the yield of grains in dependence of concentration.

If the relative P/O-quotients are plotted against the negative logarithm of concentration a dependence exists between uncoupling of oxidative phosphorylation and concentration according to the chemical constitution (Fig. 11). The phenol carboxylic acids are less effective than the hydroquinones or their quinones, these are less effective than the wellknown uncoupling substances such as the nitrophenol derivatives. The natural or synthetic growth substances such as indole-3-acetic, indole-3-butyric or α-naphthyl-acetic acid are effective in concentrations between the phenol carboxylic acids and the quinones. The uncoupling effect is over a larger range of concentration; thereby it may be, that they are called « growth » substances, because the growth promoting effect can easier be confirmed.

In the same order the different substances have also an effect on the yield of drymatter of seedlings in dependence of concentrations by which a weak uncoupling of oxidative phosphorylation occurs.

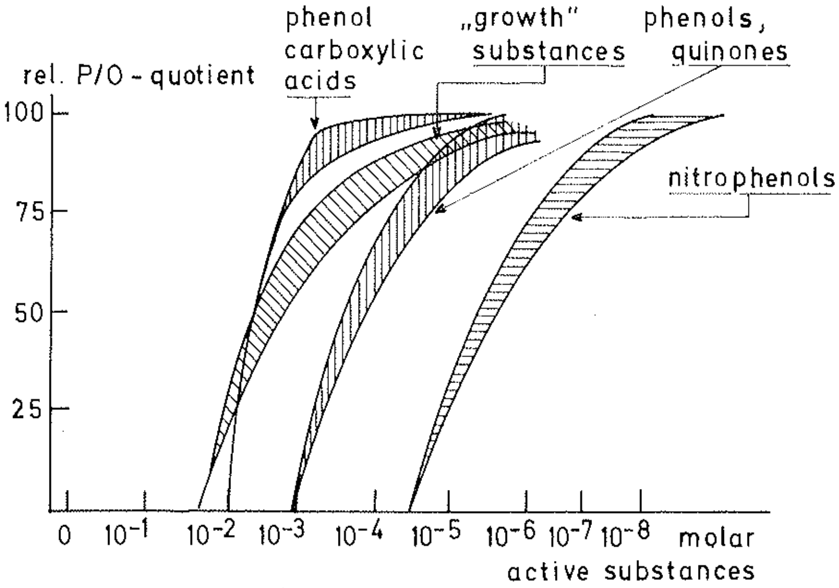

FIG. 11 — Relative P/O-quotients dependent on concentrations.

According to these experiments the explanation of the mechanism of the effect of physiologically active substances on an increased yield of drymatter of plants would be, that the increased inorganic phosphate concentration accelerates all processes, which occur by phosphorylation, and a higher production of monomer building blocks in glycolysis and citric acid cycle is effected. By weak uncoupling of oxidative phosphorylation sufficient adenosintriphosphate (ATP) is present, that polymerisation of monomers can occur to produce plant substances such as cellulose lignin, proteins and lipids. This mechanism is supported by experiments with yeast (FLAIG and DE JONG 1960a, b), and by the result, that plants with increased yield of drymatter by the action of some hydroquinones or quinones contain often a higher content of phosphorus. The increased content of chlorophyll of treated plants may also be a reason of sufficient content of ATP by photophosphorylation.

Also CHRISTEWA (1965) proposes a mechanism throngh energy metabolism, whereby the regeneration of nucleosidtriphosphate from nucleosiddiphosphate is increased and an influence on nucleic acid synthesis occurs.

4. PHYSIOLOGICALLY ACTIVE SUBSTANCES IN SOIL ORGANIC MATTER AS A FACTOR OF PLANT PRODUCTION IN AGRICULTURE?

Several times it has been mentioned, that the effect of physiologically active substances on plants depends not only on chemical constitution and concentration, but also environmental conditions play a role. In literature results are published, which show an effect of humic substances on increase of dry weight. Other authors (compare: STOUT and OVERSTREET 1950) cannot confirm these results. SÖCHTIG (1964) made extensive studies about the dependence of effects of fractions of humic substances, lignin degradation products and other active substances from different environmental conditions.

A summary of the results is depicted in Figure 12.

A maximum of yield is reached, when all growth factors such as temperature, light, humidity, oxygen tensiou in culture medium, concentration of nutrients and others are present in « optimum ». If one or several factors are in too high or too low doses, the yield decreases. The substances mentioned have a greater effect on increasing yield the more growth factors are present in too low or too high doses. Till now we did not observe, that the optimum could be significantly exceeded by the effect of physiologically active substances.

These findings explain the various results of different authors, which worked never under same conditions. Furthermore the results are a contribution to the « humus effect », which is observed by the farmer in spite of inorganic fertilisa-

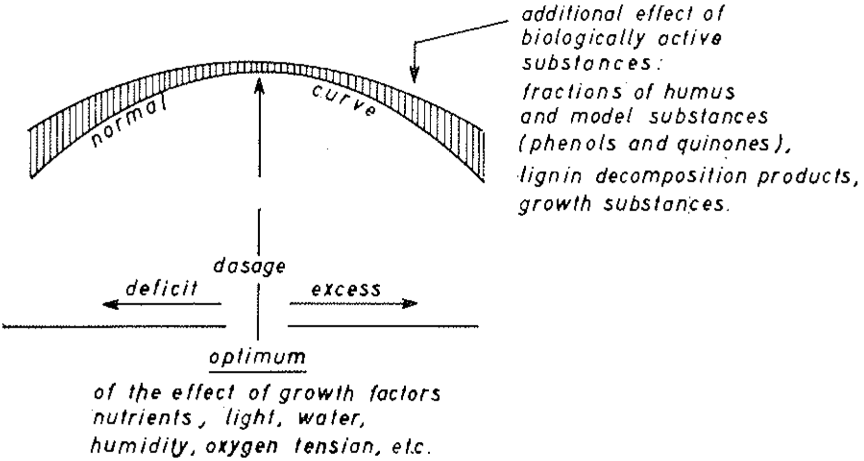

FIG. 12 — Influence of physiologically active substances on the formation of yield during alterations of growth factors.

tion. The influence of physiologically active substances on formation of yield means also a reduction of risk against unfavourable climatic and perhaps other conditions. So for instance RAUHE and LEHNE (1966) established, that the yield on the parcel with stable manure of the experiment « Ewiger Roggenbau » in Halle/Saale did not differ so much by the unfavourable climatic factors since 1879 than on the parcel with NPK. Similar observations are made also by others.

According to preliminary experiments the effects of physiologically active substances on plant growth seem to be more important in countries with extreme climatic conditions, hot temperatures and heavy rainfalls, than in countries with humide climate. The realisation of these results in practice would be interesting together with slow acting nitrogen sources based on lignin residues of paper industry (FLAIG and SÖCHTIG 1967). By microbial decomposition in soils nitrogen as well as lignin or oxidized lignin degradation products could concurrently be released.

To get a clearer insight into the physiological effect of organic substances on plant production and to transfer the scientific knowledge in practice, the efforts of individuals and institutions should be coordinated, because soil organic matter can contribute to protection of soil productivity and therewith to production of sufficient and qualified food, especially in the parts of the world with unfavourable climatic conditions and therefore with low harvest per hectar.

SUMMARY

At first the possibilities of occurrence of physiologically active substances in soil organic matter are mentioned. Then the formation of phenolic compounds from different origin is described.

Labeled compounds are mainly used to prove the uptake of physiologically active substances. For this purpose special experimental techniques are necessary, because also degradation products of the added compounds may simulate an uptake by the plant roots.

Some experiments about uptake of humic substances, phenol carboxylic acids such as lignin degradation products, thymohydroquinone, as a model substance of oxidized lignin degradation products and amino acids are described. The percentage of added compounds is higher in the roots than in the sprouts.

The phenolic compounds are mainly transformed in glucose esters, glucosides or glucose ester of glucosides inside the plant. A part is decarboxylated. The added amino acids are transformed in others.

The uptake and transport of physiologically active substances are influenced by environmental conditions. They have

the more an increasing effect on production of dry weight of young plants, the more the growth factors are not in the optimum.

Some further experiments were made for elucidation of uptake and transport in the plant. The results demonstrate, that these processes need at least partially energy and are comparable with those of uptake and transport of ions.

Furthermore the experiments let assume, that the effect of physiologically active substances on a higher or a lower production of dry weight of plants may better be explained by different uncoupling of oxidative phosphorylation than by an effect on synthesis of nucleic acids and proteins.

The favourable effect of physiologically active substances on plant growth under unfavourable climatic conditions means possibly a reduction of the risk in practice.

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DISCUSSION

Chairman: R. J. SWABY

ALEXANDER

Possibly you can explain to me the mechanism by which you account for the stimulation through an uncoupling of oxidative phosphorylation.

FLAIG

Our working hypothesis is: The formation of building blocks for the high molecular materials of plants is therefore enhanced by the uncoupling of a weak oxidative phosphorylation. A higher phosphate concentration in the cell accelerates different reactions in glycolysis, citric acid cycle etc. During a weak uncoupling of oxidative phosphorylation the content of ATP is high enough to determine the polymerisation of the building blocks to high molecular weight plant material. One must not forget that ATP is not only formed by oxidative phosphorylation. Furthermore it is interesting — we will hear more about this in the paper of Prof. CHAMINADE — that the phosphate content in the plants is higher. Therefore the possibility exists that enough ATP is present for the mentioned reactions in spite of a weak uncoupling of oxidation phosphorylation. A stronger uncoupling of the oxidative phosphorylation causes a decrease in plant growth, and finally the plant dies. This is the effect of 2,4-dichloro-phenoxyacetic acid in higher concentrations and the explanation for its effect as weed killer. With this working hypothesis the increase or decrease in plant growth can be explained.

ALEXANDER

It seems as if you want to have your cake and eat it also, because you want to have ATP formed in order to get polymerization and yet you want to uncouple oxidative phosphorylation in order to get the monomers.

FLAIG

I could not give the data for all the experiments. I told you only something about the plant, but in the case of microorganisms it is possible to uncouple and to stop uncoupling of oxidative phosphorylation. In the case of plants it should not be forgotten that the production of ATP may be increased by photophosphorylation. It was reported that the plant has a higher content of chlorophyll. Furthermore I mentioned the experiments with mitochondria.

PRIMAVESI

These substances, absorbed from the humus are so much alike micro-organic substances as you mentioned, that you had to work in a sterile medium. Do you think that the humic substances are for the most part micro-organic substances?

FLAIG

The reason why we work under sterile conditions is, that microorganisms do not transform the added compounds. If micro-organisms would degrade the added compounds then we would perhaps have an uptake in activity by a no more defined substance. We would find the activity everywhere in the metabolism and could not say what happened. The type of substances with which we worked had been degradation products of lignin, which were found and identified by different authors in soils, in composts and also in cultures of microorganisms, and to which carefully isolated lignin had been added.

PRIMAVESI

Physiologically active substances can be: *a*) directly washed out from the vegetable remaining or radicular excretions or derive from gutation water e.g., of germs of corn or rye; *b*) products of microbian decomposition, specially of proteins and lignins (depending on pH and the ambient in general, its absorption and utilization). We can therefore conclude, based on your paper, that the effect on the development on the vegetable depends on these substances and *not* on the « humus » and that these substances (quinone, phenols and amino-acids), physiologically active, can be derived in the same way from *non* humified organic matter.

FLAIG

If straw is decomposed for instance in a soil or in a model experiment in a climate chamber, then lignin degradation products can be found even after 340 days. These compounds are always formed during the decomposition of straw.

WAKSMAN

Why did Dr. FLAIG introduce in his paper the terminology of « fulvic acid » which is nothing but a soluble lignin degradation product? It was an excellent paper.

FLAIG

Oh, excuse me I believe that I have not mentioned the word fulvic acid. If I have done so I made a mistake which I shouldn't have done.

WAKSMAN

I have been interested as you know in the subject of antibiotics which are now used in all hospitals in the world since they bring about the limitation of growth of bacteria, and of certain other micro-organisms. Unfortunately antibiotics have frequently been used to replace hygiene. To substitute hygiene in the hospital by the use of the antibiotics is very dangerous, and I hope that we are not going to try to substitute soil treatment by the overall use of these organic compounds. Dr. FLAIG emphasized so much the effect of the soil organic matter upon properties of the soil which is not properly handled.

HERNANDO

I enjoyed your interesting talk, but I wish to ask you a question. It was surprising to see in Figure 9 the effect of the light. Is it that with less illumination you get a higher dry matter?

FLAIG

Your question is discussed in the written paper.

HERNANDO

As it is shown by your last slide, the effect of the organic matter products depends on the optimum condition of the different conditions of the medium to grow plants. You get a better effect when the climatic conditions are not the best. I think in relation to these matters one should take into consideration the possibility of two different effects of the organic matter on plant growth, because when we worked with humic acid (I shall show this later) under hydroponic conditions in greenhouses with temperature and humidity controls, we found that with increasing amounts of certain types of humic acid we obtained completely variable results, whereas with increasing amounts of others the growth was decreased. It may be that in your case also there is no relation with climatic conditions, there may be however something inside the product that causes this effect in plant growth.

I was surprised to hear that the potash and phosphate contents increase in the plants with the application of model products to the soil, and that the same happens with regard to iron. We found that with a saline solution the iron content in the plant decreased whereas the effect of chlorosis disappeared. We obtained plants without chlorosis but with less iron content, and therefore there must be some reason to explain that. It may be that there exists a relation between the increase in nitrogen and the decrease in sodium in the plant, as we observed it. It is also most surprising that the sodium content in the plant decreases with the application of humic acid.

FLAIG

In the presence of humic substances the content of potassium and phosphate is very often increased in the plants.

BRADFIELD

I was delighted with this paper for two reasons. I have long been puzzled by two observations which seemed to be conflicting.

1) The highest yields of crops that I have ever been able to attain I got by careful balance of inorganic nutrients in sand cultures free of all but traces of organic matter; 2) I have for years given my students this advice: if in your professional career, a farmer comes to you with a problem that is difficult, he is not getting proper yields for some unknown reason, first probe for the possible reasons. If the reasons are not obvious but you feel you must give him some advice, generally the best you can do in such a case is to advise him to put on a liberal dressing of barnyard manure. Your curve harmonises these two apparently conflicting experiences by showing that high yields can be obtained by properly balanced inorganic fertilization but if there are unfavourable factors known or unknown, organic manures may be more useful. If we work in the optimum conditions we do not observe a statistically significant effect on increase in the yield by soil organic matter. You observe two peaks. This may have different reasons. One must elucidate these reasons and they cannot be explained by such a curve as I have shown it.

[20] *Flaig* - pag. 54

ROLE SPECIFIQUE DE LA MATIERE ORGANIQUE SUR LA NUTRITION ET LE RENDEMENT DES VEGETAUX

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Jusqu'à l'époque récente de l'utilisation des engrais minéraux, le maintien de la fertilité des sols était uniquement assuré par l'apport de matière organique sous la forme du fumier de ferme.

Les Agronomes du début du XIX^e siècle considéraient la matière organique comme la source de l'alimentation des végétaux.

C'est cette conception qui a été exposée à cette époque par l'Agronome allemand THAËR dans sa « Théorie de l'humus ».

Au milieu du XIX^e siècle, LIEBIG publia son ouvrage sur « La Chimie dans ses rapports avec l'Agriculture et la physiologie » dans lequel il exposait de façon très claire la théorie de l'alimentation minérale des végétaux. Les plantes, écrivait-il, se nourrissent d'aliments inorganiques ou minéraux... Le fumier, les excréments des hommes ou des animaux n'agissent pas directement sur les végétaux par les éléments organiques qu'ils renferment, mais indirectement par les produits de leur décomposition.

Les théories de LIEBIG ne furent pas admises sans discussion par tous les agronomes. Une controverse célèbre opposa LIEBIG à BOUSSINGAULT, ce dernier considérant que l'effet fertilisant du fumier de ferme ne pouvait se limiter aux seuls éléments minéraux qu'il renfermait.

Il est incontestable que les principes énoncés par LIEBIG ont permis un énorme progrès de l'Agriculture en ouvrant l'ère de l'utilisation des engrais minéraux.

Toutefois, la théorie de LIEBIG était trop absolue; il est aujourd'hui reconnu que la matière organique joue un rôle dans la fertilité du sol.

Ce rôle est complexe et s'exerce par des mécanismes très divers, d'une part sur les propriétés physiques, physico-chimiques et biologiques du sol et d'autre part, grâce à la présence dans la matière organique en voie d'évolution de substances agissant directement sur la physiologie de la plante.

La bibliographie sur la question est considérable et cet exposé n'est nullement exhaustif.

Il n'abordera qu'un aspect limité de la question en présentant un certain nombre de faits expérimentaux pouvant servir de Thèmes à des discussions.

EFFET SPECIFIQUE GLOBAL DE LA MATIÈRE ORGANIQUE SUR LA FERTILITÉ

Lorsqu'on se propose de mettre en évidence cet effet, il importe que la technique expérimentale permette de dissocier l'effet propre de la fraction organique de celui des éléments minéraux qu'elle peut libérer au cours de son évolution.

De nombreux résultats présentés dans la littérature sont, à cet égard, difficiles à interpréter.

La comparaison, par exemple d'une fumure organique à une fumure minérale apportant la même quantité d'éléments minéraux (N, P, K....) est faussée par la différence de forme entre les éléments.

On peut « neutraliser » l'effet engrais minéral de la matière organique en opérant à des niveaux d'alimentation minérale suffisamment élevés pour que l'alimentation du végétal soit, dans tous les cas, largement assurée.

L'exploration complète de la courbe de réponse d'un végétal à une variable isolée de sa nutrition minérale, les autres éléments étant en quantité largement suffisante, paraît bien adaptée à ce genre de recherche.

Le plafond de la courbe de réponse correspond à la capacité maximum de production du sol dans les conditions expérimentales envisagées.

Nous donnons ci-après quelques résultats expérimentaux inspirés de cette technique.

I. Des essais d'une durée de six années (P. BOISCHOT et Mme G. SIMON, 1958) ont été réalisés en vases de végétation renfermant 10 kg de sol de limon additionnés de 200 g de matière organique (glucose, paille, fumier, foin, sciure de bois) en présence de deux doses d'azote minéral (1,2 et 2,4 g/pot).

Des quantités largement suffisantes d'acide phosphorique et de potasse ont été ajoutées pour que ces éléments n'interviennent pas comme facteurs limitants.

La plante d'expérience était une orge. Les résultats obtenus en présence de fumier ont été les suivants:

RENDEMENTS (INDICES DE COMPARAISON)

		1ère année	Moyenne des 6 années
	Témoin	100	100
Sans fumier			
	1,2 N	309	161
	2,4 N	317	178
Avec fumier			
	1,2 N	529	273
	2,4 N	610	285

Le sol a très fortement réagie à l'apport d'azote minéral; la forte dose d'azote n'a pas donné de résultats significativement plus élevés que la faible dose.

En l'absence de fumier, le rendement plafonne aux environs de 300 en première année et de 170 sur l'ensemble de six années.

Par contre, le fumier fait passer le rendement maximum aux environs de 600 en première année et de 280 sur l'ensemble des six années.

Cette différence ne peut être attribuée à l'Azote ou aux éléments minéraux du fumier, l'alimentation minérale de la plante étant largement assurée. Il s'agit donc bien d'un effet spécifique de la matière organique.

II. Des essais en petits vases de végétation renfermant 1 kg de sol (R. Chaminade, 1960) ont été réalisés pour tester l'influence de la matière organique sur la capacité de production.

Ces essais comportaient l'exploration complète de la courbe de réponse à l'azote en présence de cinq niveaux de P et de K.

Les doses de P étaient de 0, 50, 100, 150, 200 mg de P_2O_5 par pot, celles de K de 0, 250, 500, 750, 1000 mg K_2O par pot.

L'azote était fractionné et les apports, sous forme de $(NO_3)_2Ca$ correspondaient à 0, 40, 80, 120, 160 mg N par semaine.

Tous les vases de végétation recevaient uniformément 500 mg de sulfate de magnésium et une solution d'oligoéléments apportant Mn, Cu, Zn, Bo, Mo.

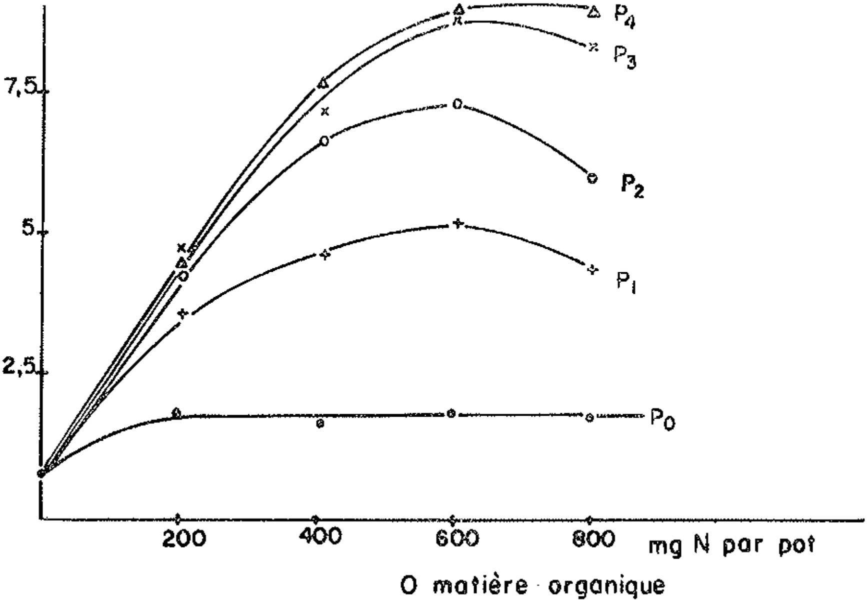
Les essais ont été réalisés sur un sous-sol de limon, très pauvre en matière organique. La comparaison portait entre le sol témoin et additionné de 2% de matière organique sous forme de tourbe fermentée.

La plante d'expérience était un Ray-grass (variété Trianon). Trois coupes successives ont été faites. Les courbes ci-dessous représentent les rendements en matière sèche obtenus (somme des 3 coupes) dans les courbes de réponse à l'Azote, à cinq niveaux de P. La dose de potasse dans ces essais était uniforme et égale à 1000 mg K_2O par pot.

En l'absence de matière organique (Courbes 1) la réaction à l'Azote est faible au niveau Po. Elle s'accentue lorsque le niveau de P augmente. Ces faits ne sont qu'une illustration de la loi du minimum. Les deux courbes P_3 et P_4 sont confondues ce qui indique qu'à partir du niveau P_3 le phosphore n'intervient plus comme facteur limitant.

Le rendement maximum atteint 9,2 g.

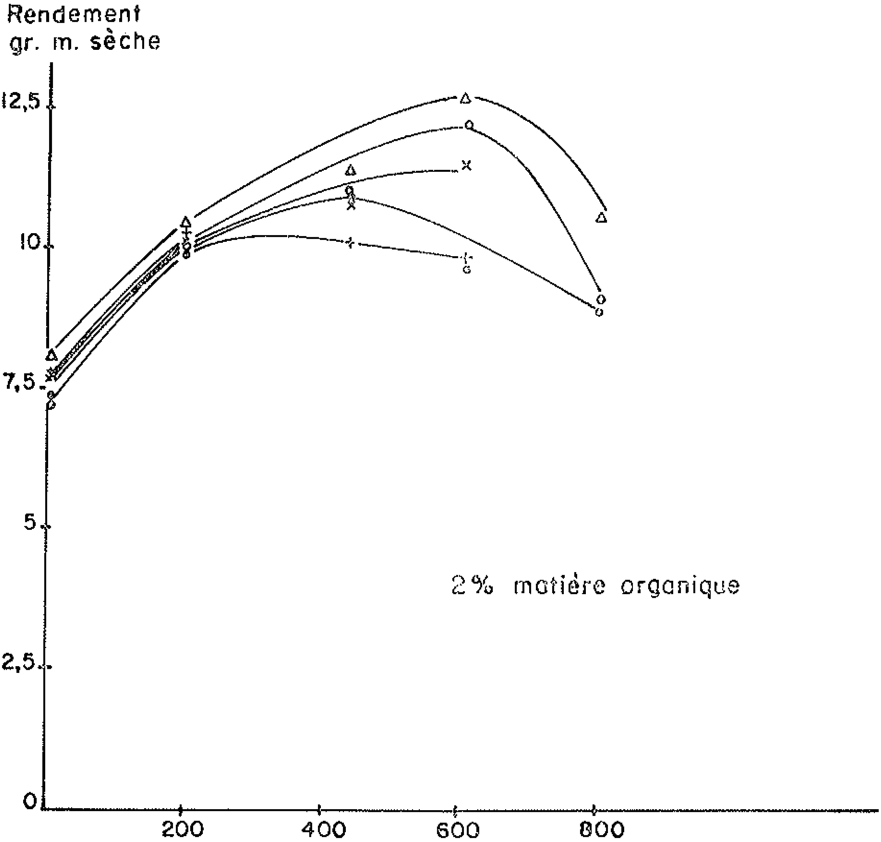
Aucun apport minéral ne peut augmenter ce rendement. La dose 800 de N ne donne en effet aucun accroissement de rendement par rapport à la dose 600. L'identité des courbes P_3 et P_4, montre que l'alimentation phosphatée est assurée



COURBE 1 — O matière organique. Rendements en fonction des apports d'Azote à différents niveaux de P.

à partir du niveau P_3. D'autre part, les autres éléments minéraux ont été ajoutés en quantités suffisamment élevées pour ne pas intervenir comme facteurs limitants.

En présence de matière organique (Courbes 2) l'origine des courbes (Traitement No) se situe à une valeur beaucoup plus élevée. Ceci provient de la fourniture d'Azote par la ma-



Courbe 2 — 2% de matière organique. Rendements en fonction des apports d'Azote à différents niveaux de P.

tière organique ajoutée au sol. La réaction à l'Azote, moins marquée que dans les Témoins sans matière organique, est cependant très nette et le rendement croît jusqu'à la dose de 600 mg N.

Les courbes P_1, P_3, P_4 ne sont pas significativement différentes; la nutrition phosphatée est assurée à partir du niveau P_2.

Mais le plafond de rendement diffère très notablement de celui observé dans les Témoins sans matière organique. Il atteint 12,8 g de matière sèche au lieu de 9,2 g soit une augmentation de 39%.

Il a été démontré précédemment que dans les témoins, le rendement maximum observé (9,2 g) ne pouvait être accru par aucun élément minéral.

On peut donc conclure que la différence observée entre les rendements maxima est bien due à une action spécifique de la matière organique.

EFFET SPÉCIFIQUE DE LA MATIÈRE ORGANIQUE SUR LA NUTRITION MINERALE

De nombreux travaux ont établi que la matière organique sous différentes formes (paille plus ou moins fermentée, acide humique, humates) avait une influence sur la nutrition minérale des végétaux.

R. BLANCHET (1957) a placé des plants de blé cultivés 40 jours en solutions minérales très diluées et ayant acquis des besoins nutritifs intenses, dans des solutions minérales plus concentrées additionnées d'humate d'ammonium à des concentrations de 0, 0,5, 2 et 5 mg/l. Il a constaté que la présence d'humus accélérait considérablement la disparition de la solution des éléments N, P, S et K. Cette action s'exerce de façon massive pendant les premières heures (6 h). Cette première phase correspond à l'adsorption des éléments à la surface des racines.

Au-delà de 12 h il s'établit une vitesse de régime correspondant à l'absorption proprement dite. Celle-ci est également plus grande en présence d'humus.

Des essais ont été réalisés par la technique de Neubauer sur sous-sol de limon (R. Chaminade, 1952) afin d'étudier l'influence de l'humus sur l'absorption des éléments minéraux par la plante. Les essais comportaient un sol témoin, non additionné d'humus et une série d'échantillons recevant 0,125 g d'humate calcique pour 100 g de sol.

Dans tous les cas des éléments minéraux étaient apportés sous forme de solutions, correspondant à des additions de 5, 10, 20, 30 et 40 mg de N, $P_2 O_5$ et $K_2 O$.

Un semis de seigle a été effectuée et les récoltes ont été analysées après 18 jours de culture. Le tableau ci-dessous donne les exportations pour 1 g de matière sèche, déduction faite des éléments apportés par les graines.

D'une façon très régulière, la présence d'humus a accru l'exportation des éléments minéraux.

On trouve dans la littérature de nombreux travaux relatifs à la modification de la composition minérale des végétaux sous l'influence de la matière organique. Les résultats apparaissent assez irréguliers et parfois, apparemment contradictoires.

Ces divergences s'expliquent parfaitement si l'on considère que dans le mécanisme d'action de l'humus se superposent deux faits: d'une part une « stimulation » générale de la croissance des plantes se traduisant pour un milieu de composition minérale définie, par une augmentation du rendement et d'autre part des modifications dans l'alimentation de la plante.

L'augmentation de l'absorption des éléments minéraux par le végétal ne se traduit pas nécessairement par un enrichissement de celui-ci (rapporté à l'unité de poids de matière sèche); l'effet de « dilution » des éléments, consécutif à l'augmentation de rendement peut avoir comme conséquence, l'absence de mo-

Qté d'éléments apportés au sol	N		P_2O_5		K_2O		Ca O		Mg O	
	sans humus	avec humus	sans humus	avec humus	sans humus	avec humus	sans humus	avec humus	sans humus	avec humus
5 mg	0,5	0,7	0,4	0,6	29,3	28,9	4,4	4,9	4,3	4,4
10	0,5	1	0,5	4,1	30	35,4	4,4	5,3	4,4	5,2
20	2,9	3,2	3	3,7	31,9	36,1	4,0	5,3	4,2	4,9
30	4,5	5,7	1,7	4,6	34,3	35,9	4,9	5,2	5,2	5
40	4,2	9,2	4,2	5,1	35,3	42,3	4,7	5,1	5,0	5,3

dification de la composition de l'unité de poids de matière sèche du végétal et même dans certains cas une diminution de la teneur, alors que l'absorption globale a augmenté.

Ces faits demandent une analyse plus approfondie; nous citons ci-après, à cet égard, quelques résultats expérimentaux relatifs au rôle de la matière organique sur la nutrition azotée et phosphatée des végétaux.

I. *Nutrition azotée*

Essais en solutions nutritives. Des cultures de Ray-grass ont été réalisées en solutions nutritives, en présence de doses croissantes de N, tous les autres éléments minéraux étant constants (R. CHAMINADE, 1958).

La composition des solutions était la suivante:

	(mg par litre)
P_2O_5	15
K_2O	100
Ca O	40
Mg O	6
S	38,8

Oligo-éléments:

Solution I:	$S._4$ Mn	0,750
	BO_4H_3	0,075
	SO_4 Ca	0,075
	SO_4 Zn	0,075
	Molybdate Mt_4	0,050

Solution II: Perchlorure de Fe 3^{cc} par litre à 30° B.

Pour 1 l de solution nutritive: 1^{cc} des solutions I et II.

Les doses N (NO_3) étaient les suivantes (mg/l):

1	17
2	27
3	37
4	57
5	77

Le milieu inerte, constitué de quartz broyé était placé dans des pots de polyéthylène percés (dimension 10 × 10 × 13). L'arrosage était effectué journellement par la solution nutritive.

Deux séries parallèles ont été réalisées. Dans l'une d'elles la solution nutritive était additionnée de 2,5 mg/l d'humate de sodium extrait de terreau.

Huit coupes successives de Ray-grass ont été faites. Le graphique ci-contre donne le résultat obtenu (Courbes 3).

Ce graphique montre que, en l'absence d'humus, le rendement plafonne à partir d'une concentration en Azote de l'ordre de 27 mg par litre.

La forte dose d'Azote a un effet dépressif.

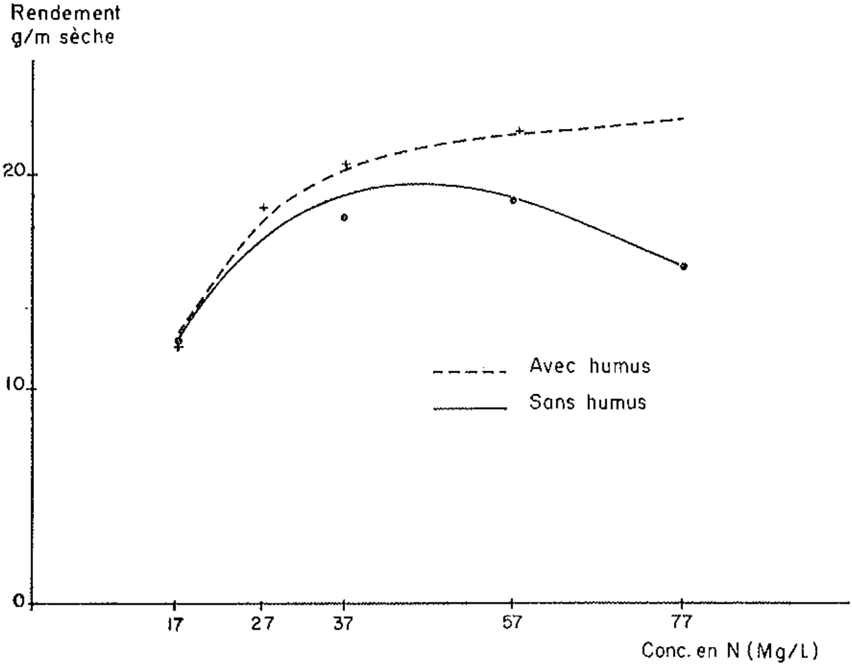
Au contraire, en présence d'humus la courbe de rendement croît avec la concentration sans qu'aucun effet dépressif se manifeste, même pour la plus forte dose d'Azote.

On peut donc conclure que la présence d'humus dans le milieu a permis au végétal d'utiliser l'Azote à ces concentrations plus élevées qui étaient inefficaces ou même toxiques en l'absence d'humus.

Essais sur sols.

Ces essais ont été réalisés en petits vases de végétation (10 × 10 × 13) renfermant 1 kg de sol. Celui-ci était un sous-sol de limon pratiquement dépourvu de matière organique.

Le but de l'essai était d'étudier l'influence d'addition de matière organique au sol sur la courbe de réponse du végétal à l'Azote (R. CHAMINADE, 1963).



Courbe 3 — Rendements en fonction de la concentration en N.

La matière organique était préparée à partir de paille de blé soumise à la fermentation en conditions contrôlées après addition d'Azote.

L'essai comportait la comparaison de paille fermentée pendant des temps variables.

Nous rapportons ci-dessus les résultats relatifs à la paille ayant subi une fermentation de 6 mois à la température de 40°.

L'humification de cette paille était très poussée. La perte de matière sèche, par rapport à la paille initiale, représentait 76%. La quantité de paille fermentée apportée au sol, correspondait à 20 g de paille fraîche pour 1 kg de sol (soit 4,8 g de paille fermentée).

L'essai a porté sur des cultures de Ray-grass (variété Trianon); quatre coupes successives ont été faites. La fumure minérale uniforme pour tous les pots (sauf pour l'Azote) était la suivante:

(pour 1 kg de sol)

0,383 g . . .	PO_4H_2K
1,847 . . .	CO_3HK
1 . . .	SO_4Mg
0,008 . . .	SO_4Mn
0,006 . . .	SO_4Zn
0,008 . . .	SO_4Cu
0,005 . . .	Acide borique
0,005 . . .	Molybdate NH_4

L'Azote était fractionné tout au long de la période de végétation, par addition hebdomadaire d'une solution de $(NO_3)_2Ca$.

Les apports d'Azote correspondaient aux quantités suivantes:

avant la 1ère coupe (en 4 apports):

0, 30, 60, 120, 180, 240, 300, 360 mg N par pot.

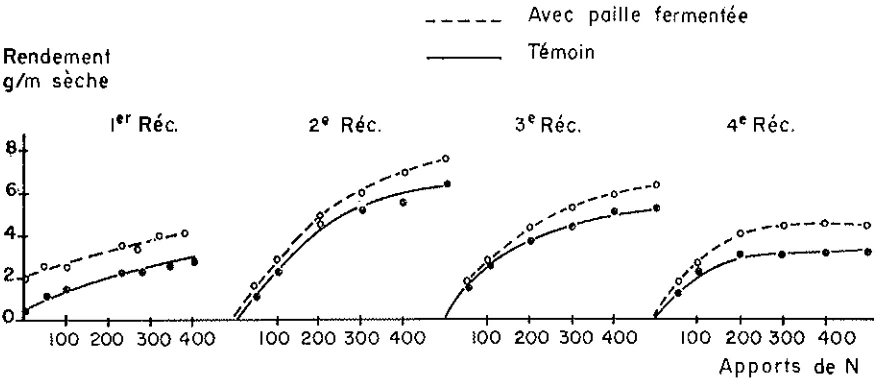
Pour les coupes suivantes (en 3 apports):

0, 50, 100, 150, 200, 300, 400, 500 mg N par pot.

Rendements.

Les courbes ci-dessous (Courbes 4) donnent les rendements en fonction des apports d'Azote.

On voit que, dans tous les cas les courbes de rendement obtenues en présence de matière organique se situent au-dessus des courbes témoin.



Courbe 4 — Rendements en fonction des apports d'Azote.

Nutrition azotée.

Dans les échantillons récoltés on a déterminé la teneur en Azote total par attaque Kjeldahl après réduction des nitrates.

Si l'on trace les courbes des pourcentages en Azote de la matière sèche en fonction des quantités d'Azote apportées, ces courbes ne révèlent aucun phénomène particulier, les teneurs en Azote de la matière sèche étant sensiblement identiques avec ou sans matière organique dans le sol.

Par contre si l'on exprime le rendement en fonction de la teneur en Azote de la matière sèche, les résultats sont très différents. Un tel mode d'expression s'inspire du diagnostic foliaire; il établit une relation entre la croissance du végétal et son alimentation.

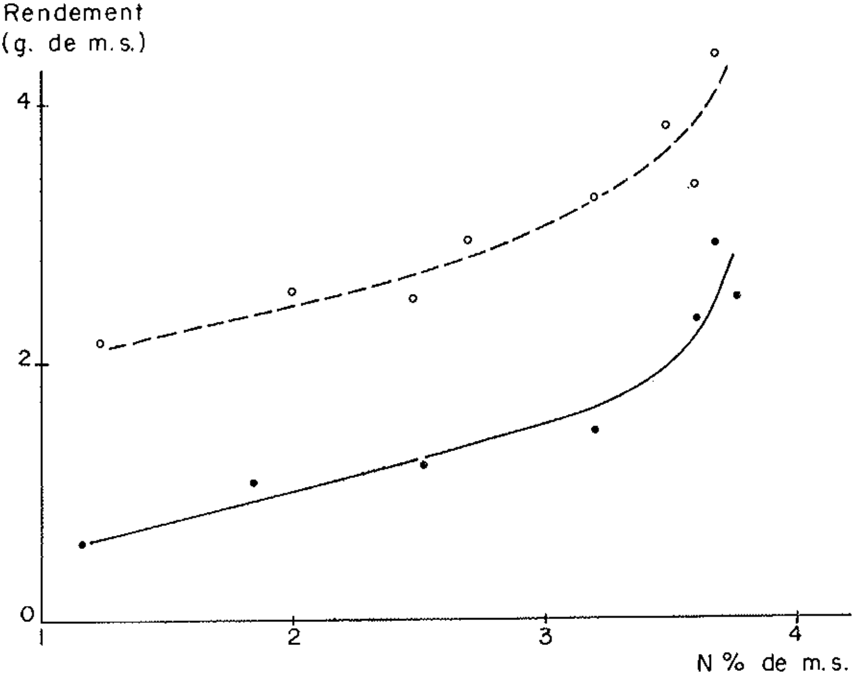
L'exploration complète d'une telle courbe se heurte à de très grosses difficultés expérimentales, surtout en ce qui concerne la fraction de la courbe située près de l'origine. On constate très généralement l'existence d'une fraction de courbe, dans laquelle le rendement croît en même temps que la teneur en Azote, rapportée à l'unité de poids de matière sèche.

Mais, il arrive un moment où la courbe tend vers la verticale, le rendement continuant à augmenter sans modification de la teneur en Azote.

Les courbes ci-contre expriment les résultats de la première récolte (Courbes 5).

Ces courbes révèlent avec une très grande netteté que, à une teneur en Azote donnée, correspond un rendement plus élevé lorsque le sol a reçu de la matière organique; ou, en d'autres termes, que la plante, pour atteindre un rendement défini, a des besoins en Azote moins élevés lorsqu'elle s'est développée en présence de matière organique.

On peut donc en conclure que la présence de matière organique dans le sol a permis une meilleure « utilisation » de l'Azote



COURBE 5 — Rendements en fonction de la teneur en N des plantes.

absorbé, la plante ayant fabriqué, à partir d'une certaine quantité d'Azote absorbé une quantité plus importante de matière sèche.

Les résultats sont exactement dans le même sens pour les récoltes suivantes.

II. *Nutrition phosphatée*

L'addition de matière organique à un sol peut agir sur la nutrition phosphatée du végétal par deux mécanismes très différents:

1) la matière organique intervient directement en modifiant la dynamique du phosphore dans le sol. Elle diminue l'intensité de la fixation du Phosphore par les hydroxydes métalliques ou les colloïdes minéraux du sol et accroît ainsi la disponibilité du phosphore pour la nutrition des végétaux (R. CHAMINADE, 1944);

2) l'effet « stimulant » de la matière organique, phénomène physiologique, se traduit par des modifications dans la croissance du végétal.

Les deux aspects de la question ont été étudiés par S. KUTE (1967).

Cet auteur a étudié la dynamique du phosphore dans trois sols de propriétés différentes: deux sols acides et un sol calcaire. Les sols ont été additionnés d'acide phosphorique sous forme de phosphore monocalcique aux doses de 0, 25, 75 et 225 ppm.

En même temps que l'acide phosphorique la matière organique était ajoutée au sol sous forme de paille broyée à des doses de 0, 1,66 g, 6,64 g par kg de sol correspondant approximativement à des apports de 0,5 et 20 T/Ha. Un apport d'Azote (1 g par 100 g de paille) sous forme de nitrate d'ammonium a été effectuée pour faciliter l'humification.

La terre a été humidifiée à la capacité aux champs. Les échantillons ont été laissés deux mois à la température de 20°.

Après cette période d'incubation les sols ont été placés 6 jours en suspension dans des solutions de Cl_2 Ca N/100 avec un rapport $\frac{\text{sol}}{\text{solution}} = \frac{1}{4}$ et le phosphore ainsi solubilisé a été dosé.

Dans tous les cas, la concentration en P de la solution en équilibre avec le sol, a été accrue par la présence de matière organique. Celle-ci a permis, d'une part un déplacement plus important du phosphore préexistant dans le sol (sol témoin), et d'autre part le maintien en solution d'une fraction plus importante du Phosphore ajouté.

Sur les mêmes échantillons de sol des cultures de ray-grass ont été pratiquées après addition au sol des éléments minéraux, autres que P, en quantité suffisante pour assurer une alimentation correcte des végétaux.

Quatre coupes successives ont été effectuées et la quantité de phosphore exportée par les végétaux a été dosée. Voici les résultats obtenus pour deux des sols expérimentés:

P exporté (mg)

	Sol acide			Sol calcaire		
	Sans m. org	Paille 1,66 g/kg	Paille 4,64 g/kg	Sans m. org	Paille 1,66 g/kg	Paille 4,64 g/kg
P_0	4,92	5,05	5,26	3,37	3,54	4,31
P_1	6,52	7,28	8,19	4,73	5,06	6,44
P_2	10,29	11,43	13,35	7,25	11,83	11,39
P_3	20,73	23,66	22,80	14,5	19,85	24,35

D'une façon très régulière l'apport de paille accroît l'exportation de l'acide phosphorique par les récoltes.

Dans le cas d'un sol acide, très pauvre en acide phosphorique la paille a provoqué, pour les faibles apports d'acide phosphorique, une diminution des quantités exportées par les plantes. Ce résultat aberrant s'explique par une concurrence entre les végétaux et les microorganismes décomposant la paille pour leur nutrition phosphatée.

COURBE DE RÉPONSE AU PHOSPHORE

Cet essai a été réalisé en petits vases de végétation, suivant la technique habituelle, sur sous-sol de limon avec le Ray-grass comme plante-test.

Il comportait deux series: l'une sans matière organique, l'autre avec apport de 20 g par kg de sol de paille de blé fermentée 6 mois dans des conditions contrôlées.

Une fumure uniforme apportait tous les éléments minéraux sauf P (K, Mg, S, oligo-éléments).

L'azote était fractionné par apport hebdomadaire de 120 mg N sous forme de $(NO_3)_2$ Ca.

Les apports de P sous forme de PO_4 H_2 Na correspondaient aux doses suivantes:

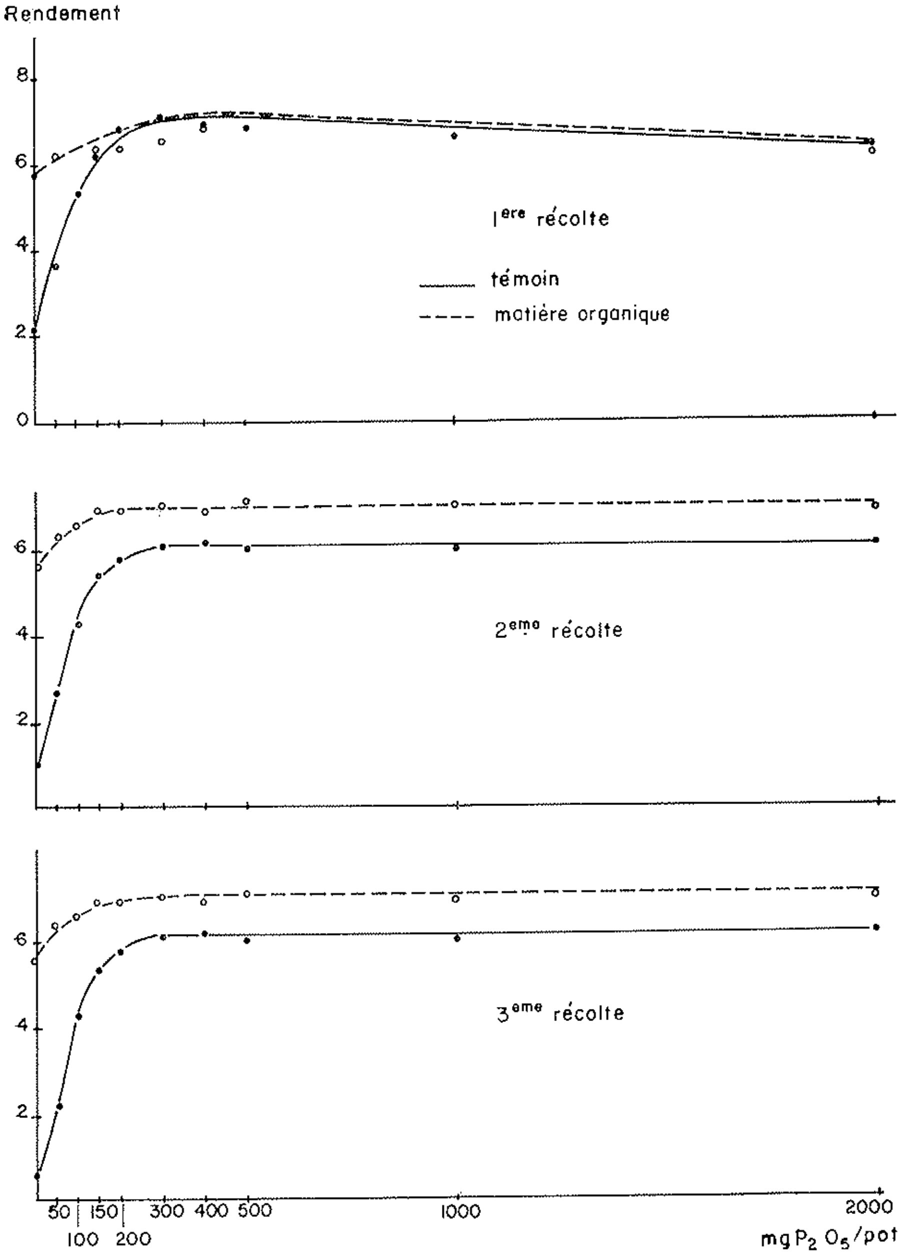
0 - 50 - 100 - 150 - 200 - 300 - 400 - 500 - 1000 - 2000 mg P_2 O_5 par pot (0 à 872 mg de P).

L'essai comportait 4 répétitions.

Trois coupes de Ray-grass ont été effectuées. Les courbes ci-contre (courbes 6) représentent les rendements obtenus pour les trois coupes en fonction des apports de P.

A la première récolte, les rendements en présence de matière organique sont plus élevés que dans les Témoins, pour les faibles apports de phosphate.

Cette différence provient de la présence dans la matière or-



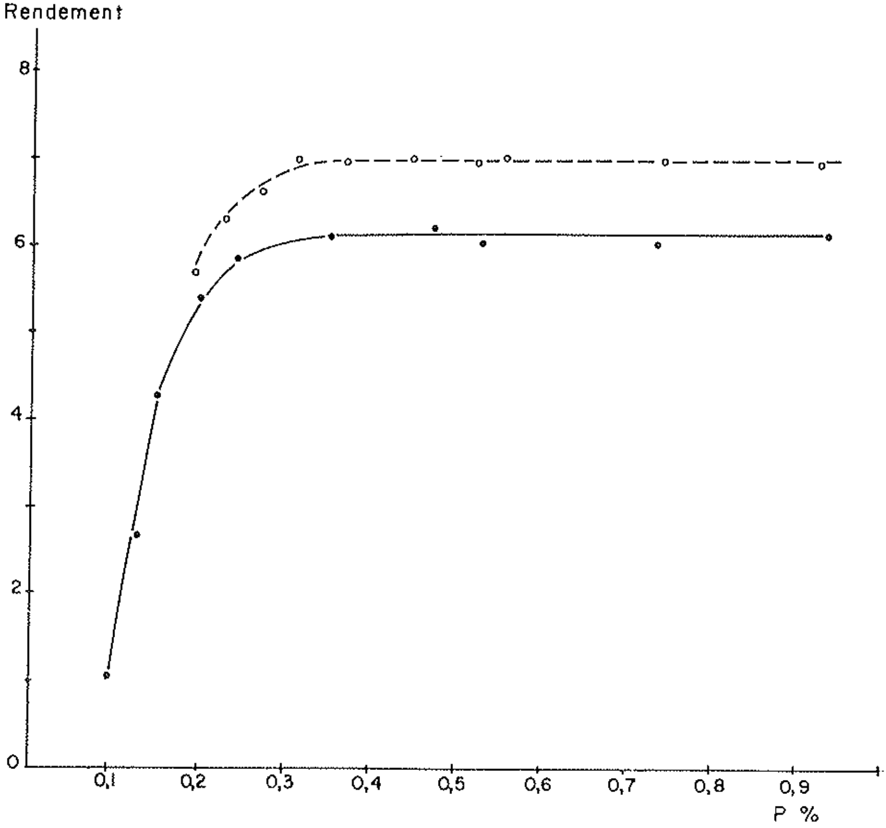
COURBE 6 — Rendements en fonction des apports de P.

ganique d'une quantité notable de P (140 mg P total pour 20 g de matière organique).

En présence d'apports plus importants de phosphates les deux courbes se confondent.

On peut donc dire que, pour cette première récolte, aucun effet spécifique de la matière organique ne s'est manifesté; la matière organique a simplement agi comme engrais phosphaté.

A partir de la deuxième récolte, apparaît une très nette divergence entre les deux courbes.



Courbe 7 — Rendements en fonction de la teneur en P des plantes.

Dans toute la zone où les courbes de rendement sont horizontales, c'est-à-dire dans la zone où la plante ne réagit plus à l'acide phosphorique, le rendement en présence de matière organique reste plus élevé (différence 14,3%).

La différence de rendement ne peut pas être attribuée dans ce cas à l'apport d'acide phosphorique par la matière organique, cette différence se maintenant lorsque l'alimentation phosphatée du végétal est largement assurée. Il s'agit donc bien là d'un effet spécifique de la matière organique.

Le phénomène s'accentue à la troisième récolte l'augmentation de rendement atteignant 20%.

Alimentation phosphatée. — L'acide prosphorique a été dosé dans les végétaux. Nous donnons ci-après les résultats obtenus à la seconde récolte.

P apporté	Témoin		2% de matière organique	
	P % de matière sèche	P exporté (mg)	P % de matière sèche	P exporté (mg)
0	0,095	0,95	0,187	10,6
21,8	0,128	3,38	0,231	14,6
43,6	0,149	6,35	0,270	17,9
65,4	0,199	10,7	0,313	21,6
87,2	0,243	14,1	0,371	25,6
130,8	0,347	21,1	0,454	31,8
174,4	0,470	29,0	0,525	36,0
218	0,531	31,9	0,552	39,3
436	0,736	44,5	0,738	51,0
872	0,934	57,0	0,827	57,0

On peut noter que la différence des exportations, jusqu'à des apports de 130,8 mg par pot reste très sensiblement constante et voisine de 11 mg P.

On sait que la quantité de phosphore apportée par la matière organique correspond à 140 mg $P_2 O_5$ ou 61 mg P.

L'apport de 65,4 mg P sous forme minérale provoque une exportation de 10,7 mg P. Tout se passe comme si le phosphore apporté par le fumier avait eu le même effet qu'une dose identique appliquée sous forme minérale.

Pour analyser l'influence de la matière organique sur l'utilisation du phosphore par le végétal, les courbes du rendement en fonction de la teneur en phosphore de la plante a été établie (Courbes 7). La corrélation rendement-teneur en P apparaît nettement dans ces courbes. Jusqu'à une teneur de 0,4% en P le rendement croît en même temps que la richesse en P.

Cette teneur de 0,4% correspond donc à l'optimum de l'alimentation phosphatée du végétal. Au-delà il y a consommation de luxe de phosphore.

La présence de matière organique ne semble pas modifier l'optimum; mais, dans tous les cas à un niveau d'alimentation phosphatée donné, caractérisé par le pourcentage de P dans la matière sèche, correspond un meilleur rendement en présence de matière organique.

Les deux mécanismes d'action de la matière organique signalés précédemment se retrouvent ici. C'est la superposition de deux phénomènes qui rend l'explication difficile.

Une meilleure « disponibilité » du phosphore pour le végétal sous l'influence de la matière organique peut expliquer les faits observés dans la zone où le rendement est limité par l'alimentation phosphatée.

Par contre, si cette seule explication était retenue, les rendements devraient s'égaliser lorsque l'alimentation phosphatée est largement assurée.

L'expérience montre qn'il n'en est rien; la « stimulation » de la croissance, par la matière organique, liée vraisemblablement à l'action sur des phénomènes métaboliques (respiration, réactions enzymatiques) se manifeste également et est seule responsable des augmentations de rendement lorsque la nutrition de la plante est correctement assurée.

CONCLUSIONS

Les faits expérimentaux exposés sont relatifs à la mise en évidence d'une action spécifique de la matière organique sur la nutrition minérale et le rendement des végétaux.

L'étude des mécanismes physiologiques intervenant dans l'action spécifique n'a pas été abordée dans cet exposé.

Les résultats obtenus montrent que la matière organique doit être considérée comme l'un des facteurs de la fertilité des sols. Sur le plan des conséquences agronomiques, ces résultats apportent des arguments quant à la nécessité de surveiller le bilan humique des sols cultivés et d'adopter les techniques culturales et les systèmes de culture en vue de la conservation des réserves organiques des sols.

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DISCUSSION

Chairman: R. J. SWABY

PRIMAVESI

Prof. CHAMINADE, I would like to say that your data on the tables of your excellent paper are in conformity with our experiences in Brazil. Only, in Brazil we have in special conditions the fact that the application of fertilizers does not give an economic response. Generally, we have the same results like you have shown. We know also the effect of humus on plant nutrition and made the experience that these better nourished plants resist better the drougths than plants from fields without organic matter and active soil structure.

JENNY

In your earlier experiments in which you added humus extracts to solutions, do you know anything about the size of the humus particles? Were they by any chance colloidal?

CHAMINADE

I have no indications on this point.

JENNY

Was humus in colloidal form?

CHAMINADE

Yes.

JENNY

Is there a possibility that this effect could be explained in part by the contact theory?

CHAMINADE

It is possible; I have not given an explanation on the mechanisms of the action. I have given experimental results; it is quite possible that the colloidal state of the humus was responsible in mineral solutions of the effects observed: but in soils, I think it is not possible, because there is a very high fixation of humate by mineral colloids of soil.

BRAMAO

Prof. CHAMINADE, I would like to ask you a question of detail. You explained the curves corresponding to the pots and you said that one represented an experiment without organic matter and the other with 2% of organic matter. Could you kindly explain, as I missed it, the origin and nature of the organic matter used in this particular experiment?

CHAMINADE

I have used 2 types of organic matter. In the first experiments I have described, the organic matter was a peat treated with ammonia and incubated; in the second experiment, the organic matter was straw incubated at 40°C with the addition of water and nitrogen and then incubated for six months. This was an artificial manure made in the laboratory.

FLAIG

I would just like to make a short comment as to whether the humic acids have been colloid or not. It does not really mean much, because if you make experiments in water cultures, the humus colloids are degraded and you get particles with a lower size. They are degraded so that they can also be taken up. We made the following experiment: we electrodialyzed humic acids and afterwards we put them in a tube for dialyzing, closed it at both ends and gave the tube in the nutrient solution. Another part of the electrodialyzed humic acids are given directly in the nutrient solution. In both cases, you have the same effects, because after some time — between 5 and 14 days — the electrodialyzed humic poids which were in the closed tube go through the membrane. The humic acids are degraded by the oxygen which is in the suspension of the humic acids.

JENNY

I should like to see an experiment conducted during 15 minutes, before degradation sets in.

FLAIG

In 15 minutes you have no effect. I told you about some experiments of FÜHR and SAUERBECK. They observed after 15 minutes only an absorption on the surface of the roots.

JENNY

But the ions in the solution could be tagged with radioactive isotopes, and hence their uptake measured.

THE ACTION OF HUMIC ACID OF DIFFERENT SOURCES ON THE DEVELOPMENT OF PLANTS AND THEIR EFFECT ON INCREASING CONCENTRATION OF THE NUTRIENT SOLUTION

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INTRODUCTION

A great number of works have been carried out about humic acid, which show the importance of its effects on plant growth.

The humic acid acts both on the aerial part and on the roots of plants; the results obtained depend on the mineral content of the nutrient medium used, as well as on the level of humic acid applied.

The action of humic acid on the plants is carried out by its active groups (phenols, carboxyls, amines, etc.) which take part in the metabolic processes of the vegetals, that is, the respiration, absorption of nutrients, their synthesis, photosynthesis etc. Therefore it would have a great influence on growing of plants.

Bearing these facts in mind, as confirmed by many researchers (1, 2, 3, 4), we have thought it would be interesting to study the effect, on plant growth, of humic acid from different materials. Thus we have started from two humic acids of quite different origin: farm manure, E, with a humification period of one year, and a peat, T, produced by humification of vegetable residues in a much longer time.

The analysis of these acids [7] gave the following results:

	N %	Carboxylic groups (m.e.) in 100 gr. acid	Phenolic groups (m.e.) in 100 gr. acid
Humic acid E . .	3,4	99	105
Humic acid T . .	1,2	61	193

which show that both the time of humification and the original material, lead to substances of very different functional contents.

We thought that the difference in effect of the different material and types of organic matter: peat, farm manure, compost etc., might be related to the different types of humic acid present. Therefore we started an experiment (the first one in this paper) to study the difference in effect of humic acid in the growth of plants in hydroponic conditions. In this experiment we used as medium of culture the nutrient solution of Hoagland and Snyder [8], and ground quartz as support, to which different levels of humic acid were added.

In order to maintain the mineral fertilization constant and eliminate the phenomena of fixation and absorption of nutrient substances produced in the soil, these experiments were carried out in hydroponic cultures.

We made two more experiments to find out the reducing effect of humic acid on the toxicity of the salty medium on plant growth. The first of these two experiments was developed with solutions of different salt concentrations but always balanced. We also used the Hoagland and Snyder solution with three levels of concentration, single, twice and three times the standard one.

We made the third experiment also with increasing salt levels but unbalanced so as to get conditions more similar to the soil conditions, because in the soils the salt effect is always produced by unbalanced conditions.

The first and second experiments were developed with humic acid in solid state to apply it to the solution to produce a suspension. We did that because we could not find a method to obtain a « molecular suspension ». And this is why these experiments took less time than the third one, in which we could use a « molecular suspension ». This method was developed in our Lab. after the second experiment had already been prepared.

In the third experiment it was possible to use the « molecular suspension », and therefore we were able to continue the experiment until the end of the growing season of the plant, because with the molecular suspension there is no problem to maintain the same concentration of humic acid as long as we need it.

The humic acid was extracted from the farm manure by the TYURIN method [10] and its purification was attained by means of collodion bags.

The molecular suspension of humic acid is obtained by continual stirring and centrifuging in distilled water. The concentration of this molecular suspension is determined by permanganimetry.

These experiments were carried out in a greenhouse with temperature and humidity controls.

The plant used in these experiments was corn (Zea mays).

1st EXPERIMENT

HERE WE USED HUMIC ACID E (EXTRACTED FROM FARM MANURE) AND HUMIC ACID T (EXTRACTED FROM PEAT)

In this experiment we grew the corn for only 34 days.

The levels of humic acid used, and their influence on the weight of the plant are shown on Table no. 1. The values shown here are the mean of four repetitions.

TABLE 1 — *The action of the humic acids E and T on the aerial part and the root of the corn (maize).*

Treatments		Grammes				Δ in percents			
Nutrient solution + mg. A.H./Kg.Cz.	Kind of humic acid	Fresh aerial part	Dry aerial part	Fresh root	Dry root	Fresh aerial part	Dry aerial part	Fresh root	Dry root
0		2,4	0,2	1,6	0,1				
6	E	3,9	0,4	2,4	0,2	58,5	100,0	50,0	100,0
	T	2,0	0,2	1,0	0,07	−16,7	0,0	−37,5	−30,0
12	E	3,1	0,2	1,8	0,1	29,2	0,0	12,5	0,0
	T	2,4	0,2	1,4	0,1	0,0	0,0	−12,5	0,0
24	E	2,6	0,2	2,0	0,1	8,4	0,0	25,0	0,0
	T	1,8	0,2	1,4	0,1	−25,0	0,0	−14,4	0,0
48	E	2,7	0,2	1,3	0,1	12,5	0,0	−18,8	0,0
	T	2,5	0,2	1,2	0,1	4,2	0,0	−25,0	0,0
96	E	3,3	0,3	2,1	0,07	36,0	50,0	31,3	−30,0
	T	2,5	0,2	1,2	0,1	4,2	0,0	−25,0	0,0

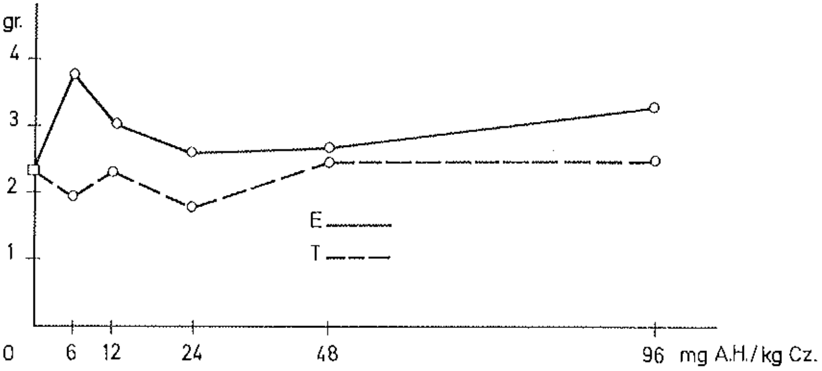
mg. A.H./Kg.Cz. = mg. of humic acid per Kilogramme of Quartz
E = humic acid from farm manure
T = humic acid from peat
Δ = increase
Dry = it means dried with heat air to 60°C.

We have observed that humic acid E brings about definite increase in the development both of the root and the aerial part for treatments of 6 and 96 mg. Whereas the humic acid T produces a minimum for the level of 6 mg. and two maxima for

12 and 96 mg. but always below those obtained with the nutrient solution alone (^{1}) (Graphs, nos. 1 and 2).

With regard to the absorption of elements (Graph, no. 3) we think it is interesting to point out that the humic acids tried out, decrease in general the absorption of potassium they only increase for low levels of application but do not produce a definite effect in the other elements except nitrogen. (See also Table no. 2).

The humic acid E, at every level produces greater absorption of nitrogen (^{2}) while that of humic acid T only produces

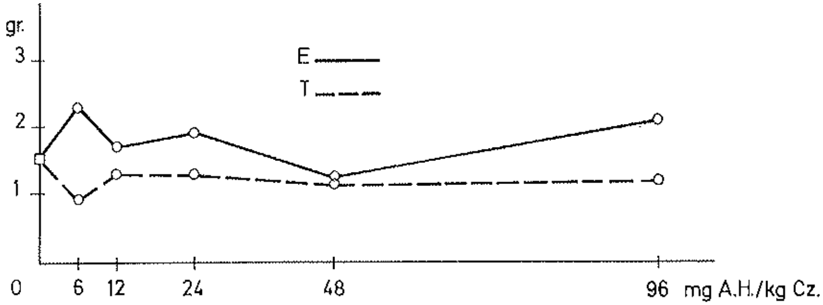


GRAPH. NO. 1 — The action at different levels of the humic acid E (extracted from farm manure) and humic acid T (extracted from peat) on the weight of the aerial part of the corn (Zea mays).

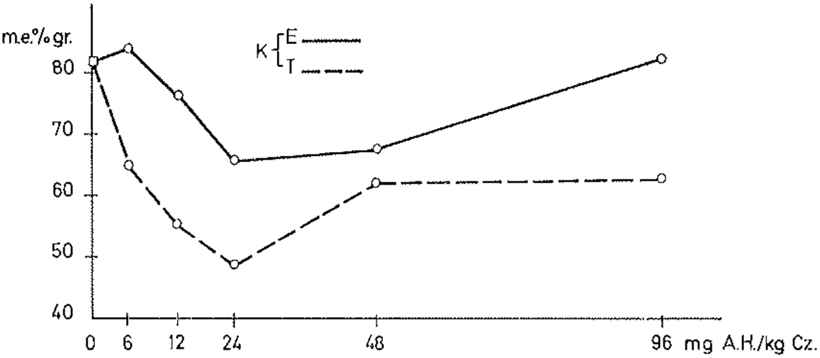
(^{1}) The statistical study shows that the differences in weight obtained between the nutrient solution alone, and with the levels of 6 and 96 mg. of the humic acid E (E_6 and E_{96}), are significant, whereas none of the differences is significant in the results obtained with the nutrient solution alone, and with the different levels of the humic acid T.

Very significant is the difference in response of plants to the treatment of E_6 and to every T level used. On the other hand, there is also a good significance between treatments E_6 and E_{24}.

(^{2}) This coincides with the results obtained by KHRISTEVA [9] and CHAMINADE [2] on the utilization of nitrogen by the plants in function to humic acid.



GRAPH. NO. 2 — The action of different levels of the humic acids E and T on the weight of the roots of the corn.



GRAPH. NO 3 — Potassium contents of the corn plants grown with different levels of the humic acids E and T.

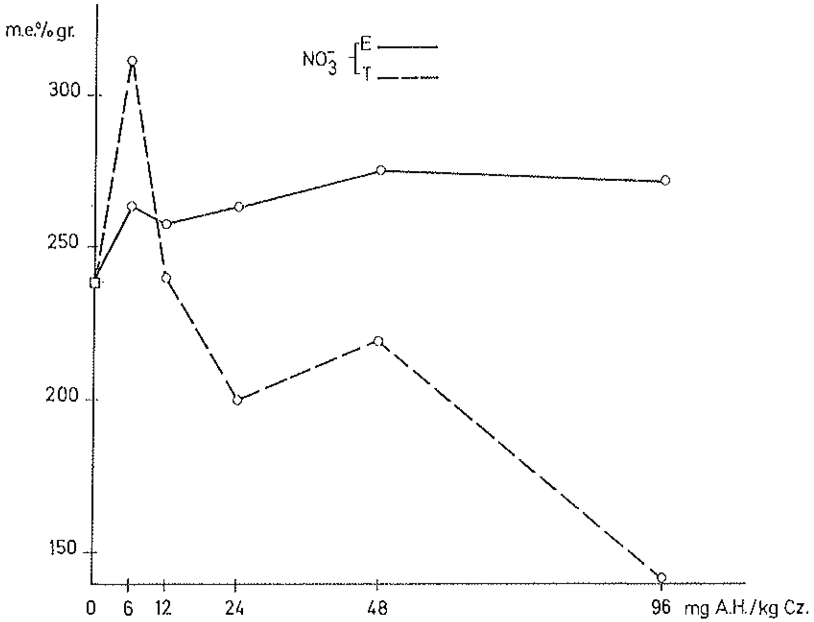
TABLE 2 — *The action of the humic acids E and T on the mineral contents of the aerial part of the corn (maize).*

Treatments		m.e. % gr. of the dry aerial part				
Nutrient solution + mg A.H./Kg.Cz.	Kind of humic acid	NO_3^-	$PO_4^{\equiv}$	K^+	Ca^{++}	Mg^{++}
0		239	10,0	82	30,0	46,0
6	E	264	11,0	85	33,7	44,1
	T	312	16,0	65	35,0	48,0
12	E	258	15,0	80	32,0	38,3
	T	240	12,0	59	36,0	32,5
24	E	264	18,9	66	30,0	32,1
	T	200	15,0	49	42,0	38,8
48	E	276	9,5	68	30,3	52,0
	T	220	14,0	63	36,0	34,3
96	E	273	16,0	84	35,0	48,2
	T	143	13,0	63	32,0	30,3

mg. A.H./Kg.Cz. = mg. of humic acid per Kilogramme of Quartz
E = humic acid from farm manure
T = humic acid from peat

it at the treatments of 6 and 12 mg., and the effect is the contrary at other levels. (Graph. no. 4).

We think that this difference in the behaviour of the corn with the treatments of humic acids of both sources is due to the different action on the plant metabolism of the acids tried out.



GRAPH. NO. 4 — Nitrate contents of the plants of corn growth with different levels of the humic acids E and T.

The mechanism of the action of humic acid on metabolic phenomena of plants, is very difficult to explain. There are several theories which we present briefly in the following paragraphs (6, 8, 10, 11).

a) Hypothesis of the formation of complexes between humic acid and mineral ions.

b) Hypothesis that considers the presence of free humic acids to produce an increase in cellular permeability).

c) Hypothesis founded on the metabolic activity of quinonic groups contained in humic substances and on the influence of the latter on the activity of different enzymes.

d) Hypothesis according to which the humus provides the plant with growth factors (vitamins and auxins).

As these different hypothesis only solve partial aspects of the action of humic acid on the plants and in order to explain the results obtained in the experiments carried out in this research, we have developed the following hypothesis:

ACTION OF HUMIC ACID ON PLANT GROWTH

The development and consequently the increase in weight of the plant, is the result of the two most important effects of the humic substances:

the action on respiration,
the action on synthesis and photosynthesis.

Let us consider how humic acid acts upon each of these physiological phenomena.

The humic acid molecules are formed fundamentally by two parts. One of them consists of a series of quinonic and phenolic groups, forming a « redox » system. This system acts upon the phenomena of oxo-reduction that take place in the plant metabolism and thus the respiratory intensity of the plants increases and in consequence, there is a decreasing of oxygen in the medium.

The other part of the molecules is formed by a mixture of nitrogenous compounds, principally amino acids and proteins, which confer an enzymatic character. The enzymatic reactions are catalytic reactions, therefore the enzymatic action of humic acid on the photosynthetic processes can be developed from very low levels of application of the acid. These increases in photosynthesis and synthesis produced by humic substances, being catalytic actions, are not in direct relation with the amount applied.

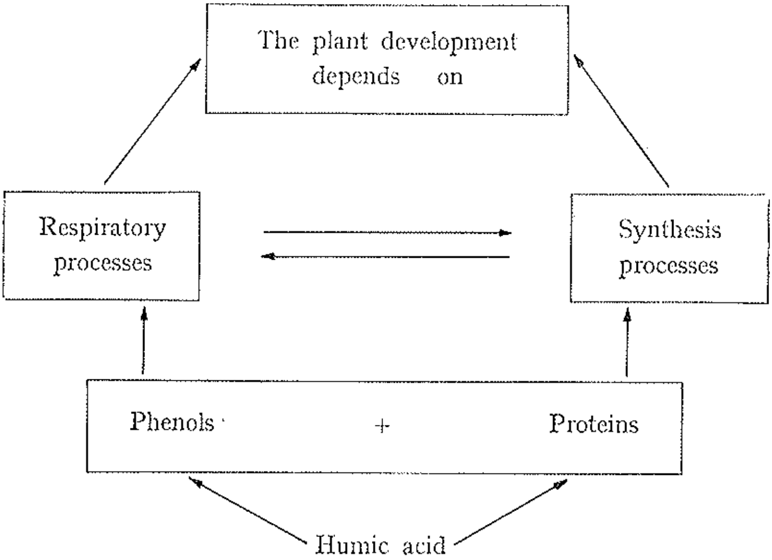
The actions of humic acid on the respiration of plants are oxydation processes in relation with phenolic groups; and because of that, the respiratory phenomena of the plant can be increased proportionally within certain limits, when the amount of humic acid is increased.

However, we must take into account that, even if the increase in the respiratory processes are very favourable for the development of the root system, the acceleration of mineral and carbon nutrition, the influence on the absorption and transpiration of the water, etc., we must not forget that these respiratory processes are performed at the expenses of a consumption of reserve substances of the plant, therefore an excess in the increase of those processes will bring forth a diminution in the weight of the plant both by consuming a great amount of reserve substances and by producing a desequilibrium in the metabolic processes, and especially because this increase requires a better aeration and if the latter does not occur we can get troubles in the growing of plants.

Therefore this action of the humic acids on the respiration, which at low levels is beneficial, if applied up to certain high limits can become pernicious.

The respiration processes, as well as those of photosynthesis and synthesis do not act upon the plant development in an independent way, but are intimately related and depend directly on each other. Therefore, any action applied on one of them, will necessarily affect the other. That is, in order that the plant development follows a normal course, the activities of both processes must be related in a certain way or, in other words, there must be an equilibrium between the activities of both processes so that when the equilibrium becomes unbalanced in either direction, the plant development will undergo a series of troubles in its metabolic processes, and in consequence, a diminution of its development.

Schematically it can be shown thus:



We can see here how the humic acid acts upon the plant development through the equilibrium that exists between respiratory processes and those of synthesis.

Whenever the humic acid acts upon both processes in a way that if no unbalance appears in either of them, its action results in an increase of the plant growth. On the contrary, the action that predominates on either of the two processes will bring forth a desequilibrium and consequently a diminution in the growth of the plant.

Therefore, the application of very low levels of humic acid will produce an increase in the synthesis processes (catalytic action produced by very small levels), however, the respiratory processes will increase little, but consequently there will be an increase in the plant weight as can be observed in the results.

For certain levels of application of humic acid E, such increases must be produced in both processes that the equilibrium subsists together with a higher activity in both, therefore, for such treatments the result is an increase in the production of vegetal matter.

This higher activity in both processes implies a higher absorption of nutrients on the part of respiration, if the aeration conditions are sufficient, and on the part of synthesis the possibility (as having more activity) of a quicker utilization of nutrients for the building up of a higher amount of matter in the same lapse of time of plant growth.

When the levels of application of humic acid are increased, the processes of photosynthesis and the enzymatic ones do not increase proportionally, whereas the respiration processes do, and consequently a metabolic unbalance appears, which causes a diminution in the production. Within the limits of the levels of humic acid producing the functional metabolic unbalance, the plants may experience fluctuations in the yield, that is what has been observed in the results. Anyway, it is possible to get a new equilibrium increasing the quantity applied as it is observed for the level of 96 mg. humic acid E.

The humic acid T does not produce an increase in the plant growth, it seems to be due to a lower percentage of nitrogen compounds and at the same time has almost twice the number of phenolic groups, which produces a desequilibrium for each level used.

With this humic acid, a higher absorption of nitrates only occurs in the case of very low levels (6 mg./Kg. quartz), most probably due to the action on the respiratory process, although it is not balanced with the enzymatic activity, and thus no increase in weight is observed.

EXPLANATION OF THE DIFFERENT BEHAVIOUR OF THE HUMIC ACIDS STUDIED

As a consequence of the fact that humic acid T is richer in phenolic groups and poorer in nitrogen compounds than humic acid E — as shown by the analysis mentioned before — the action of both acids on the metabolic phenomena which affect the plant development, must be different.

At similar levels of application of both humic acids, the plant will uptake different amounts of activating groups of both the enzymatic and the respiratory functions, so that the optimal level of application of both acids will be different. This is what happens in fact, as with a level of 6 mg. of humic acid E we can obtain an increase in the production of 58,5% while an application of 96 mg. of humic acid T is necessary to obtain an increase of only 4,2%.

Among the levels of both humic acids tried out these are clearly the two ones which provide the plant with amounts of active groups that increase, not only the respiratory function but also, those of synthesis in a balanced way, what results in an increase in production.

For both acids, the other levels cause functional desequilibrium and, consequently, a decrease of production in relation to the optimum, but in the case of acid E, are always higher than the results obtained without applying the acid, whereas in the case of humic acid T these desequilibria are so strong that the production is lower than that produced in absence of this acid.

Therefore, and as shown on Graph. no. 1, according to the levels of application of the acids, there is a whole series of fluctuations in the yields.

They are due, mainly to the fact that, when varying the quantities of both acids, the actions produced by the humic acids are not proportional to the amounts applied as the effects on plant development is the result of the additional effects of the different components of the humic acid used.

In this work, the different behaviour of the two humic acids applied has been clearly put forward, as both the uptake of nutrients as their synthesis are completely different, which we ascribe to their different composition in phenolic groups and nitrogenous compounds, trying to explain the results obtained with the hypothesis we suggest.

2nd EXPERIMENT

EFFECTS PROVIDED BY HUMIC ACID EXTRACTED FROM FARM MANURE ON CORN GROWING IN NUTRIENT SOLUTION OF HIGH BALANCED MINERAL CONCENTRATION

Considering that humic acid can reduce the toxicity caused on the plants by the salt, we prepared this second experiment to find out if humic acid can produce a higher yield of plants with a higher mineral concentration than the normal solution.

Due to the fact that in the first experiment the action of humic acid E from farm manure was much more efficient than the humic acid T from peat, we thought it interesting to make this experiment by using only humic acid T.

We have used similar levels of humic acid as in the previous experiment and have tried them out with the HOAGLAND and SNYDER nutrient solution at single (SN), twice (2SN) and thrice (3SN) the normal (1) concentrations. The solution is thus always balanced but the concentration varies. The solutions have respectively: 1·80, 3·37 and 10·10 millimhos/cm.

The plant used is also corn but the growth period in this case, was 80 days.

---

(1) Standard.

RESULTS OBTAINED

As we can observe from Table no. 3, the aerial part of the corn grown with humic acid in nutrient solutions of high mineral concentration, does not weigh more than those obtained with nutrient solution of a normal concentration without humic acid, which shows that the action of humic acid on plant metabolism is not able to remove completely the depressive effects produced by the high mineral concentration used, in this experiment.

But what we do observe is that plants treated with humic acid and high mineral concentrations are mostly of greater weight than those not treated with this acid.

The beneficial action of humic acid on the weight of the aerial part of the corn obtained with nutrient solution of concentration twice the normal with different levels of humic acid is clearly shown by the statistical study of the results.

It is interesting to point out the great influence of the humic acid levels on the development of the corn, which is clearly shown on Graph. no. 5.

We can also observe clearly that with the three nutrient solutions used, the action of humic acid is not a function of its concentration in the medium.

Here are three peaks at 6, 24 and 96 mg., with the exception of the most concentrated solution (3SN) in which the second peak is displaced to a higher level (48 mg.) and the third does not appear. Perhaps the third peak might appear at higher concentration of humic acid.

These peaks, according to the hypothesis given before, correspond to concentrations of humic acid in which both the action on respiration and enzymatic one are balanced.

The effect of the highest concentration in salts is to reduce the peaks and even displace them (3SN).

In the roots, the same effects are observed but less markedly.

TABLE 3 — *The action of humic acid in balanced nutrient solutions of a high mineral concentration on the corn.*

Treatments		Grammes				Δ in percents			
mg. A.H./Kg.Cz.	Nutrient solution	Fresh aerial part	Dry aerial part	Fresh root	Dry root	Fresh aerial part	Dry aerial part	Fresh root	Dry root
	SN	91,0	9,2	37,7	3,7				
0	2SN	70,6	7,5	27,2	2,5				
	3SN	53,8	5,5	23,0	2,7				
	SN	100,2	10,8	39,2	5,1	10,1	17,4	4,0	38,0
6	2SN	77,9	8,0	31,5	3,3	10,4	6,7	15,8	32,0
	3SN	61,0	6,1	29,0	2,9	13,4	10,9	26,1	7,4
	SN	87,0	9,3	30,4	4,5	—4,4	1,1	—19,2	21,6
12	2SN	77,4	8,0	29,1	3,3	9,6	6,7	7,0	32,0
	3SN	55,7	6,3	23,6	2,9	3,5	14,5	2,6	7,4
	SN	97,6	10,2	33,7	5,1	7,3	10,9	—10,6	38,0
24	2SN	82,7	8,9	34,6	4,4	17,1	18,7	28,2	76,0
	3SN	53,8	5,5	24,1	3,2	0,0	0,0	4,8	18,5
	SN	91,4	11,0	32,4	4,5	0,4	19,6	—14,0	21,6
48	2SN	73,8	7,2	28,4	3,1	4,5	—4,0	4,4	24,0
	3SN	55,5	5,9	25,0	2,8	3,2	7,3	8,7	3,7
	SN	92,0	11,1	29,9	4,7	1,1	20,6	—20,7	27,1
96	2SN	83,4	8,6	35,6	4,4	18,1	14,7	31,0	76,0
	3SN	37,4	4,2	16,1	2,2	—30,5	—23,6	—30,0	—18,5

mg. A.H./Kg.Cz. = mg. of humic acid per Kilogramme of Quartz
SN = Normal nutrient solution
2SN = Nutrient solution twice the normal
3SN = Nutrient solution thrice the normal
Δ = increase

With respect to the absorption of nutrients only in the uptake of nitrates is observed a similar behaviour to the one of plant weight, which means there exists a quantitative relation for the same concentration of the nutrient solution, between the uptake of nitrates and the production.

This is not true with different concentrations because the uptake of nitrates is higher (Graph. no. 6) for higher concentrations of the medium and in these cases the yields are lower (Graph. no. 5). But if, instead of the m.e. of nitrates % grammes of plants we consider the totals absorbed, then the relationship keeps on, as the production being lower, the total amount of nitrates absorbed is also lower (Table no. 4).

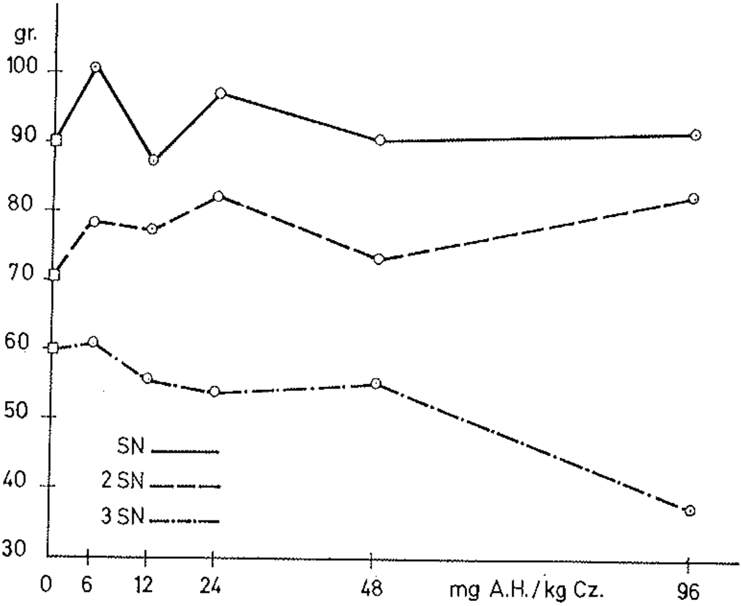
For the other elements no important differences are appreciated in general with the levels of humic acids applied. Only that humic acid produces a greater uptake of them, increasing the respiratory process, independently from a higher plant growth be attained or not, which is logic, because in the plant weight as we saw before only the sum of the respiratory and enzymatic effects appears.

An exception is the case of sodium, because there exists a tendency to diminution in the aerial part contents by the presence of humic acid which is very favourable in practice. This case is the only one in which the percentages absorbed are lower when the concentration of the medium is higher (Table no. 4).

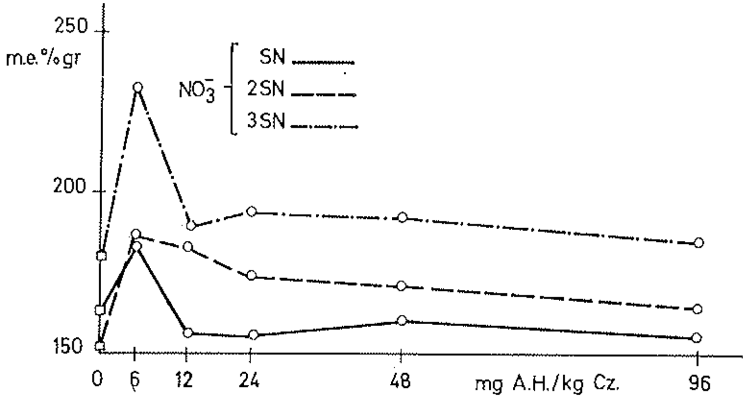
All of these results usually present the opposite when considering the root (see Table no. 4).

ACTION OF HUMIC ACID ON THE EFFECTS OF TOXICITY PRODUCED BY THE HIGH MINERAL CONCENTRATIONS IN THE BALANCED NUTRIENT SOLUTIONS

The high mineral concentrations of the solutions used, produce a series of toxic effects as we can appreciate in Fig. 1.



GRAPH. NO. 5 — The action of different levels of humic acid on the weight of the aerial part of the corn plant grown in nutrient solution of a single (SN), twice (2SN) and thrice (3SN) the standard concentration.



GRAPH. NO. 6 — The action of different levels of humic acid on the nitrate contents in the corn plant grown in nutrient solution of a single (SN), twice (2SN) and thrice (3SN) the standard concentration.

TABLE 4 — *The action of humic acid in balanced nutrient solutions of a high mineral concentration on the mineral contents of the corn.*

Treatments		m. e. % gr.												Aerial part
		Dry aerial part						Dry root						
mgA.H./Kg.Cz.	Nut. sol.	NO_3^-	$PO_4^{\equiv}$	K^+	Ca^{++}	Mg^{++}	Na^+	NO_3^-	$PO_4^{\equiv}$	K^+	Ca^{++}	Mg^{++}	Na^+	$E_{NO_3^-}$
0	SN	164	15,5	120	30,5	33,6	1,4	106	9,3	84	60,0	48,4	1,8	15,1
	2SN	153	18,2	140	23,8	30,0	1,3	113	21,5	114	56,0	31,0	1,2	11,5
	3SN	178	21,5	157	31,0	29,8	2,3	122	34,0	120	71,0	27,2	1,3	9,8
6	SN	184	14,0	109	28,0	37,0	0,9	57	7,0	56	40,0	38,9	1,4	19,9
	2SN	187	18,4	146	30,0	34,7	1,1	97	21,2	98	63,0	34,6	1,7	15,0
	3SN	234	21,3	165	35,0	33,1	1,3	124	28,3	120	57,0	25,5	1,3	14,3
12	SN	156	15,0	146	37,0	42,4	1,4	94	10,1	72	55,0	43,4	1,3	14,5
	2SN	184	22,7	144	31,0	33,3	0,8	92	16,2	108	40,5	27,3	1,6	14,7
	3SN	190	22,5	162	31,5	30,4	1,0	144	40,2	120	86,0	20,2	2,2	12,0
24	SN	156	15,2	125	29,7	42,2	0,6	64	7,2	49	42,2	38,0	2,1	15,9
	2SN	175	18,7	148	32,3	36,3	1,7	97	16,2	104	57,0	30,0	1,7	15,6
	3SN	195	24,0	164	35,0	28,7	1,9	134	32,7	122	72,0	26,6	1,8	10,7
48	SN	161	15,0	111	29,0	35,5	1,0	85	7,5	71	59,0	36,7	1,5	17,7
	2SN	172	20,5	156	34,0	32,2	1,1	110	19,2	113	60,0	35,2	1,7	12,4
	3SN	193	23,7	160	37,7	33,7	1,1	117	31,0	132	67,0	28,0	2,0	11,4
96	SN	156	15,0	110	30,5	36,3	0,8	74	7,5	55	55,0	43,0	2,0	17,3
	2SN	165	19,5	147	37,5	31,6	0,8	85	15,0	115	58,0	32,4	1,8	14,2
	3SN	186	25,0	157	40,5	28,0	0,6	163	32,5	120	67,0	22,1	2,1	7,8

mg. A.H./Kg.Cz. = mg. of humic acid per Kilogramme of Quartz
SN = Normal nutrient solution
2SN = Nutrient solution twice the normal
3SN = Nutrient solution thrice the normal
$E_{NO_3^-}$ = Total nitrogen uptake by the corn, expressed conventionally as nitrate

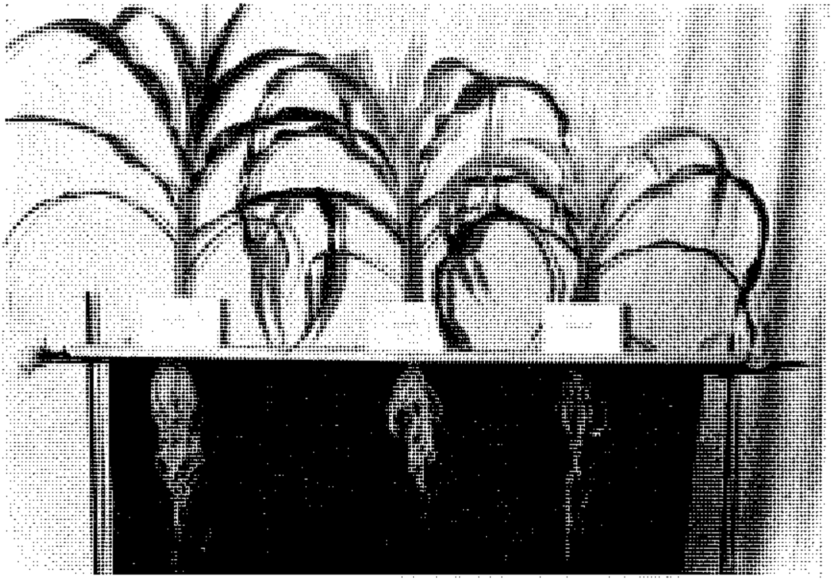
There we observe a diminution of the plant development as the mineral concentration of the solution increases. The diminution in the weight of the aerial part is a consequence of the shortening of internodes, caused by an excess of phosphorus absorbed. (Table no. 4).

The plant submitted to the action of 2SN and 3SN presents a chlorosis in their leaves, which can be produced, among other causes, by a diminution of the magnesium contents in the aerial part and the root, this being an important cation necessary in most of the partial reactions in the glucolysis and respiration cycles.

The results obtained in the treatments of nutrient solution of standard concentration with different levels of humic acid, confirm the results obtained in the part of the first experiment carried out with humic acid from farm manure, that is: there is an increase of the weight of the plant in the presence of humic acid with an optimum level corresponding to that of 6 mg/Kg. quartz.

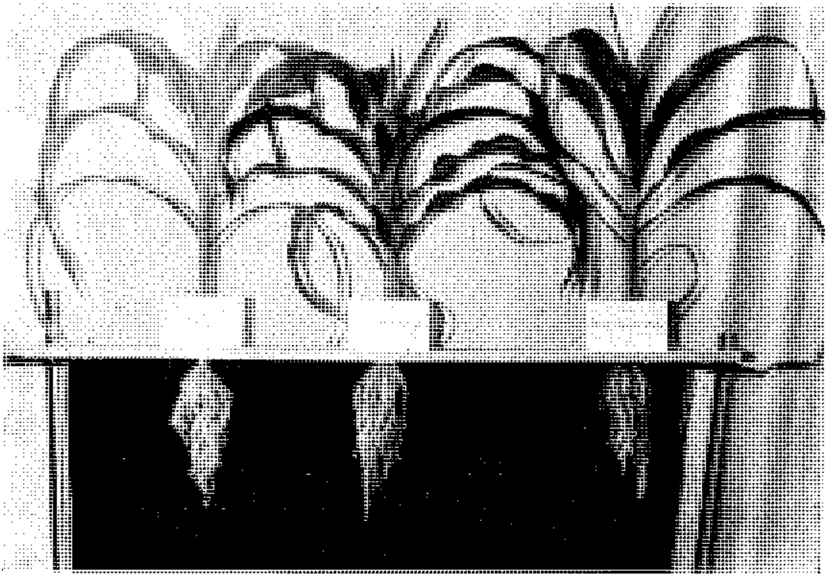
The correcting effects of humic acid are shown already with the level of 6 mg. (Fig. nos. 2 and 3) as the plants obtained with this quantity and 2SN and 3SN show very attenuated effects on chlorosis and shortening of internodes which appeared in the plants when not treated with the acid, instead of the increase in uptake of phosphate.

In Table no. 4 we observe that the plants treated with humic acid produce a greater uptake of nutrient elements than those not treated with the acid, therefore they should show more intensively the toxic effects produced by the excess of mineral concentrations in the medium, however, as we have shown in the above paragraph, this is not so. Therefore we deduce that the humic acid acts upon the metabolic processes of the plant by activating the processes both of respiration and synthesis, in a way that a great part of the excess of mineral nutrients uptaken by the plant are rapidly synthetised and transformed into plant matter. In this way the toxic effects which cause the



SN 2SN 3SN

FIG. 1 — Effect produced on corn by nutrient solutions in increasing concentrations.



2SN/0mg A.H./Kg.Cz. 2SN-24mg A.H./Kg.Cz. 2SN-6mg A.H./Kg.Cz.

FIG. 2 — Reduction by means of different levels of humic acid, of the effects of toxicity produced in the plant by a nutrient solution of a concentration twice the standard.

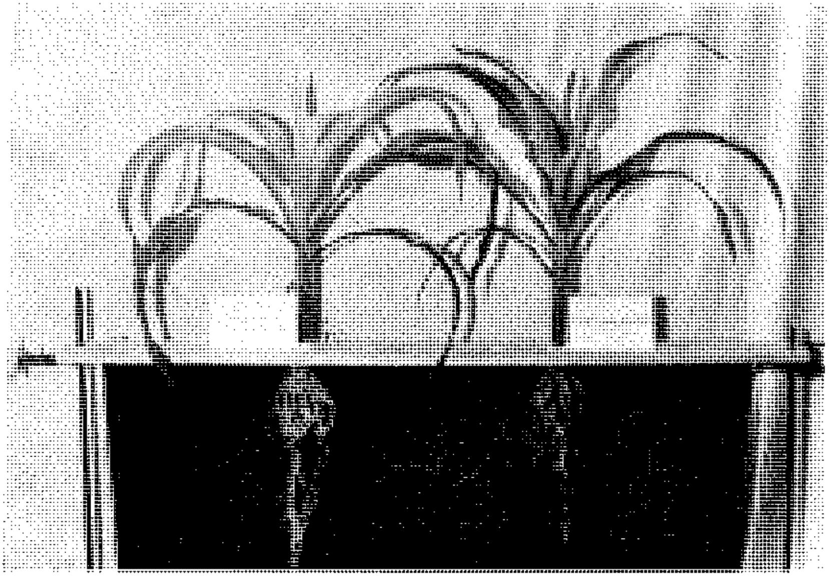


FIG. 3 — Beneficial effect produced by the application of 6 mg. of humic acid on corn grown in a nutrient solution of a concentration three times the normal.

diminution in the plant weight and the appearance of external signs of nntrients toxicity (chlorosis, shortening of internodes, narrower leaves, diminution in the radicular system, etc.) are not produced in such intensity.

The reduction of chlorosis fulfilled by the humic acid can have an explanation in the greater absorption of nitrogen and magnesium (essential elements for building up chlorophyll), performed by plants by the effects of that acid (Table no. 4).

The optimal levels of the applications of humic acid are different according to the mineral concentration of the nutrient solution (Table no. 3). In this experiment it is respectively 6 mg. for SN, 96 mg. for 2SN and 6 mg. for 3SN.

The fact of the existence of optimal levels of humic acid and the fact that they are not related with the mineral concentration, justifies our hypothesis.

Thus, for a certain mineral concentration, the activation of the respiratory processes produced by the increasing levels of humic acid will bring forth a different absorption of nutrients, and when this higher mineral uptake is synthesized and transformed into plant matter by means of a higher activity of the synthetic and photosynthetic processes, the balanced activation of the two fundamental processes (respiration ⇄ synthesis) produce an increase in the plant matter.

In these cases we have found levels of humic acid which produce an increase in the production. However, when both processes are disphased, the higher mineral concentration within the plant are not transformed into plant matter, because the synthesis processes are not increased; therefore the levels of humic acid which phoduce such effects will bring forth a diminution of the yield.

What we have just said is perfectly justified with the level of 96 mg. and 3SN, where the diminution of weight is the effect of the unbalanced relation between the nutrients absorption (export) and the consequent synthesis processes.

3. REDUCTION BY MEANS OF HUMIC ACID OF THE TOXIC EFFECTS PRODUCED IN CORN BY DIFFERENT CONCENTRATIONS OF UNBALANCED MINERAL SOLUTIONS

The results obtained in the previous experiments show the reduction effect by humic acid on balanced solutions with high mineral concentrations. That is why we find interesting the study of the action of humic acid on plants submitted to different levels of unbalanced mineral solutions, as is usual in saline soils.

Here we used « molecular suspension » of humic acid so that the concentration of the acid is sure to be constant throughout the whole experiment.

The corn we have chosen for the experiment is considered one of the plants sensitive to salinity [5], so that saline solutions of conductivities higher than 4 millimhos/cm., will produce a clear diminution in the plant weight.

On this base we have selected nutrient solutions with a salinity of 5,15 millimhos/cm. and 12,60 millimhos/cm. The salinity was produced by adding a mixture of Cl_2Ca, ClNa and SO_4Mg in equal proportion, to the standard nutrient solutions.

The quantity added of each of these salts is of 15 m.e. for the treatment of the lower salinity (5,15 millimhos/cm.) and of 45 m.e. in each litre of nutrient solution for the higher level of salinity (12,60 millimhos/cm.).

Since we find no clearly proportional effects on plant growth by the amounts of humic acid applied, we use in this experiment a larger number of levels so as to get better information about the effects of humic acid.

Each of the saline concentration has been tried out with 0 - 2 - 4 - 8 - 12 - 24 - 48 - 80 - 100 - 120 - 140 and 160 milligrammes of humic acid per litre of nutrient solution. As usual we used ground quartz as inert support.

The experiment has been carried out in a greenhouse during two months and a half. Four repetitions of each treatment were made.

In this case we evaluate some microelements to get information about the effect of humic acid in their uptake.

RESULTS OBTAINED WITH THE SALINE SOLUTION OF 5,15 MILLIMHOS/CM.

The results obtained for the salinity level of conductivity: 5,15 millimhos/cm. (Salinity 1), represented on Table no. 5, show clearly the important diminution of production brought forth by saline solution. At the same time they also show the improvement due to humic acid for certain levels of its application, and the consequence of which is a great increase in weight of the aerial part of the plant (Graph. no. 7). This variability in the effect of the different levels agrees with what has been observed in the previous experiments and confirms the suppositions brought forward in our hypothesis. The peaks corresponding in this case to 12 and 120 mg./l. that is, they have been displaced, as we had already observed partially in the previous experiment.

With regard to the uptake of elements, one of the effects produced by salinity is the diminution in the uptake of nitrogen by the plant (Table no. 5), this effect disappears with the application of humic acid, as is proved by the fact that plants obtained with it, contain nitrogen at an even higher rate than with the regular solution.

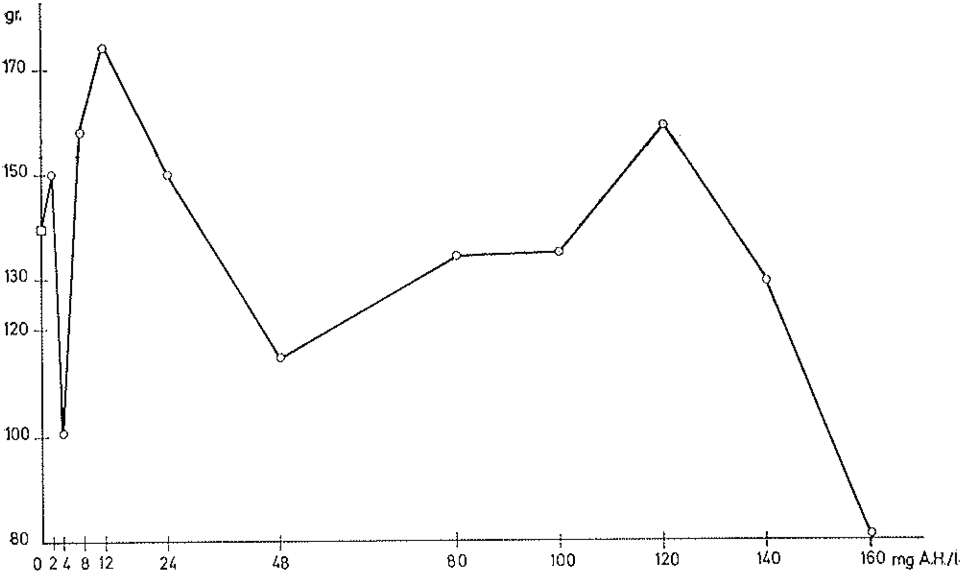
In relation to potassium (Table no. 5) we observe a tendency towards an increase in the uptake with the application of humic acid.

The saline solution produces plants with calcium and sodium contents (Table no. 5) much higher than those obtained with the normal solution, in accordance with the higher level

TABLE 5 — *The action of humic acid in saline solutions on the mineral contents of the aerial part of the corn.*

Treatments		Weight		Dry aerial part								
				m. e. % gr						p. p. m.		
Salinity conductivity in millimhos/cm	A.H. mg/l	Fresh aerial part	Dry aerial part	NO_3^-	$PO_4^{\equiv}$	K^+	Ca^{++}	Mg^{++}	Na^+	Fe	Mn	Zn
0	0	219,6	38,4	125,0	13,1	71,3	27,3	41,7	1,0	145,0	128,3	42,5
5,15	0	139,7	27,0	103,5	11,8	73,7	41,7	95,0	33,0	205,8	196,6	42,5
»	2	150,7	27,4	112,9	12,7	77,7	31,3	85,0	25,0	141,7	195,6	31,6
»	4	101,7	24,1	125,0	15,2	86,7	39,2	108,0	25,7	136,7	247,3	30,0
»	8	158,1	28,0	131,4	12,7	82,7	32,5	93,3	25,3	162,5	130,6	45,8
»	12	174,6	28,5	136,0	13,3	77,3	32,5	86,7	15,0	200,0	151,7	44,2
»	24	150,1	28,6	132,9	11,1	73,0	27,5	93,3	15,5	180,0	205,0	44,0
»	48	115,4	25,5	138,6	16,8	90,7	35,0	88,3	26,6	195,0	195,7	32,3
»	80	134,0	25,4	122,1	13,1	80,0	27,5	75,0	13,5	182,5	218,3	33,3
»	100	134,6	25,9	124,3	12,8	88,3	33,3	93,3	25,0	117,5	212,3	33,3
»	120	159,2	30,1	114,3	10,6	77,3	31,7	100,0	32,0	130,8	155,0	37,5
»	140	129,5	26,2	128,6	11,7	94,0	35,0	110,0	28,0	137,5	160,0	33,3
»	160	81,3	24,7	130,0	13,2	87,3	48,3	139,0	46,5	187,3	284,0	29,8

A.H. mg/l = humic acid mg. per litre.



GRAPH NO. 7 — The action of different levels of humic acid on the weight of the aerial part of the corn plant grown in a saline solution of 5,15 millimhos/cm. conductivity.

of calcium and sodium in the salt solution. But as soon as the humic acid is employed, these calcium and sodium contents decrease clearly.

Only for the highest level of humic acid tried out corresponding to levels of 160 mg./l., the contents of the plants in Ca and Na are higher than those obtained with the saline solution alone.

All this has a great importance in its practical application and we may think that very high levels of organic matter can be of no use in the reduction of the effects of salinity of the soils.

The ratio K/Ca decreases by the effect of salinity. The reducing action of humic acid is shown as it increases this ratio and nears it to one obtained with the standard solution. We must note an exception, that with the highest level (160 mg. humic acid/l.) there appears a diminution in the ratio K/Ca making it equal to the one obtained with saline solution alone (Table no. 6).

The effect of salinity is shown by a great diminution of the ratio Mg/Na, which increases by the addition of humic acid and in general tends to higher plant weight with higher values of this ratio (see Table no. 6).

The effect of reducing action of humic acid on the salinity of solutions is shown by the cation export (E_c) (Table no. 6), which for levels between 2 and 100 mg. of humic acid per litre, tends to near the value of cation exports of the normal solution and are below that produced by the saline solution tried out.

With levels of humic acid over 100 mg./l., the cation exports have much higher values than those obtained with saline solution alone.

The analysis of iron show a higher content of this element in the plants submitted to the action of salinity. This content decreases in the presence of certain levels of humic acid (Graph. no. 8) and thus, in these cases, the values are nearer to the shandard solution and also show clearly that the chlorosis is not related to the amount of iron present in the plant.

Also manganese increases under the effect of salinity and by the effect of humic acid only at certain levels of this acid does the content of manganese go down (Table no. 5).

It is interesting to note that the highest values in iron correspond to the lowest values of manganese and reciprocally.

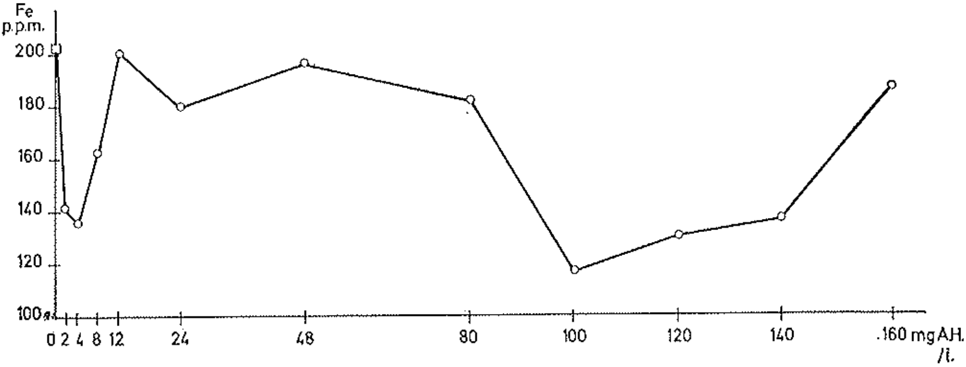
With respect to zinc, we can say that its fluctuations in relation to the levels of humic acid tried out are similar to the production ones (Table no. 5). The salinity has no effect on its contents in the plant.

The ratio Ca/Mn does not vary by the effect of salinity, however the presence of humic acid modifies this ratio and we

TABLE 6 — *The action of humic acid in saline solutions on the cationic relationships and exports of the aerial part of the corn.*

Treatments		Weight		Cationic relationships						Exports			
Salinity conductivity in millimhos/cm	A.H. mg/l	Fresh aerial part	Dry aerial part	$\frac{K}{Ca}$	$\frac{Mg}{Na}$	$\frac{Ca}{Mn}$	$\frac{Fe}{Mn}$	$\frac{Mn}{Zn}$	$\frac{Fe}{Zn}$	$E_{NO_3^-}$	$E_{PO_4^{\equiv}}$	E_{Mi}	E_c
0	0	219,6	38,4	2,6	41,7	0,21	1,13	3,0	3,4	48,0	5,0	121,3	54,3
5,15	0	139,7	27,0	1,8	2,9	0,21	1,05	4,6	4,8	27,9	3,2	120,1	65,7
»	2	150,7	27,4	2,5	3,4	0,16	0,72	6,2	4,5	30,9	3,5	101,1	60,0
»	4	101,7	24,1	2,2	4,2	0,16	0,55	8,2	4,6	30,1	3,7	99,8	62,6
»	8	158,1	28,0	2,5	3,7	0,25	1,24	2,9	3,6	36,8	3,6	94,9	65,5
»	12	174,6	28,5	2,4	5,6	0,21	1,32	3,4	4,5	38,8	3,8	112,8	60,3
»	24	150,1	28,6	2,7	6,0	0,13	0,88	4,7	4,1	38,0	3,2	122,7	59,9
»	48	115,4	25,5	2,6	3,3	0,18	0,99	6,1	6,0	35,3	4,3	107,9	61,4
»	80	134,0	25,4	2,9	5,6	0,13	0,84	6,6	5,5	31,0	3,3	110,3	49,8
»	100	134,6	25,9	2,7	3,7	0,16	0,55	6,4	3,5	32,2	3,3	94,0	62,1
»	120	159,2	30,1	2,4	3,1	0,20	0,84	4,1	3,5	34,4	3,2	97,3	72,5
»	140	129,5	26,2	2,7	3,9	0,21	0,86	4,8	4,1	33,7	3,1	86,7	70,0
»	160	81,3	24,7	1,8	2,9	0,17	0,66	9,5	6,3	32,1	3,3	123,8	79,3

A.H. mg/l = humic acid mg per litre
E_{Mi} = micro-elements export
E_c = cationic export (macroelements)



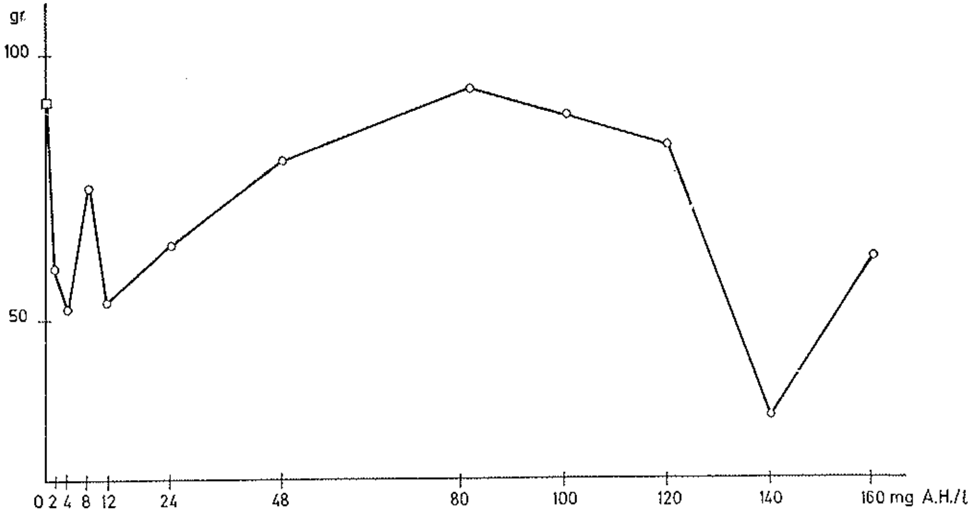
GRAPH. NO. 8 — The action of different levels of humic acid on the iron contents in corn plant grown in a saline solution of 5,15 millimhos/cm. conductivity.

have observed that the highest weights of the plant are obtained for those levels of humic acid where the Ca/Mn ratio is nearer to the mineral solution alone (Table no. 6).

The presence of humic acid has a great influence on the ratio Fe/Mn, and very different results are obtained for the several levels of acid used. The highest value of this ratio corresponds to the greatest weight of the plant. In general, a correspondence is observed between the low values of that ratio and the smaller weights of the plant.

The Mn/Zn and Fe/Zn ratios, increase by the effect of salinity; the different levels of humic acid modify these ratios within very wide limits, the greatest plant weights coinciding with the lowest values of this ratios.

The salinity has no effect on the export of microelements E_{Mi}, but the action of humic acid produces a smaller export of them. A series of fluctuations have been observed depending on the levels of humic acid applied.



GRAPH NO. 9 — The action of different levels of humic acid on the weight of the aerial part of the corn plant grown in a saline solution of 12,60 millimhos/cm. conductivity.

RESULTS OBTAINED WITH THE SALINE SOLUTION OF 12,60 MILLIMHOS/CM.

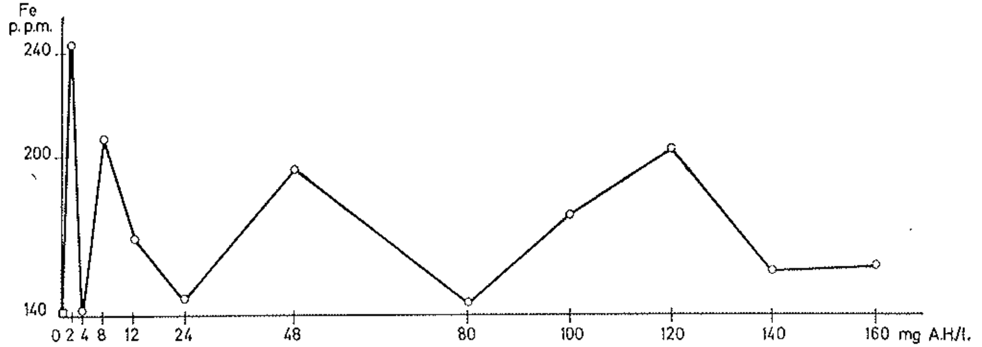
With saline solutions of 12,60 millimhos/cm. (salinity 3) only for 80 mg. of humic acid/l., an increase in the weight of the aerial part of the plant is obtained, whereas with other levels the weights obtained are smaller than those produced with saline solution alone (Graph. no. 9).

With regard to the uptake of elements (table n. 7), we can say that the behaviour of the humic acid does not change the effects of the salinity, only for phosphorus where a higher uptake is obtained, for the microelements Fe, Mn and Zn, the values of which are much higher than those produced with the saline solution alone (Graphs, nos. 10 and 11), and for the

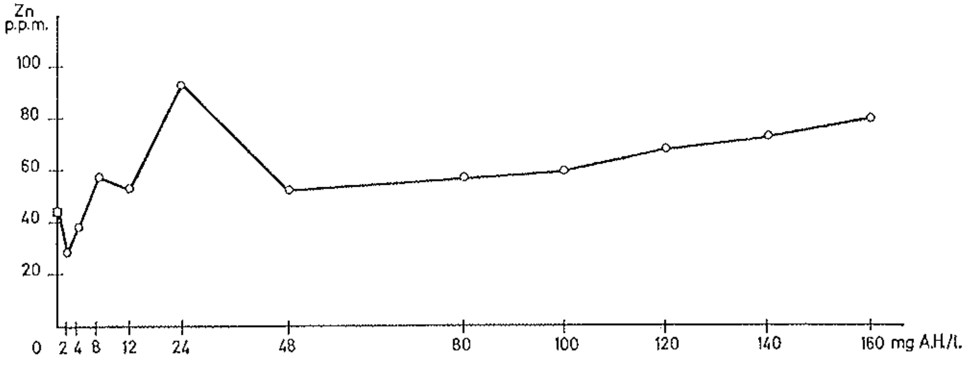
TABLE 7 — *The action of humic acid in saline solutions on the mineral contents of the aerial part of the corn.*

Treatments		Weight		Dry aerial part								
				m. e. % gr						p. p. m.		
Salinity conductivity in millimhos/cm	A.H. mg/l	Fresh aerial part	Dry aerial part	NO_3^-	$PO_4^{\equiv}$	K^+	Ca^{++}	Mg^{++}	Na^+	Fe	Mn	Zn
0	0	219,6	38,4	125,0	13,1	71,3	27,3	41,7	1,0	145,0	128,3	42,5
12,60	0	91,1	21,5	130,7	15,0	81,7	41,7	132,3	98,7	141,7	252,3	44,2
»	2	60,2	18,0	142,1	17,1	90,0	38,3	113,3	62,1	245,0	276,7	29,2
»	4	52,2	14,0	157,1	19,7	91,7	50,0	150,0	63,0	142,5	219,0	39,2
»	8	75,8	18,1	142,1	18,6	80,0	55,0	183,0	54,0	208,3	131,7	68,3
»	12	53,8	14,6	132,1	19,9	93,3	41,7	170,0	37,8	170,0	510,0	54,2
»	24	63,7	16,4	125,0	16,7	77,5	42,5	129,8	58,3	147,3	301,7	93,3
»	48	80,2	16,9	131,4	16,5	92,3	40,0	116,7	35,3	196,7	419,3	52,5
»	80	94,4	16,3	132,1	16,8	95,0	42,5	120,0	24,8	145,6	387,5	57,5
»	100	88,5	14,6	125,0	14,8	82,5	35,0	92,5	20,9	179,1	522,0	60,7
»	120	83,4	14,8	131,4	20,1	100,0	41,7	121,6	31,8	204,2	308,7	68,3
»	140	32,3	10,9	135,7	22,5	101,7	50,0	150,0	72,3	155,8	490,0	72,5
»	160	61,9	13,7	150,0	21,7	97,0	46,7	135,7	25,5	157,5	579,0	80,0

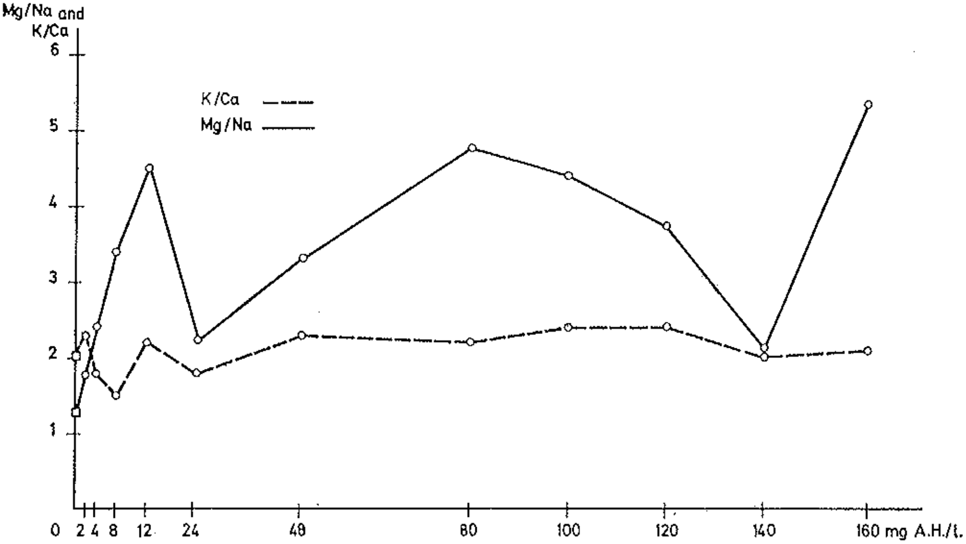
A.H. mg/l = humic acid mg. per litre.



GRAPH. NO. 10 — The action of different levels of humic acid on the iron contents of the corn plant grown in a saline solution of 12,60 millimhos/cm. conductivity.



GRAPH. NO. 11 — The action of different levels of humic acid on the zinc contents of the corn plant grown in a saline solution of 12,60 millimhos/cm. conductivity.



Graph. no. 12 — The action of different levels of humic acid on the ratios K/Ca and Mg/Na in the corn plant grown in a saline solution of 12,60 millimhos/cm. conductivity.

ratio Mg/Na (Graph. no. 12) where a series of fluctuation with a clear increase is observed, but the ratio K/Ca presents no definite tendency.

No relation is observed between the weight of the plant and the contents in NO_3^-, K, etc., nor with the ratios Ca/Mn, Fe/Mn, Mn/Zn and Fe/Zn. (See Table no. 8).

DISCUSSION OF THE RESULTS

In the uptake of mineral substances by the plant, we have to consider, among other, two fundamental factors: respiration and concentration of nutrients in the outside medium. The

TABLE 8 — *The action of humic acid in saline solutions on the cationic relationships and exports of the aerial part of the corn.*

Treatments		Weight		Cationic relationships						Exports			
Salinity conductivity in millimhos/cm	A.H. mg/l	Fresh aerial part	Dry aerial part	$\frac{K}{Ca}$	$\frac{Mg}{Na}$	$\frac{Ca}{Mn}$	$\frac{Fe}{Mn}$	$\frac{Mn}{Zn}$	$\frac{Fe}{Zn}$	$E_{NO_3^-}$	$E_{PO_4^{\equiv}}$	E_{Mi}	E_c
0	0	219,6	38,4	2,6	41,7	0,21	1,13	3,0	3,4	48,0	5,0	121,3	54,3
12,60	0	91,1	21,5	2,0	1,3	0,17	0,56	5,7	3,2	28,1	3,2	94,2	76,2
»	2	60,2	18,0	2,3	1,8	0,14	0,89	9,5	8,4	25,6	3,1	99,2	54,7
»	4	52,2	14,0	1,8	2,4	0,23	0,65	5,5	3,6	21,9	2,8	56,1	49,7
»	8	75,8	18,1	1,5	3,4	0,42	1,58	1,9	3,1	25,7	3,4	73,9	67,3
»	12	53,8	14,6	2,2	4,5	0,08	0,33	9,4	3,1	19,3	2,9	107,2	50,0
»	24	63,7	16,4	1,8	2,2	0,14	0,49	3,2	1,6	20,5	2,7	88,9	50,5
»	48	80,2	16,9	2,3	3,3	0,20	0,47	7,9	3,8	22,2	2,8	112,9	48,0
»	80	94,4	16,3	2,2	4,8	0,11	0,38	6,7	2,5	21,5	2,7	96,3	46,0
»	100	88,5	14,6	2,4	4,4	0,07	0,34	8,6	2,9	18,3	2,2	111,2	33,7
»	120	83,4	14,8	2,4	3,8	0,14	0,66	4,5	2,9	19,4	2,9	86,0	43,6
»	140	32,3	10,9	2,0	2,1	0,10	0,32	6,8	2,2	14,8	2,5	78,3	40,8
»	160	61,9	13,7	2,1	5,3	0,08	0,27	7,2	1,9	20,6	2,9	111,9	41,8

A.H. mg/l = humic acid mg per litre
E_{Mi} = micro-elements export
E_c = cationic export (macroelements)

first of them acts by increasing the uptake of nutrients and the second one acts in a way that the plant tends to equal the osmotic pressure of the outside medium with that of its own cellular juice. Both phenomena are fulfilled up to certain limits, within which the plant can live and over or below which, turgescence and plasmolysis phenomena may appear and even cause cellular death.

In this work the increase of E_c observed in plants grown with saline solutions (5,15 millimhos/cm.), can have an explanation in the high osmotic pressure of the outside medium. The plant, to equal that pressure to its own cellular juice, increases the uptake of nutrients, thus producing an E_c higher than in regular solution.

In the case when humic acid is applied, there appears a diminution of the E_c (Table no. 6). This result is apparently completely anomalous. Thus we have plants with lower internal concentration in nutrients, in spite of the higher concentrations existing in the medium. But the reason herefore lies in the higher development of the plant with humic acid.

The production of vegetable matter depends on the equilibrium existing between the uptake of elements and the capacity of the plant to transform them into an integral part of itself.

In the case of saline solutions, this equilibrium is broken as there is a great increase in the uptake of certain mineral elements produced by the high osmotic pressure of the solution while the transformation of those elements does not take part. In consequence, this unbalanced state brings about an excessive accumulation of mineral elements inside the plant and therefore a toxicity.

The beneficial effect of humic acid on the development of the plants, as we have just said, is based on the influence of that acid, both on the processes of uptake of nutrients and especially in this case on the synthesis related to those elements.

The direct intervention of humic acid has been proved on the formation of chlorophyll and, therefore, on the processes of photosynthesis [13]. If we bear in mind that magnesium is one of the fundamental components of chlorophyll, and that high concentrations of sodium are very toxic for the plants, there should exist an optimal relationship between both to obtain the highest yield. In the case of our experiment with high salinity unbalanced and the lower level of salt, this relationship is 41,7 and we have been able to observe that the saline solution without humic acid lowers it to 2,9 and that due to the action of humic acid, it goes up to 6,0, which coincides with the highest yields in saline solution. That is to say, the effect of humic acid for certain levels of application, is shown in the increase of the ratio Mg/Na.

But as the values of magnesium keep within nearer limits than the ones of sodium, the action of humic acid means mainly a diminution in the contents of sodium of the plant.

In the other experiment, with the highest salinity, we show again the existence of optimal levels in the application of humic acid, which produces greater yields, but only reduces in part the toxicity produced by high saline concentrations, with the level of 80 mg. of humic acid per litre, probably because of too high salinity of the treatment of 12,60 millimhos/cm. for growing corn.

As we have said repeatedly, the greater weights of the plant are attained for those levels of humic acid which increase in a balanced way the processes both of respiration and of synthesis.

One of the most characteristic actions of humic acid is the decrease of chlorosis induced by saline solutions. This fact may be justified by the higher uptake of nitrogen as well as by the elevation of the Mg/Na ratio, but not for an increasing in the iron uptake.

With the salinity corresponding to 12,60 millimhos/cm., the plants will be submitted to a very high osmotic pressure, therefore they uptake quantities of mineral elements that are much higher than with the normal solution and produce the toxic effects due to salinity.

In spite of the great diminution of the sodium contents which is observed as a beneficial effect of humic acid on the plants with the highest salinity used, this acid increases practically always, at least with the levels used here, the whole mineral unbalances caused by this salinity.

In the 3rd experiment, the only one in which we evaluated the microelements, we can clearly see that the exports of microelements (E_{Mi}) of the plants treated with humic acid are lower than the exports produced with saline solution only. Bearing in mind that the microelements fulfill essential functions of synthesis in the vegetal metabolism, we have deduced that the humic acid possibly facilitates the functions of those microelements in the plants. All that confirms the hypothesis, we have enuntiated, of the intervention of humic acid in vegetative processes of synthesis.

CONCLUSIONS

— We show clearly that humic acid, of different origins, behave in different ways in their action upon the vegetal growth.

— The plants obtained with humic acid E (from farm manure) present normal colour and constitution, while those obtained with humic acid T (from peat) present symptoms of deficiency and small growth.

— The humic acid E produces increase in weight both in the aerial part and the root of the corn. The optimal level of application is that of 6 mg./Kg. quartz, with which increases of hundred per cent are obtained in the dry weight of the aerial part as well as in the root. On the contrary, humic acid T does not bring forth increase in weight of the aerial part whereas it produces a diminution of the weight in the root.

— Both acids increase the absorption of phosphate and put down that of potassium; this fact will have to be taken into consideration when calculating the levels of application of phosphate and potash fertilizers.

— As to nitrogen, humic acid E produces an increase in its absorption practically for all levels applied, however, humic acid T produces an increase only in the lower levels. Increasing the amount applied, the absorption decreases very much. For magnesium, there is a minimum in the intermediate levels, for both humic acids.

— In nutrient solutions at a concentration higher than standard humic acid produces plants of greater weight than without it. This is the reason of the importance of its application, as better yields can be obtained. But there is a limit in the application from which the beneficial effects not only disappear but become harmful. Therefore, in soils of a high mineral concentration, this effect must be carefully taken into consideration, as inadequate levels of organic matter can produce effects opposite to those expected. This is mainly the reason of the difficulty in knowing the level of organic matter which is most adequate in each case.

— For each of the three nutrient solutions tested (single, twice and thrice the standard) there exist different optimal levels of application of humic acid with respect to the weight of dry plant obtained, which correspond: in the standard nutrient solution, to 6 mg.; in a solution twice the standard to 24 mg. and in a solution thrice the regular, to 12 mg. This means that for a maximum of production there must be a close relationship between the level of humic acid (organic matter) and the mineral concentration of medium.

— The humic acid produces — in balanced nutrient solutions with a concentration above standard — a definite action that consists in increasing the absorption of nitrogen and magnesium by the plant, which explains its effects on the formation of chlorophyll and, therefore of the green parts of the plant.

— The plants of corn grown in balanced nutrient solutions at concentrations above standard, show characteristic symptoms of toxicity, such as: leaves of a yellowish colour, shortening of the internodes and necrose in the root system. These effects disappear by the action of humic acid, or decrease in such a way that the plants produced are much more developed and weigh more, not only the aerial part but also the root.

— The unbalanced saline solutions of conductivities 5,15 and 12,60 millimhos/cm. produce an important decrease in the weight of the plant with respect to a solution of standard concentration, this is, a loss of weight around 30% with the first conductivity and the 60% in the second one.

— The humic acid in solutions of 5,15 millimhos/cm. produces, for most of the levels tested, a higher yield with respect to the saline solution, although it is never possible to obtain values of weight as high as those attained without salinity.

— With the too high nutrient solution of 12,60 millimhos/cm. of conductivity, the humic acid produces, practically, decreasing in plant weight.

— Maybe here, the unbalance produced by the nutrient solution in the plants is so high that the action of humic acid increases the unbalance, because the effect on synthesis, result very small, in relation to the high uptake of elements from the mineral solution by the plants.

— The quantities of humic acid applied at the levels of salinity tested, do not show proportionality with the weight of plant obtained.

— The effects of humic acid on plant growth in saline solutions are shown by a great diminution in the absorption of sodium, as well as an increase in the absorption of nitrogen, therefore, in soils where salinity is mostly produced by sodium salts, the applications of adequate levels of farm manure will be highly beneficial.

— Most levels of humic acid have a clear influence in the ratio Mg/Na, perhaps an important fact for the correcting effects of chlorosis by humic acid.

— The export of microelements is lower for those plants grown in conditions of salinity and in presence of humic acid than for those grown without humic acid. Probably the functions of microelements are favoured by humic acid.

— The most interesting and unexpected result is that, due to the complex action of the humic acid upon the plants, the levels applied are not proportional to the effect obtained, therefore the calculation of the appropriate optimal level of the organic matter to be applied would require procedures much more complicated and exacted than those of application of mineral fertilizers.

— To explain the results of the applications of humic acid on the development of plants, we propose the hypothesis according to which the molecule of humic acid acts upon the respiratory processes through its phenolic groups and upon the processes of synthesis throngh its aminoacid groups. As the equilibrium respiration $\rightleftharpoons$ synthesis directs the development of plants, any variation in this equilibrium produced by the type of humic acid — variable richness of phenolic groups and aminoacids — or by the quantity of it applied can explain the fluctuations in production obtained in the experiments.

SUMMARY

In the first part of the present paper we carry out the study of the different behaviour of two humic acids of different origin: a humic acid E from farm manure and another T, extracted from peat.

The analysis of both shows a greater nitrogen and carboxylic groups contents for the humic acid E and a greater proportion of phenolic groups for the humic acid T.

The first experiment was fufilled in hydroponic cultures, with ground quartz as a support. The plant used was corn (Zea mays) applying levels of 0 - 6 - 12 - 24 - 48 and 96 mg. of humic acid per kilogramme of quartz.

The results of this experiment have shown that with the humic acid E, the plants obtained have a normal colour and constitution, while the ones obtained with humic acid T show symptoms of deficiency and small development.

A greater uptake of elements is produced by plants treated with humic acid than by those that were not.

In the second experiment of this paper we study the effect of humic acid on the corn plants treated with balanced nutrient solutions with a concentration above standard. We have used solutions of a single concentration (SN), twice (2SN) and thrice the standard (3SN) and levels of humic acid of 0 - 6 - 12 - 24 - 48 and 96 mg. of humic acid per kilogramme of quartz.

The results show that for each one of the three nutrient solutions tried out, there exist different optimum levels of application of the humic acid, as well as an increase in the uptake of nitrogen and magnesium.

Due to the effect of humic acid, the symptoms brought about by toxic nutrition, shown by plants treated with solutions of a concentration above the standard one, disappear or greatly decrease.

In the third experiment of the work we applied levels of 0 - 2 - 4 - 8 - 12 - 24 - 48 - 80 - 100 - 120 - 140 and 160 mg.

of humic acid E per litre of unbalanced solution of a high saline concentration, the conductivities of which are 5,15 and 12,60 milimhos/cm.

The saline solutions tested bring forth a great decrease in the weight of the plant with respect to the normal solution, but for 5,15 millimhos/cm., most of the levels of acid applied increase the yield, but the values produced with the standard solution are never attained.

For 12,60 millimhos/cm., there are no good effects of the humic acid. On the other hand, there is a higher decrease of plant weight with every level used except the one of 80 mg./l. of solution.

In the plants that have been treated with humic acid in that medium, there appears a clear increase of the Mg/Na ratio together with another one in the uptake of nitrogen.

In the three experiments the level of humic acid applied is not proportional to the effects obtained, which shows that the behaviour of the humic acid is different from that of mineral fertilizers.

We introduce a hypothesis trying to explain these special effects of humic acid on the plant growth and which is in synthesis:

In the molecule of humic acid, phenolic groups and amino-acid ones, have a fundamental part. The former act mainly on the respiratory processes of the plants and the latter on all the synthesis phenomena. The plant development depends on the equilibrium respiration $\rightleftarrows$ synthesis, and any displacement in that equilibrium reduces plant growth.

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DISCUSSION

Chairman: R. CHAMINADE

CHAMINADE

Je voudrais vous demander la permission, pendant que j'occupe de façon très éphémère le fauteuil présidentiel de dire quelques mots en français, essentiellement pour remercier Monsieur le Professeur LORA-TAMAYO et le Docteur HERNANDO pour l'invitation qu'ils m'ont transmise d'assister à cette Semaine d'Etude de l'Académie Pontificale des Sciences et qui m'honore beaucoup. Je voudrais aussi ajouter mon hommage à la mémoire du Prof. ALBAREDA dont la perte a été si vivement ressentie dans tous les milieux scientifiques et agronomiques.

PRIMAVESI

Let me congratulate you on your magnificant paper, Prof. HERNANDO. The results show that the acids of humus of different origin behave in a different way and that acids of humus from stable manure give healthy plants and that those of peat are chlorotic ones. This conforms completely with our observations. We found also that humus of pseudogleys with pH4.0 had an injurious effect on soil and plant.

The great difference of acids of humus, proved in different soils and plants, was known to us and we are happy, that also our eminent Spanish colleague had this experience.

BAVER

I was very much interested in your results of the effects of humus on overcoming the deleterious influence of salinity. On gray hydromorphic clay soils in Hawaii, which were reclaimed from swamps along the ocean where the soil was three times saltier than the ocean, they drained the land and applied large quantities of organic matter into this heavy clay to improve its physical properties. It was also found that the salinity effects were reduced and this land now is producing around 14 tons of sugar per acre every two years — we have a two year crop. This is practical verification of your experiments.

HERNANDO

Perhaps I did not make myself quite clear. I intended to say that the important point of these results is that there is no proportional effect between the plant growth and the amount of humic acid we applied. This is the surprising result. The other point is, of course, quite easy to understand. You may not realize that there is not a proportional effect between the amount of the organic matter applied and the growth of the plants. In some cases the yield can be increased with certain amounts of organic matter and decreased with higher amounts, as I have shown it in my paper.

BAVER

This plantation has found that unless they use organic matter on soil that they cannot reclaim the sodium saturated land.

[22] *Hernando* - pag. 48

FLAIG

I am very interested in your results Prof. HERNANDO and I have some questions. I would like to ask you first if the peat has been composted or not. There are some experiences in Polish literature that fresh peat would diminish the yield of plant if it is added to the soil, and only if it is composted it would give good results.

HERNANDO

This humic acid from peat is produced by a manufacturer of chemicals in Great Britain; the name I don't remember. It is a dry product that we used in the experiments together with humic acid extracted from farm manure.

The experiment in relation with chlorosis was made only with humic acid from farm manure and not from peat. In the first experiment we used both, but later on, we used only the second one, since we did not get any good results with the humic acid from peat.

FLAIG

You say that humic acids are redox-system. You have another redox-system in the case of the humic acid fractions from manure and in the case of the humic acid fractions from peat, because in the peat humic acid fractions have a higher content of phenolic OH-groups. Have you measured the redox potential in relation to the effect of humic acids?

HERNANDO

I am afraid we don't make the evaluation of the redox potential, we are not equipped to do that.

FLAIG

We made measurements of redox potential of different substituted benzoquinones. These were added to nutrient solutions for experiments with seedlings of cereals. Only in a few cases we had relations between the redox potential of substituted *p*-benzoquinones and the effect on the amount of dry matter of seedlings. But if another substance was used which had a similar redox potential then we did not get the same results as received with the substituted *p*-benzoquinones.

CHAMINADE

My question is a technical one. In your first experiment with mineral solutions and quartz, have you added humic acid at different levels to the quartz?

HERNANDO

In the first two experiments we added humic acid. This is the reason why the first experiment took only 34 days. At the beginning it was impossible to maintain the humic acid in colloidial suspension, but in the third experiment we found a good method for it, which we used since then.

CHAMINADE

In this case, do you put a dry humic acid, mixed with quartz?

HERNANDO

Yes, well mixed in the solution. The humic acid remains for a short time in the suspension. One cannot say when it is finished.

The suspension gets clear because of the small amount. I suppose, however, that with the aeration system the humic acid remains in the solution for one or two weeks, may be more but I am not sure about that. I believe that the amount of humic acid in suspension is very small as it cannot be detected with a chemical method. There might exist other tests, and I think that Prof. WAKSMAN will agree with me on that.

FLAIG

I have another question. In some of your curves you have two peaks dependent on the amount of humic acid fractions. What is your explanation of these two peaks?

HERNANDO

The only explanation I can give lies in the hypothesis we presented. The action of humic acid expresses itself in two different effects: the phenolic group on respiration, and the amino-acids and proteins on synthesis.

The first one depends mostly on the quantity applied; the effect of the amount in the second case is not so clear. There are sometimes interferences between both effects. The effect in respiration of the phenolic groups causes an increase in the consumption of the plant matter. The process of synthesis produces an increase in the plant material. So, if there is a higher consumption of plant matter, the result will be a reduction in growth; it may also be that there is not enough aeration, in the soil which may arouse complicated problems. I tried to simplify this question: It can be shown that the effect of humic acid presents different aspects, producing an increase and decrease in the growth of plants, always independently of the amounts of humic acid applied.

SWABY

I'd like to offer another explanation for this second peak. I am wondering whether it is possible that for the first peak you are dealing with a situation where you haven't got the normal rhizosphere organisms developing on your plants, so you are experiencing a pure humic effect. For the second peak it's possible that the rhizosphere micro-organisms have developed. Two of my people, ROVIRA and BOWEN, have shown that when you get a full compliment of rhizosphere organisms on the roots of plants you get two to three times the uptake of nutrients that you get in sterile plants. Now, I am not infering that you started with sterile plants, but you might at first have had plants that were rather lacking in rhizosphere organisms and then they gradually developed. This could lead to a better uptake of some of the nutrients.

HERNANDO

This may be a clearer interpretation anyway. But what I would like to impress is that in the first experiment with an increasing application of humic acid, we got both increasing and decreasing in plant growth. However, there may be certain aspects we cannot interpret correctly without hypothesis and your explanation may give a fuller explanation to the one I have given.

ELEMENTS POUR UNE DOCTRINE DE L'UTILISATION DES MATIERES ORGANIQUES

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Il etait évident, étant donné la qualité des personnalités conviées à ce Colloque, que les aspects les plus fondamentaux des problèmes posés par la matière organique des sols seraient examinés. Je ne parlerai donc pas des travaux français dans ce domaine; mon collègue CHAMINADE vous en donnera un exemple. Aussi, j'ai cru qu'il serait utile de traiter l'aspect pratique du problème, c'est-à-dire la technologie de l'emploi des matières organiques. En effet, quel que soit les mécanismes élémentaires de l'action de ces substances, leur efficacité, ces résultats n'auront d'intérêt que dans la mesure où ils se traduiront par des avantages techniques substantiels.

Ceci m'amène dès le départ à évoquer le côté psychologique de la question. En France, et il ne me serait pas possible de traiter ce sujet d'une manière plus générale, les problèmes posés par la matière organiqne des sols font l'objet de controverses passionnées. Pour certains, il n'y a pas d'agriculture sans matières organiques, on parle d'ailleurs plus volontiers d'humus, pour d'autres, il ne s'agit que d'un constituant banal qui se trouve par accident dans le sol, mais qui présente peu d'intérêt sauf quand sa présence est gênante. Cette situation est d'autant plus regrettable qu'elle a des implications économiques et que, suivant que l'on est partisan ou pas des matières organiques ou de l'humus, on accepte ou on n'accepte pas certains systèmes de cultures, on détruit ou on ne détruit pas les résidus organiques par exemple issus des villes.

Il faut d'abord s'interroger sur la prise de position absolue des partisans de la matière organique. Celle-ci se rattache à une tradition très ancienne, celle de l'humus. Or, n'oublions pas que le mot signifie sensiblement terre en latin, ce n'est qu'avec le temps qu'il a désigné un groupe de constituants du sol. Mais ceux-ci ont la réputation de conférer aux terrains une fertilité presque inépuisable.

Cette croyance s'appuie sur une théorie vitaliste et l'on sait combien elle est profondément enraciné dans le subconscient même de techniciens authentiques. Suivant cette théorie la vie ne pouvait provenir que de la vie et l'humus était le seul aliment possible des plantes, c'est encore ce que l'on trouve clairement exposé dans la doctrine de THAER.

La situation est si confuse que j'ai dû pour en rendre compte employer simultanément les mots matière organique et humus, c'est qu'effectivement il règne encore, même parmi nous, une grande ambiguïté à ce sujet. On pourrait rappeler à ce propos la discussion qu'en a faite WAKSMAN [1], mais on peut la résumer en comparant deux points de vue. Pour le forestier, l'écologiste, le pédologue qui décrivent des profils ou des terrains, le mot humus recouvre toutes les matières organiques du sol. Or, il suffit d'examiner les définitions ou les descriptions que l'on donne d'un mohr ou d'un moder pour constater qu'il s'agit de systèmes et non pas de substances ou d'un groupe de substances, puisqu'on les caractérise par la superposition de couches de matières organiques plus ou moins évoluées.

A côté de ces définitions, les agronomes, considèrent l'humus comme un groupe de substances de couleur brune à noire ayant en moyenne un rapport C/N de l'ordre de 10 et offrant une grande résistance à la dégradation par les microrganismes. Dans ce sens, seule une partie des constituants de l'humus des écologistes est considérée comme réellement humus, l'autre fraction étant constituée par des matières organiques peu ou pas évoluées.

On sait combien il est difficile de distinguer par des méthodes chimiques ce qui est humus et ce qui ne l'est pas, c'est pourquoi nous avons utilisé pour les distinguer une méthode physique, la séparation par densité.

En principe les matières organiques peu évoluées flottent à la surface des liqueurs denses alors que les matières organiques évoluées, que nous considérons comme humus, restent fixées sur la fraction minérale et sont entraînées dans le fond des récipients. Nous savons que cette méthode n'est pas parfaite, qu'elle a des limites, mais nous l'utilisons parce que nous préférons une méthode qui à 90 ou 95% permet d'isoler d'un même sol une fraction ayant un rapport C/N de l'ordre de 15 ou 20 d'une autre fraction dont le rapport C/N est de l'ordre de 9 ou 10 que de ne faire aucune distinction [2].

En particulier, la fraction légère subit une transformation rapide ou assez rapide dans les sols, c'est-à-dire qu'en 1 à 4 ans on ne retrouve pratiquement plus de débris incorporés, alors que ce que nous considérons comme humus se détruit avec une vitesse de l'ordre de 1 à 3% par an.

Deux faits essentiels caractérisent la transformation de la matière organique libre en humus, c'est d'une part, la libération d'une partie importante des éléments minéraux qu'elle renferme avec une nuance toutefois pour l'azote, et par ailleurs, le fait qu'au cours de son évolution une fraction variant de 0 à 50% se transforme en matière organique liée ou humus [3].

C'est certainement par l'apport des éléments minéraux qu'elles renferment que les matières organiques ont acquis dans le passé, quand on ne savait ni doser les éléments minéraux, ni apporter d'engrais, leur réputation d'être l'aliment des plantes. Car, depuis que les agronomes du 19me siècle, LIEBEG en particulier, ont montré que les plantes pouvaient se nourrir exclusivement à partir de matières minérales, on sait que la première vertu d'un apport de matière organique est de transporter avec lui des substances minérales qui assurent la nutrition des végétaux. D'ailleurs, des pratiques traditionnelles comme l'écobuage, c'est-à-dire l'incinération des chaumes, d'herbes, ou l'essartage qui consistait à apporter des matières végétales grossières sur le sol et à les brûler, représentaient déjà des fertilisations exclusivement minérales; dès le 16me siècle, B. PALISSY le faisait déjà remarquer.

Si la matière organique n'est plus en elle-même un aliment de la plante, elle ne peut donc intervenir que comme une condition, c'est-à-dire qu'elle ne pourra marquer son action que

— par la façon dont elle libérera ses éléments minéraux;

— par les effets directs d'accélération de croissance, c'est-à-dire agissant comme une hétéro-auxine, on en favorisant certaines fonctions;

— par une action indirecte sur les propriétés physiques ou chimiques du sol.

Enfin, contrairement à ce qu'une tradition, qui se reflète jusque dans le langage poétique, peut affirmer les matières organiques quelles qu'elles soient n'ont pas qu'un rôle bénéfique. Non seulement elles constituent le support de presque tous les parasites des végétaux, mais en agissant sur la flore du sol elles peuvent créer des conditions de concurrence tant pour l'alimentation du végétal que pour la respiration des racines. Enfin parmi l'immense variété de ses constituants chimiques il en est qui peuvent avoir une action franchement toxique.

C'est-à-dire que nous devons demander à l'expérience, soit de mettre en évidence une action primaire en appelant ainsi l'action due aux matières minérales renfermées dans les substances organiques, des actions secondaire directes liées à l'accélération de la croissance, des actions secondaires indirectes se manifestant à travers l'état physique des sols de même qu'il sera nécessaire d'éviter la manifestation d'actions antagonistes.

Ayant ainsi esquissé certaines données du problème, examinons comment on a essayé de le résoudre et quels sont les résultats qui paraissent acquis.

I. LES PROBLÈMES DE L'EXPÉRIMENTATION

Il est tout d'abord impossible de faire une expérience agricole de longue durée avec un témoin sans matières organiques puisque chaque culture laisse par ses racines, ses chaumes ou ses collets des résidus dans le sol. Quand on parle de l'action des matières organiques, celle-ci doit donc se concevoir comme résultant d'un apport supplémentaire obtenu:

— en enfouissant dans le terrain des parties du végétal généralement exportées, comme les pailles;

— en introduisant dans les rotations des cultures permettant l'accumulation d'un certain stock de matières organiques vivantes qui sera incorporé lors du retournement de la végétation;

— enfin, par des apports prélevés sur des surfaces voisines ou provenant de sources parfois lointaines tels que les fumiers et les résidus urbains (gadoues).

Ceci nous amène à tenter un classement des différentes substances qui peuvent être apportées.

a) *Substances à rapport C/N faible.*

- Viande, déchets de poisson, os et sang desséché.
- Cornes et cuirs torréfiés et déchets de laine, tourteaux.
- Déjections d'animaux, en particulier mouton et oiseaux, guanos.

b) *Substances à rapport C/N moyen plus ou moins fermentées au préalable.*

— Fumier, compost, gadoues de ville.

c) *Substances à C/N élevé.*

— Pailles, broussailles diverses, goémon, tourbes.

— Bois de taille de vigne, brindilles d'arbres.

— Résidus industriels divers (marc de raisin, coques d'arachides, etc.).

D'une façon générale on admet, du moins en France, que, quand on apporte des matières organiques ayant un C/N inférieur à 12 ou 15, on ne provoque pas d'effets dépressifs liés à des fixations d'azote par les microrganismes du sol. Ceci est particulièrement vrai des substances du groupe 1, qui sont d'ailleurs généralement considérées comme des engrais. En France, on paye même plus cher l'unité d'azote dans ces produits, ils sont employés en culture maraîchère ou en horticulture, car ils ont la réputation d'assurer une alimentation continue des végétaux.

Les substances provenant du groupe 2, du moins lorsqu'elles sont convenablement préparées, ont l'avantage de ne pas bloquer l'élément fertilisant et libèrent au contraire progressivement ceux qu'elles renferment. C'est ainsi que l'on admet que le fumier produit la moitié de son effet en première année, un tiers en seconde année et le reste en troisième année. Le rythme de cette action est à rapprocher de ce que l'on peut attendre de certaines substances du groupe 1, tels que les cornes, les cuirs torréfiés et les déchets de laine. Mais ces substances ont un autre avantage, c'est que les fermentations qu'elles ont subies semblent avoir détruit les germes de parasites qu'elles renfermaient, ou au moins, avoir considérablement atténué leur virulence. C'est ainsi que l'on parle de fumiers propres pour désigner ceux dans lesquels les semences de plantes adventices ont été détruites.

Les substances du groupe 3 ont comme caractéristique commune d'être assez résistantes ou parfois très résistantes à la fermentation et suivant le cas, elles peuvent provoquer des baisses de rendement sévères par bloquage de l'azote disponible et peuvent être aussi d'autres éléments fertilisants. L'effet est rarement marqué quand il s'agit de matérieux plus difficilement fermentescibles. Mais elles peuvent avoir des actions directes sur les propriétés physiques du sol qui paraissent assez néfastes, par exemple en limitant la circulation de l'eau non saturante, ou favorables dans la mesure où elles permettent une meilleure circulation de l'eau saturante et de l'air. Appliquées en surface elles constituent des mulchs et jouent un rôle favorable sur la conservation de l'eau et du sol.

Bien entendu, la plupart des résidus végétaux provenant des récoltes, ou laissés au cours du défrichement, font partie de cette catégorie sauf quand ils proviennent des légumineuses ou de plantes jeunes (engrais verts). Toutefois, il est essentiel de souligner que les matières organiques produites sur place ne sont pas apportées passivement, elles ont un rôle actif. En effet, les végétaux en s'installant dans le sol colonisent par leurs racines les fissures, les cavités. Elles peuvent les élargir et jouent par là le rôle de véritables outils, encore que leur action ait des limites, mais celle-ci ajoute beaucoup à leur rôle propre. Enfin, ce sont eux qui assurent également le maintien de la flore et de la faune favorable ou parasites des sols.

Cette première revue montre déjà combien il est difficile de poser le problème des matières organiques, mais aussi qu'il est possible, à partir d'une classification relativement grossière, de prévoir certaines catégories de comportement et, par là, de codifier dans une certaine mesure les conditions de leur emploi.

Encore faut-il que l'on puisse préciser si leur incorporation au sol est bénéfique. En effet, malgré les risques que cela comporte, nous voyons chaque année, même en France, des agriculteurs brûler leurs résidus de récoltes pour éviter les inconvénients dûs à leur incorporation au sol; il n'est pas exagéré de dire que cette mesure concerne actuellement 3 ou 400.000 hectares de nos cultures. De même le feu est un des moyens le plus employé pour faire disparaître la masse considérable de résidus organiques qui restent à la surface du sol après un défrichement. Quant à la transformation de ces résidus en fumier ou en compost elle est très coûteuse, et nécessite la présence de bétail dont l'exploitation est considérée comme peu rentable.

Rappelons maintenant les différents effets qui ont été observés.

2. EFFETS FERTILISANTS

Toutes les expériences effectuées montrent que l'incorporation de matières organiques au sol permet d'assurer le maintien de la production grâce aux matières minérales qu'elles contiennent si les quantités sont suffisantes. On peut citer comme exemple caractéristique les essais de longue durée poursuivis à ROTHAMSTED [4] et à GRIGNON [5]. Mais le problème est de savoir s'il y a une action conjuguée de la matière organique et de la matière minérale. De nombreuses expériences conduites en Europe tendent à montrer que les éléments fertilisants introduits sous forme minérale sont plus actifs apportés à quantités égales. Le rapport de Rothamsted de 1962 confirme ce point de vue, mais avec une nuance; si pour 56 essais, 47 correspondent à ce point de vue, dans 9 cas sur sols légers les matières organiques donnent une augmentation de rendement spécifique. En 1967, P. GILLIER [6] signale un fait identique sur arachides et sur mil également en sols légers au Sénégal.

MULLER [7] à Antibes coustate également qu'à doses égales les éléments minéraux apportés seuls sont au moins aussi actifs que sous forme de constituants de la matière organique.

Toutefois, les arrières-effets sont généralement plus marqués quand la fertilisation a été organique.

Ces résultats montrent l'intérêt qu'il y a à utiliser les résidus organiques du fait de leur teneur en matières minérales, car, autrement, il faut les remplacer par des apports d'éléments fertilisants. C'est un point important pour l'économie générale des pays qui doivent acheter leurs engrais hors de leurs frontières.

3. EFFETS SPÉCIFIQUES DÛS À LA MATIÈRE ORGANIQUE

Dans ce cas on s'est efforcé de mettre en évidence l'action propre des matières organiques en compensant les effets qui pouvaient être liés à la fertilisation minérale. La meilleure solution consiste à élever les fumures minérales jusqu'à ce qu'elles n'agissent pratiquement plus sur le rendement. Si à ce moment la fumure organique permet d'accroître la récolte, il faut bien admettre que celle-ci a une action différente des matières minérales seules. C'est ce qu'ont montré une série d'essais effectués en pleine terre par BARBIER et BOISCHOT [6]. Les résultats de MULLER [7] à Antibes vont également dans ce sens, l'interaction matières organiques-azote ne se manifestant que pour des apports élevés (20 t. paille, 300 unités N). CAVAZZA [9] a également pu les reproduire dans la région de Bari. Il est évidemment très difficile, à partir de résultats globaux comme ceux-là, de préciser le mécanisme d'action de la matière organique. Seuls des essais plus précis, permettent de pousser plus loin l'analyse.

On peut ajouter à ces observations celles de DELAS [10] concernant une interaction favorable, fumures organiques-fumures minérales, dans les vignobles du Médoc.

Lors d'une étude systématique de vergers de pêchers en Ardèche GRAS et DEFFONTAINES [11] n'ont pas pu mettre en évidence, par le comportement des arbres et leur rendement, l'action d'une fumure organique superficielle. Par contre, il existe une corrélation hautement significative entre l'enracinement d'arbres et l'enfouissement de matières organiques lors du défoncement précédant la plantation.

Cet effet paraît très constant; j'ai eu l'occasion de le retrouver en étudiant le vignoble de l'Armagnac où, à la fois sur les vignes âgées et sur les jeunes plantations, les effets constatés sur l'enracinement et sur la croissance des jeunes plants se sont montrés spectaculaires [11].

Malheureusement dans ces dernières circonstances, il est très difficile de distinguer ce qui peut revenir à l'amélioration des propriétés physiques et ce que l'on peut attribuer à la nutrition et aux effets spécifiques des matières organiques introduites dans le sol.

4. EFFETS INDIRECTS SUR L'ALIMENTATION DES VÉGETAUX

Parmi les observations assez nombreuses on peut rappeler celle, déjà ancienne, de POTEL [12] qui a pu montrer qu'après apport de fumier les blés avaient un grain plus riche en azote que sans apport de fumier, des faits du même ordre ont été constatés derrière des cultures de luzerne. Ce mécanisme d'alimentation continue, qui est celui recherché par l'emploi d'engrais azotés à action progressive tels que les tourteaux, les cornes torréfiées, etc. paraît être un facteur important tant pour la qualité que, peut-être aussi, pour la quantité de la récolte.

En effet, on a préconisé en France une technique de fertilisation azotée du maïs par enfouissement d'engrais 30 jours avant la floraison de l'épis mâle; des accroissements substantiels de rendement ont été obtenus, mais ceux-ci sont d'autant plus marqués que le sol était pauvre en matières organiques. Autrement dit, il semble que dans les sols riches en matières organiques il se libère assez d'azote au cours de la croissance du végétal pour que celui-ci trouve à s'alimenter au moment où ses exigences sont les plus marquées.

Des effets du même ordre, bien que moins nets, ont été signalés en ce qui concerne l'alimentation phosphatée des plantes, en particulier en terre calcaire après infouissement d'engrais verts.

5. ACTIONS INDIRECTES PAR LES MODIFICATIONS DES PROPRIÉTÉS PHYSIQUES

Rappelons brièvement les effets favorables du mulching en soulignant toutefois que cette action n'est vraiment bénéfique que s'il tombe fréquemment de petites pluies ou si l'on irrigue. Quand le végétal traverse une longue période sans précipitations la technique risque d'être néfaste, surtout si on commence à l'utiliser quand la plantation est jeune, car elle provoque une certaine localisation des racines au voisinage de la surface du terrain. Dans ces conditions, il devient à nouveau assez hasardeux de discuter si les modifications de l'alimentation phosphopotassique du végétal qui se manifestent sont dues à la localisation des racines dans les zones plus riches du sol ou sont attribuables à l'action des matières organiques.

L'effet de couverture s'est montré particulièrement efficace quand il s'est agit de semer des prairies temporaires en terre sableuse après une culture de vigne. Les mulchs ont provoqué une levée régulière et une végétation particulièrement abondante du ray grass d'Italie. Dans ces conditions, on peut attribuer l'effet aussi bien à une protection du jeune semis permettant une meilleure alimentation en eau, qu'à un blocage du cuivre souvent toxique dans les sols légers cultivés en vignes, qu'à une action spécifique sur la nutrition ou l'enracinement. Il est à noter qu'il faut utiliser pour la couverture un fumier bien décomposé.

Quant à l'action des matières organiques sur la stabilité de la structure du sol elle n'est plus à prouver. Toutefois, cet effet n'est obtenu, comme l'a montré MONNIER [13], que si l'on assure un mélange intime de l'apport organique avec la fraction minérale. Il semble que ce soit là la raison de l'efficacité extraordinaire des racines des graminées prairiales, celles-ci s'insèrent dans la masse du sol, colonisent les moindres fissures soit créées par une action mécanique, soit provoquées par la fissuration du sol au cours de son dessèchement, comme TRI [14] l'a récemment mis en évidence. Mais les effets dûs à des cultures de courtes durées sont plus ou moins fugaces et dépendent étroitement des conditions d'humidité du sol qui précèdent les périodes de chutes de pluies. Un enfouissement d'engrais verts par exemple, a une action qui se limite à quelques mois. Les enrichissements en matières organiques par apports de fumier ou par l'action de prairies temporaires d'une durée supérieure à trois ans, exercent un effet de beaucoup plus longue durée.

Encore faut-il que les conditions de milieu permettent de tirer parti de cet effet bénéfique. Améliorer 15 ou 20 cm du sol quand le sous-sol est lui-même en mauvais état physique, revient à laisser à la plante en période humide une dizaine de centimètres de terre à peu près aérée pour développer ses racines; c'est insuffisant. On ne peut espérer tirer un plein effet de cette amélioration que si, simultanément, on assure l'écoulement de l'eau au niveau des semelles de labour soit par un système de planches, soit à l'aide de canaux suffisamment nombreux débouchant sur des collecteurs bien placés. Bien sûr, une structure stable permet de créer des lits de semence assurant une bonne germination, mais si cette phase du développement des végétaux est nécessaire à l'obtention d'une bonne récolte, elle ne produit son plein effet que quand l'alimentation minérale, les possibilités d'installation des racines sont assurées dans le sous-sol et l'alimentation en eau maintenue à un niveau convenable.

On ne peut passer sous silence l'action de cultures intercalaires d'herbe dans les vergers. L'action anti érosive a été maintes fois prouvée. Des effets bénéfiques ont souvent été signalés, mais ils ne réussissent que si l'on évite la compétition entre l'herbe et les arbres, tant pour les aliments minéraux, l'azote en particulier, que pour l'eau. Cela suppose l'irrigation ou des précipitations abondantes.

6. LES EFFETS DÉFAVORABLES

Ceux-ci concernent divers types de phénomènes. Considérons d'abord ceux relatifs au parasitisme. Il y a là une variété de situations, une complexité dans les interactions qui semblent rendre impossible toute tentative d'analyse détaillée. Suivant les types d'organismes, ce seront les évolutions en milieu aérobie, ou en milieu anaérobie, qui permettront de détruire les parasites. Rappelons que c'est là l'un des avantages des fermentations préalables que l'on fait subir aux composts et aux fumiers et qui permet d'obtenir des matières organiques exemptes de germes actifs.

Il nous paraît utile de citer à ce propos une observation récent de DENARIE [15]. Celui-ci travaillant à Madagascar a eu l'occasion de constater que certains traitements, et en particulier l'inoculation des légumineuses, ne donnaient pas toujours des résultats significatifs. S'inspirant de tecniques locales, il eut alors l'idée d'apporter du fumier à la dose de 5 à 10 t/ha, mais localisé par poignée. Voici les rendements obtenus sur haricot:

Essai haricot HC 12 (rendement en graines)

Traitements		Niveaux de fertilisation		
		N1	N2	N3
Sous-traitements	Sans fumier	320	668	666
	Avec fumier	853	1.231	1.391

Ce résultat a été confirmé par trois autres essais, et il est à noter que le mélange d'une quantité double de fumier au sol n'a pas eu d'efficacité. Ces faits illustrent bien les difficultés que nous évoquions. Dans le cas considéré, il semble que les jeunes racines en se développant dans le fumier soient protégées contre les attaque des nématodes.

Du point de vue chimique rappelons le bloccage d'azote si les matières enfouies ont un rapport C/N élevé.

Mais il est d'autres effets défavorables dûs à la matière organique que l'on observe très fréquemment dans les sols de mauvaise structure; c'est la formation de pseudo gleys. Ceux-ci limitent l'enracinement des végétaux, provoquent des asphyxies de racines se traduisant par des nécroses et par une réduction des facultés d'absorption. Il y a tout lieu de penser qu'il se produit de véritables intoxications. Les conséquences sur le rendement sont assez considérables, nous avons pu, à plusieurs reprises, noter des diminutions de rendement allant de 20 à 40% et plus; quant aux plants pérennes, ces accidents entraînent souvent leur disparition.

Si l'on se souvient des remarques que nous avons faites à propos des inconvénients résultant de l'enfouissement de masses importantes de matières organiques grossières qui gênent la circulation de l'eau, limitent le développement des racines, créent des irrigularités dans les semis, on conviendra que les agriculteurs sont fondés à brûler ces substances qu'il peuvent considérer à bon droit comme indésirables.

7. ELEMENTS POUR UNE POLITIQUE DE LA MATIÈRE ORGANIQUE

Après ce tour d'horizon qui avait surtout comme objet de rappeler des faits connus en les illustrant par des observations ou des expériences récentes, essayons d'imaginer ce que peut être une politique raisonnable de l'emploi des matière organiques.

L'agriculteur doit d'abord s'efforcer d'enfouir le maximum de résidus végétaux pour éviter une perte d'éléments minéraux. Si les productions sont relativement élevées cette restitution peut suffir à maintenir dans le sol une certaine activité « biologique ». Celle-ci se concrétise par la libération progressive des éléments minéraux. Cette action est celle qui explique le mieux les effets directs observés, nos recherches devraient être développées dans ce sens. Il faut y ajouter un accroissement de l'activité de la faune du sol qui maintient un état physique favorable, la stabilisation de celui-ci par l'« humus » résultant de la décomposition de ces substances.

Mais en général l'étude des bilans de matières organiques montre que les équilibres que l'on obtient dans ces conditions correspondent, au moins pour la France, à des teneurs relativement basses. On peut alors se demander si l'agriculteur doit faire un effort pour augmenter son stock d'humus, ou s'il peut se contenter des effets résultant de la décomposition d'une grande masse de matière organique fraîche n'ayant qu'un faible coefficient de transformation en humus. Il semble que pour un certain nombre de sols caractérisés par une texture favorable, c'est-à-dire un rapport argile/limon de l'ordre de 1 et une teneur en argile supérieure à 15% environ, cette politique soit satisfaisante. C'est celle qui est appliquée dans nos exploitations produisant 50 à 60 q de blé, 70 à 80 q de maïs, 50 t de betteraves sucrières. Une enquête effectuée par un laboratoire privé, le SAS, a montré que dans ces bonnes terres de limon il existait une corrélation inverse entre la teneur en matière organique des sols et leur productivité.

Mais cela ne veut pas dire que l'on puisse impunément descendre au-dessous de certains seuils. Ainsi dans les sols de limon battant une teneur en matières organiques de 1,6 à 1,8% constitue une limite. Dans les terres argilo calcaires de la Champagne Pouilleuse l'observation montre que après des défrichements relativement récents les difficultés de travail du sol, une mauvaise alimentation en azote des plantes se manifestent plus ou moins rapidement. Il semble qu'une teneur en matière organique supérieure à 3% soit nécessaire pour éviter ces accidents [13].

Dans les terres très légères, le recours à la matière organique et la constitution d'une réserve d'humus paraît indispensable surtout si l'on veut installer des cultures pérennes ou cultiver des légumes ce qui est fréquemment le cas. Il faut alors avoir recours à des apports de fumier, de gadoues ou introduire dans les rotations des cultures de prairies temporaires d'assez longue durée pour créer ou maintenir un stock d'humus. On peut citer à ce sujet une expérience qui semble assez démonstrative effectuée par l'I R H O au Sénégal [17]. Les chercheurs de cet Institut ont pu montrer qu'il fallait une jachère enherbée de 2 à 3 ans pour maintenir les rendements en arachides, même en assurant une fertilisation chimique. Détail singulier, les parties aériennes de la jachère doivent être brûlées. Il n'y a pas d'explication à ce fait, mais on peut supposer que cette condition est liée aux influences défavorables des matières organiques enfouies dans ces sols légers et sous un climat sec. De ce point de vue il faut se rappeler que la plupart des effets de la matière organique sont d'autant mieux marqués que celle-ci est mélangée intimement à la matière minérale, ce qui suppose le broyage des résidus végétaux, surtout quand ils sont grossiers.

Seules des actions particulières, comme celles observées par Denarie à Madagascar, impliquent une localisation; il faut noter aussi qu'il ne s'agit pas d'une matière organique quelconque mais du fumier.

Si l'on considère maintenant les terres très riches en argile, il semble que là encore les matières organiques jouent un rôle déterminant. Il s'agit surtout d'une action sur les propriétés physiques. En effet, à partir de 35 à 40% ces terres deviennent difficilement maniables en période humide, mais elles le sont tout autant en période sèche en raison de leur cohésion. Or, ces mêmes terrain, lorsqu'ils reçoivent en abondance des matières organiques ou qu'ils portent des prairies temporaires convenablement traitées, peuvent être travaillés même à la bêche presque en tout temps.

CONCLUSIONS

L'ensemble des remarques ou des observations présentées dans ce texte rappelle qu'il n'y a pas « les matières organiques » mais « des matières organiques », j'entends par là des groupes de substances qui peuvent se caractériser approximativement par leur rapport C/N et leur fermentescibilité.

Quand on parle d'apports de matières organiques, il faut distinguer l'origine de ces substances. Celles-ci peuvent résulter d'un accroissement de la production sur place ou d'un transfert de matières organiques produites ailleurs. De toute façon, il y a production de matières organiques sur place dès qu'il y a agriculture et si il dit y avoir un transfert, il faut que l'on en produise ailleurs en quantité suffisante.

Il faut distinguer dans l'apport de matière organique:

— les cas correspondants à la mise en culture de sols pauvres ou la recherche d'un effet de choc pour augmenter une production à un niveau très bas, ceci correspond à un transfert temporaine;

— le cas d'une utilisation sur place d'une quantité importante de matières organiques, ce qui exige une fertilité élevée. Celle-ci implique presque toujours une fertilisation minérale, car des plantes produisant une ou plusieurs dizaines de tonnes de matière sèche/ha absorbent des quantités d'éléments fertilisants tres importantes.

Quand on décide d'apporter des matières organiques ou d'enrichir le sol, il faut savoir pourquoi, c'est-à-dire avoir procédé au préalable à une analyse du milieu et mis en évidence un problème aussi précis que possible.

On doit alors choisir le type de matières organiques convenables et préciser, par une expérimentation suffisamment réfléchie les conditions de son emploi. En particulier, il y a lieu d'éviter les effets secondaires plus ou moins défavorables.

Il semble donc dangereux d'adopter des systèmes de cultures conduisant à la destruction ou à une exportation systématique des matières organiques. Malheureusement du point de vue économique il est bien difficile d'évaluer le prix que l'on peut payer ces avantages ou au moins cette assurance.

Il résulte de ces considérations que certains aspects des problèmes agricoles sont insuffisamment étudiés. En effet la démarche de la plupart des chercheurs est d'interpréter les problèmes en termes de science fondamentale, c'est-à-dire de procéder à une analyse de plus en plus poussée. Or, ces problèmes n'ont de sens au point de vue pratique, leurs solutions ne peuvent trouver d'application, que dans la mesure où ils correspondent à des situations de terrains suffisamment définies. L'exemple de l'utilisation des matières organiques me paraît parfaitement illustrer cette conception. Les conséquences en sont d'autant plus importantes, surtout si l'on envisage le cas des pays en voie de développement, qu'elles ont pour corollaire la formation de techniciens, d'ingénieurs voire même de chercheurs capables d'appliquer les principes de la méthode scientifique, avec un esprit dégagé de préjugés, aux problèmes tels qu'ils se posent au niveau de la pratique. C'est me semble-t-il à cette condition que l'immense effort effectué dans tous les laboratoires portera tous ses fruits et en particulier assurera des conditions de vie satisfaisantes dans les pays actuellement les moins favorisés.

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DISCUSSION

Chairman: R. CHAMINADE

CHAMINADE

Thank you very much my dear colleague for your excellent paper. You have treated the question as an agronomist and you have examined many aspects of the delation between organic matter and soil fertility, exactly the subject of our meeting, and you have shown also that organic matter was like Esope's tongue sometimes the best, and sometimes the worst. The discussion is open.

HERNANDO

I enjoyed your interesting paper very much. I should like to ask a rather economic question about straw not dealt with in my paper. You say that a high yield arouses some problem in turning the large quantity of straw into the soil. We have this problem since several years in Spain, where we tried to bury the straw, to have the soil cleaned and well cultivated on the surface to sow the cereal. We found now that this method must be changed completely because, it is not necessary, and during one of my visits to the United States I discussed the problem with people in Oregon who had got very similar results in growing cereals over there. The only right thing to do is to use a cultivator to work the soil as shallow as possible, to keep the straw mainly on the surface, but to cut the soil, to remove the roots, to keep the soil without covering the stubble completely. After 2 or 3 months it is possible to seed with the straw sometimes some decomposition, and sometimes not. This depending on the rainfall. At the beginning the farmers said that it was impossible to grow cereal there, that these conditions were worse than ever. But the result was that in the first year the yield was nearly the same with this method, and after 7 or 8 years the yield presented a substantial increase. You may say that the straw will accumulate, and the problem will get worse. This is not so, because during the winter and especially in spring this mulching is decomposed in the soil.

HENIN

Je précise que mon but a été de présenter des problèmes, il ne m'a pas été possible faute de temps de parler des solutions. On peut faciliter l'évolution de la paille, en l'enfouissant par un léger labour. Mais si l'automne est humide, la terre se comporte comme une éponge et il devient parfois impossible de labourer correctement.

Maintenant quand on incorpore au sol chaque année des quantités aussi importantes de paille, avec l'azote nécessaire, il se développe une faune très importante. La structure n'est pas très stable mais le travail de la faune est si intense que le sol ressemble à de la farine. Il est alors très difficile de le travailler, il ne « passe » pas sur le versoir; on doit alors le rendre un peu plus compact. Une fois de plus, j'insiste sur la nécessité de savoir s'adapter à chaque situation.

HERNANDO

There are no difficulties in removing the plants through cultivation only to leave the new plants to grow.

HENIN

Je n'ai pas bien compris votre commentaire à propos du mélange de la paille et du sol.

HERNANDO

Don't worry about mixing the straw into the soil. The stubble must be removed, but the straw must not be thoroughly mixed with the soil. This is important.

The other point is that the effect of the organic matter is to reduce the damage of the nematodes. I am not a specialist in nematodes, but it is difficult for nematodes to get into the organic matter, so that the roots can easily develop. This can be easily observed in the Canary Islands on the banana trees. For many years the banana trees are troubled by the nematodes, and the farmers reduce this damage considerably by applying high amounts of organic matter to the soil.

HENIN

A propos des nématodes, j'insiste sur le fait qu'il n'y a protection des racines, que si on a placé le fumier par poignées. La même quantité, ou plus mélangée au sol ne produit pas l'effet. Il faut donc être très précis à la fois quant à l'interprétation de l'expérience, et à la description des conditions de l'observateur.

HERNANDO

I say both. The nematologists in the Canary Islands look upon this problem with a scientific and practical view, as they say, because the organic matter contains a certain substance, which one, I do not remember, and this substance exerts a certain effect on nematodes — this is the scientific point. The practical point I explained before.

SWABY

I am very interested in this problem you have on the disposal of bulky stubble. At one time we had this also, however it is less a problem to us now, because on our cereal farms we always have sheep and if you put sheep into a stubble they knock it down very quickly — so quickly that it serves as a stubble mulch. Now I don't know enough about your farms to know whether you have enough animals to do just that. That is one question, I should like to ask another which will not take long.

HENIN

Je vais d'abord répondre à cette première question. Dans le passé, il était courant de faire pâturer les moutons sur les chaumes mais pour des raisons économiques et sociologiques cette technique a été abandonnée. Il devient difficile de trouver des bergers, il faut orienter la production de manière à nourrir les animaux pendant une bonne partie de l'année; l'utilisation des chaumes ne constituant qu'un appoint. Comme il apparaît difficile de résoudre tous ces problèmes, de nombreux agriculteurs ont abandonné l'élevage du mouton.

SWABY

The second qnestion was an observation we have made. When you are running a fertilizer trial, such as you did on peanuts with and without organic manure and phosphorous; you very frequently find in about two or three years a decline of a crop. We have sometimes wondered what this was due to until calling in a Pathologist or an Entomologist and they usually end up finding that there is some pathogen or pest that has increased. I wondered if this can explain some of the decline that you have been getting in the peanuts.

HENIN

Je précise que l'on a pas cultivé les arachides pendant trois ans, il y a eu un mil entre les deux cultures d'arachides. Il ne semble donc pas que l'explication soit d'ordre pathologique.

BAVER

I would like to review my comments of the other day with respect to nematodes. We found the same thing in North Carolina where we have lots of nematodes. Dr. LINFORD of the Pineapple Research Institute in Hawaii, a number of years ago, studied the effect of the organic matter on nematodes and found there was a trapping of the nematode by certain fungi during the decomposition of organic matter. We found in our rotations where we had good organic matter decomposition, the tobacco crop was free of nematodes.

HENIN

Ce qui fait l'originalité de l'observation de Monsieur DENARIE, c'est que le résultat n'est observé que si l'on enfouit le fumier par poignées. Si l'on enfouit deux ou trois fois plus de matière organique en la mélangeant au sol, il n'y a pas d'effet. Par ailleurs, les racines ne sont pas attaquées par les nématodes même lorsqu'elles ne sont plus dans la poignée de fumier, ce qui a conduit l'auteur à faire la même hypothèse que celle que proposait le Prof. HERNANDO sur l'existence d'un produit ou d'une flore protectrice.

BRAMAO

I have one small observation. I have enjoyed seeing your slides of soils, two particularly showing the roots of a grape plant. In one of the cases you used organic matter and the roots were very well developed. Iu the other cases you used fertilizers and the roots were not so well developed. But from the slides one could see that the soils were different. One had the feeling that the second slide represented a soil showing the characteristic signs of oxygen deficiency which would harm root development.

HENIN

Il est évidemment difficile de préciser si le développement des racines des vignes est dû à la structure du sol ou à un autre facteur. C'est pourquoi j'ai présenté l'effet d'un sous-solage avec placement d'engrais à titre de comparaison. Vous avez pu remarquer que même dans la fissure laissée par la sous-soleuse le développement des racines est tout de même beaucoup moins abondant, bien que l'aération soit bonne. Un autre facteur d'ordre physique ou chimique doit jouer quand on enfouit du fumier. C'est pour justifier cette hypothèse que j'ai présenté les deux projections.

GENERAL DISCUSSION OF PAPERS PRESENTED ON 25 APRIL 1968

Chairman: R. CHAMINADE

HERNANDO

I think those who are interested more in the natural aspects and in agronomy problems (practical problems) should have a joint discussion this evening with Prof. JENNY as Chairman, and may be also with those of more theoretical Physical and Chemistry aspects. I daresay that yesterday in the session of more theoretical chemistry and physics we arrived at clear propositions. Well, there are two possibilities, either to be separated or to join with us. Some of the participants in the yesterday's meeting of physics and chemistry were mostly interested in practical problems, and this evening we are going to have a meeting on these other aspects.

CHAMINADE

Thank you very much Prof. HERNANDO. Gentlemen, I think we have 37 minutes for this discussion and it is open on all the papers which have been presented today. Papers of Prof. PRIMAVESI, of Prof. FLAIG, of Prof. HERNANDO, of Prof. HENIN and also my own paper. The discussion is now open - Prof. PRIMAVESI.

PRIMAVESI

The paper of Prof. HENIN was very interesting, including various experiences made in Brazil in the States of São Paulo and in Rio Grande do Sul. Very interesting is the part referring that it is necessary to distinguish the origin of the organic matter. In this direction, I think it is also interesting to make a petition to Prof. BRAMAO to study the possibility of organizing experiences in various countries of the tropics and sub-tropics.

SWABY

I direct my question to Prof. FLAIG. I am a little ignorant because I don't know the concentrations of some of the physiologically active quinones that are likely to occur in soils. Unless they are in reasonably high amounts, I imagine they would not have an effect on plants and yet we know that many of these quinones are very inclined to polymerise and so this must reduce their concentration, perhaps below the level where they are physiologically active. I would like to have your comments on this.

FLAIG

Prof. SWABY, to answer your question I must begin to say that the concentration of vanillic acid and substances of this type are between 10^{-5} to 10^{-4} molar approx. in the soil. The favourable physiological effect of the quinones on plant growth is at a concentration, that is 10 or 100 fold lower than the one of phenolic acids. Until now one did not succeed to isolate quinones from soils but they could be isolated from cultures of micro organisms. You are right, some of them polymerise relatively easy. It had been possible for instance to show that vanillic acid dimerises to dehydrodivanillic acid and that this acid can be decarboxylated to the corresponding quinone. Furthermore it could be shown that α-conidendrin is degraded to methoxy-p-benzoquinone. This is also a degradation product of vanillic acid. The concentration of the physiological activity of such quinones is between 10^{-6} to 10^{-4} molar. It is certain that isolation of this quinones from the soil is not easy in such low concentrations. But evidence is given by the experiments in microbial cultures. During decomposition of organic material, for instance straw, this I mentioned this morning, it is possible to identify during the whole time of decomposition different phenol carboxylic acids which can be derived from lignin.

I mentioned *Epicoccum nigrum*; one can isolate also different phenols from the culture of this microorganism.

I would say, it would be fruitful work if one could identify other different phenolic and quinonoid compounds from the soil — a work, which has been begun by SHOREY and SCHREINER nearly 40 years ago.

ALEXANDER

My question is to Prof. PRIMAVESI. I feel obliged to point out some distinct differences between a few points made in yonr paper and our own observations or information that I am familiar with on microbes in temperate soils. Time does not permit me to deal with more. For example, you comment on the occurrence of anaerobic fungi or the production of acids by fungi in anaerobic soils. You also state that fungi killed plants by the production of methane and nitrite. You raise a point about antibiotics being produced and being present in soil. These are just some of the points which don't agree with any of our own experiments, or experiments I am familiar with. Do you wish to comment on these points? Do you observe anaerobic fungi in soils? I am not very familiar with such organisms. There are some which can grow under anaerobic conditions in laboratories but these are not of ecological significance. Likewise, what evidence do you have for antibiotics being produced in soil? Dr. WAKSMAN has pointed out, I think very aptly, that our knowledge of antibiotics is derived from culture studies and it is still problematic whether they are produced in natural conditions or not.

PRIMAVESI

It is not easy to the colleagues of the temperate zones to understand our problems. I invite Prof. Alexander to study with us *in loco* our problems.

To your question: I did not comment on the occurrence of anaerobic fungi, but on fungi in anaerobic soils. In the State of Rio Grande do Sul, we found proliferous fungi flora in compact anaerobic soils.

ALEXANDER

That does not prove that they are doing anything in the soils.

FLAIG

I have a question for Prof. HENIN. You told us such interesting things about the use of straw as soil organic matter. You are also familiar with the work of SAUERLANDT, Völkenrode, who found that about after five years it is no longer necessary to give additional nitrogen to decompose straw, and that after this time no nitrogen fixation occurs when using every year straw as organic material. This means that the soil is enriched with organic nitrogen compounds, which are mineralized. I would like to ask you what is your opinion about this slow acting nitrogen source from humified straw for plant growth, because we are interested in slow-acting nitrogen fertilizer from the chemical point of view.

HENIN

Si j'ai bien compris votre question, le Prof. SAUERLANDT à constaté qu'après cinq ans d'apport conjugué de paille et d'azote minéral il n'était plus nécessaire d'utilizer l'azote, les quantités libérées dans le sol étaient suffisantes pour éviter les inconvénients du blocage de cet élément; je suppose que la terre était sableuse. Si la terre est plus argileuse, la situation est différente. Dans l'expérience de MULLER après six ans l'apport d'azote est encore nécessaire.

Il semble qu'en terre légère et sous votre climat les matières organiques se minéralisent plus et il doit se former moins d'humus. Les effets cumulés de la paille et de l'azote sont alors comparables à ceux d'un engrais azoté organique comme les tourteaux. Quant à l'effet sur les cultures il dépend du climat qui en contrôle l'activité biologique, l'azote pouvant être minéralisé plus ou moins tard dans le sol.

FLAIG

I agree that is necessary to give every year inorganic nitrogen in such an amount, which is necessary for the growth of the crop plants.

HERNANDO

I would like to comment on the excellent paper of Prof. CHAMINADE. You demonstrated very clearly the effect of organic matter applied to the soil with different levels of nitrogen. Without organic matter yields do not increase although you applied double amounts of nitrogen compounds. To some extent it is the same as with the problems of phosphate, nitrogen, potash etc. When you showed us that with the increased application of phosphate you did not obtain a higher yield, everybody will understand that phosphate is of no use in this case for plant growing. We can only say that the phosphate level is too high in this soil, and therefore, the yield cannot be increased by applying phosphate, and one cannot say that the application of phosphate to the soil in general would not be necessary. It is the same with potash, if you have a soil with a very high level of potash, and still you apply potash this does not increase the yield. I believe it is the same with organic matter. If you add organic matter to a soil, like the one you showed us, i.e. which needs no organic matter, you do not get any increase in the yield. In making an experiment with soil that needs any organic matter, you can increase the yield.

CHAMINADE

Yes, I think I agree completely with Dr. HERNANDO. The problem of organic matter is like all agronomical problems. General conclusions are always difficult. For example we know that phosphoric acid is a good fertiliser but we know that some soils do not need phosphatic fertilizers. I think it is the same thing for organic matter. When the level of organic matter in the soil is sufficient, additional organic matter does not give the effects I have shown. I have worked on a subsoil, containing a very small amount of organic matter and in this case the effect of the addition of the organic matter, was a positive effect, but I am not sure with a surface soil containing a certain quantity of organic matter whether the result will be the same; it is impossible to know the exact amount of organic matter, over which organic matter is not useful. That depends on the nature of the soil. In sandy soils it is not at all the same level than in clay soils.

HENIN

Je souhaite présenter une remarque générale. Nous considérons souvent les phénomènes en physicien, c'est à dire que nous envisageons des relations simples comme celle établie par le Prof. BAVER entre la porosité et le rendement des betteraves à sucre. Je crois que nous devons penser comme des médecins, c'est-à-dire considérer que nous avons à traiter des êtres vivants qui ont une histoire et qui peuvent compenser certaines situations. Par example, dans une terre battante la germination d'un blé peut être mauvaise, mais si le printemps est favorable, le tallage peut être important et la récolte aussi élevée que celle obtenue dans un terrain où la germination a été bonne. La fertilisation azotée doit être adaptée aux différents phases du dévéloppement d'une céréale

Si l'on examinait plus en détail l'action des matières organique en fonction des phases du développement nous aurions probablement plus d'informations.

ALEXANDER

I would like to carry Prof. HENIN's analogy one step further. Occasionally the physician kills the patient! There are still many examples where the use of organic matter, judiciously or injudiciously, leads to a number of deleterious effects. You point out the effect of farmyard manure on legumes interpretable on the basis of nematode control. There are many other examples where organic matter has a beneficial effect in controlling plant disease. On the other hand, there are a reasonable number of examples, I am not sure whether an equal number or a greater number, but a reasonable number of examples where the addition of organic matter makes a disease situation worse. So let us use our physician's knowledge with considerable care.

HENIN

Le Prof. ALEXANDER a beaucoup d'humour. Mon idée n'est pas de plaider en faveur d'effets magiques des matières organiques, mais seulement de préciser les conditions d'observation permettant de tirer plus de conclusions de nos expériences.

SWABY

I address this question to yourself Mr. Chairman: In your work that you shrowed this morning, the stimulating effects of humic acids upon rye grass, I could not help but wonder whether your results might not be explained by some work we did ourselves years ago. We were testing a number of nutrient solutions to see which ones were best for growing plants in sand culture. We tried quite a number and found almost all of them had much too high a concentration of one element or another. In other words, there was imbalance of nutrients. Now I know that you were particularly careful to apply nitrogen by split applications and phosphorus by having many levels, but the element that we have found that was often in far too high a concentration in some of these nutrient solutions was copper. Copper happens to be extremely good at combining with humates. It forms a very firm bond which seems to be partly a chelation bond and partly ionic. Consequently, humates are extremely good at detoxicating solutions that contain copper. I am not implying this is the whole explanation for some of your work but could it be a partial explanation?

CHAMINADE

Prof. SWABY do you speak about experiments on soil or in solutions?

SWABY

I only confined remarks to experiments on sands and solutions, not any containing clay, because toxic copper is no problem in clay.

CHAMINADE

In the mechanism of humic acid it is possible that there is a chelating effect of humic acid on minor elements. But in those experiments I think that the quantities of minor elements which were in the solution were sufficient for not having deficiencies of minor elements. I have tried several concentrations of minor elements to prevent deficiencies.

SWABY

I am afraid you are misunderstanding my question. I am implying that the solutions had toxic amounts of copper — not deficiencies of copper and that your humus was taking some of this toxic copper out of the solution.

CHAMINADE

The solution contained 0.075 mg/l of SO_4 Cu. I do not think that this concentration be toxic.

BROADBENT

Returning to the question of your corn that was grown in nutrient solution, I noted, as nearly as one could diagnose that deficiency from a kodachrome slide, that your corn which received no organic matter looked as if it had iron deficiency. Whereas where you had added the humic acid to it this deficiency was corrected. In what form was the iron present in the nutrient solution in the absence of humic acid?

CHAMINADE

We have used several forms of iron in the solutions. We had no symptoms of chlorosis in plants nor symptoms of toxicity.

JENNY

I share the impression of Dr. BROADBENT, that you might have had an iron deficiency. In much of the earlier nutrient solution work, before the iron chelates were introduced, it was a regular practice to add iron humates to serve as a source of iron.

HENIN

Il me semble que dans notre revue nous n'avons pas assez envisagé l'influence des matières organiques, sur la toxicité ou les carences dues aux oligoéléments, il me semble que seul le Prof. HERNANDO en a parlé.

Cependant en pratique nous évitons la toxicité du cuivre en associant un chaulage et un apport de matières organiques. On a constaté également des carences en manganèse provoquées par le chaulage de terres riches en matières organiques.

BRADFIELD

I would like to ask Mr. CHAMINADE what is his theory for the effect of the organic matter in his experiments.

CHAMINADE

I think Prof. FLAIG knows much better than I this aspect of the question; my main work was to have experimental facts well established but I have not examined the physiological interpretation of the facts. This aspect of the question is treated in the paper of CHRISTEWA.

FLAIG

The question about iron deficiency or the possible influence of soil organic matter on metabolism is like putting together small stones for a mosaic. At first we investigated seedlings of cereals and found in the case of addition of different types of physiological active substances, such as humic fractions with lower molecular weight, phenols, quinones, lignin degradation products (about 30), different types of synthetic and natural growth substances and uncouplers like nitrophenols, that metabolism is changed. The content of starch decreases and the content of reducing sugars increases. The activities of some enzymes increase such as saccharase, aldolase and some others decrease. Furthermore we found that in the citric acid cycle some acids are increased or decreased. For instance, the content or citric acid increased, fumaric acid decreased because the activity of succinodehydrogenase decreased. Also the content of pyruvic acid increased. Furthermore the content of organic phosphate decreased and inorganic phosphate increased. These were the experiments with seedlings of plants. Some of these observations could also be made with plants in pot experiments. Then we investigated some phosphorylation reactions with yeast. We found that the respiration of yeast was increased by addition of physiologically active substances in certain concentrations. Furthermore, the work with yeast showed us that the substances altered the metabolism at a central point and that phosphorylation reactions were changed. Therefore, we worked with mitochondria of rat liver or of cabbage. Part of the results are mentioned in the paper. In my lecture I have shown why we use the weak uncoupling of oxidative phosphorylation as a working hypothesis to explain the increase of dry matter which can be observed when different physiologically active substances are given in different concentrations to the cultures of plants.

ALEXANDER

As long as you keep the presumed effect on oxidative phosphorylation relations as a working hypothesis, I am willing to accept it. But I think what you are pointing out are still correlations; that is, the various changes in enzymatic level, changes in concentration of various metabolites, etc. And as you know far hetter than I, rat liver mitochondria and plant mitochondria are free of cells and free of tissues, so it is a little difficult to extrapolate from these conditions to those of the entire plant.

FLAIG

I said we proved the results, which have been found with yeast, or with plant seedlings, with the mitochondria in the case of phosphorylation. We don't only conclude from the experiments with mitochondria that the weak uncoupling of oxidative phosphorylation is the effect. We are not so convinced that these substances have their main effect on RNA and protein synthesis. According to the papers which appeared after a meeting of the New York Academy of Science in September 1967, some doubts arose also in different authors on this theory. I commented a little also on the experiments we made in this direction with lignin degradation products and microorganisms.

STUDY WEEK'S FINAL GENERAL DISCUSSION ON 26 APRIL 1968

Chairman: BRADFIELD

Secretary: BROADBENT

BRADFIELD

Before we start on the main business of this morning, Prof. HERNANDO has a few points to bring up.

HERNANDO

Could the corrected copies of the Report be returned quickly to enable the Final Report to be issued within 6 months.

WAKSMAN

I propose that we should also send a telegram to Prof. HERNANDO and Prof. LORA-TAMAYO, thanking them for their organisation of the Study Week.

BRADFIELD

I call for approval of Prof. WAKSMAN's suggestion and asks Dr. BROADBENT to be Secretary for the morning.

BRADFIELD

We have three Committees which were appointed yesterday. They have had meetings and they have reports to submit. I shall call upon the Chairman of each of these Committees to report the recommendations. There will, inevitably, be a certain amount of duplication and there will probably be some additional recommendations made from the floor. In order to eliminate these unnecessary duplications and incorporate the suggestions which come from the floor and to arrange these recommendations in a logical sequence we will need some time and I would suggest that after we have passed through this preliminary stage that the Chairman of each of the Committees meet together and do this job of eliminating the overlapping in their Reports. They should also place the various recommendations in a proper sequence. All the necessary parts will probably not fit very logically together so we will have to do a little polishing to put it in final form but I think we should make every effort to finish these two jobs before we adjourn to-day. Then we will request someone to do further revision so we can have the Report in its semi-final form, ready for your consideration by 8.30 to-morrow. It will not take long but, will give everyone opportunity to suggest elimination and last minute additions.

HENIN

Il me paraît souhaitable que nous puissons disposer du texte des résolutions établies aujourd'hui, de façon que chacun puisse le lire soigneusement et puisse ainsi donner en toute connaissance son opinion demain matin.

BRADFIELD

I ask Prof. JENNY to present his statement.

JENNY

Last night we discussed three aspects. First, and most important, an umbrella draft to cover definitions and the concept of the entire work on organic matter. Secondly, we enumerated a list of functions of soil organic matter. We assume that this is being covered by other Committees, and our list is merely a check that nothing has been omitted. Thirdly, we composed a list of recommendations for improving soil conditions in various areas of the world.

I will read to you now the overall umbrella-type introductory statement which we discussed at length last night. Prof. FRANZ has summarized a part and I have integrated it with the other aspects. This is the first version and it is open for discussion.

The organisms in and on the soil constitute the soil ecosystem. It is an open system. Substances, especially organic matter, are continually added and removed. During any period of time the change in soil organic matter equals the gain minus the loss. Under natural conditions a dynamic equilibrium or steady state is reached in which the gains by nitrogen fixation and photosynthesis and the losses as a result of decomposition balance each other. This equilibrium state, which is reflected in the organic matter content of the soil, depends on a variety of factors, such as climate, plant material, flora and fauna, etc., and varies widely over the surface of the earth. Man disturbs the natnral ecological equilibrium by accelerating the losses and reducing the influx of carbon and nitrogen; the organic matter content of the soil is thereby lowered, reducing its fertility and even destroying it completely. On the other hand, man may shift the balance of input and output of organic matter in his favour and thereby improve the crop producing capacity of the land.

BRADFIELD

Do you think we need such a statement as this as an introduction to our Report?

WAKSMAN

Mr. Chairman, I think it is very necessary, and if I could have a few minutes I would like to present another statement, not the same one presented by the agronomy group, but a statement by a senior microbiologist.

I would like to present a similar summary as Dr. JENNY presented on behalf of the group, but my summary is not presented on behalf of the microbiology group, but on my own behalf. The various problems involved in the relation between organic matter and soil fertility take into consideration four distinct phenomena.

First, *the soil as a living system*. Aside from its mineral composition and organic matter or humus content, the soil also contains an extensive population of living organisms. These range from the smallest bacteria and protozoa, actinomycetes and filamentous fungi to the large mushroom fungi, root systems of various plants, insects and insect larvae, as well as animals. These normal soil inhabitants are living in or upon the soil. They bring about the transformation of fresh organic plant and animal residues that find their way into the soil. They also bring about the synthesis of large quantities of fresh organic materials in their own bodies which contribute in a very appreciable manner to humus formation.

Secondly, *the soil is not a static but in a dynamic condition*. The activities of the numerous soil-inhabiting organisms result in a series of changes in the composition of the residual organic matter, and are accompanied by a continuous stream of carbon dioxide, absorption of oxygen, liberation of nitrogen in the form of amino acids and ammonia, and the liberation of phosphorus and other minerals in available forms. These processes make the continuation of fresh plant growth possible. The various forms of life which inhahit the soil exert also a number of influences upon one another, which are either associated or antagonistic in nature. The microbial population of the soil also exerts a variety of influences upon plant growth, due to the formation of growth stimulation and growth inhibiting substances. The decomposition of the different chemical constituents of the fresh plant and animal residues in the soil does not proceed at a uniform rate. The carbohydrates effect the decomposition of the proteins resulting in fresh synthesis of microbial cell substance. The lignins and tannins influence greatly the decomposition of the proteins, forming complexes with them, thus affecting the liberation of nitrogen in the available forms.

Thirdly, we must consider *the stable organic matter accumulating in the soil and known as humus*. This is what makes the soil fertile and gives it a kind of a buffer against extreme changes in fertility. Humus is more or less in a state of chemical equilibrium and is characterised by certain physical properties, notably dark colour, porosity, moisture holding capacity, as well as certain chemical properties, notably a stable carbo-nitrogen ratio. Although more resistant to attack by microorganisms, humus still undergoes gradual but slow decomposition, bringing about the liberation at a continuous rate of the carbon and nitrogen in it, although this change is not as rapid as that of the fresh plant or animal residues. It takes place, nevertheless, at a definite rate.

Finally, we must consider *the part played by man in modifying the soil*. Is it not written in The Bible that the Creator has made man out of the earth I would like to quote from The Old Testament of The Bible « ... and The Creator said 'Let us make Adam out of the Adama' ... ». This is particularly significant. Man has come from the soil and continuously modifies the soil. One need only list the action of man in cultivating and bringing about the various changes in the soil.

The papers presented in this symposium have dealt with the various aspects of the problems listed here and intended to give us a better understanding of the nature and transformation of soil organic matter and its role in soil fertility.

BRADFIELD

This is a very interesting statement. There is one question in my mind on hearing it for the first time. It seems to me that it contains some material which should probably be placed in different parts of the Report. For example, you have given certain details regarding microorganisms which I think might more appropriately be incorporated in the microbiology section of the Report. On the other hand, there are a few statements which I think would fit in very well in the general statement which Dr. JENNY has prepared. I suggest that this statement, prepared by Dr. WAKSMAN, be referred to the Chairman of the Committees and that they consider the proper place to incorporate this report.

HERNANDO

Following Prof. JENNY's statement, I perfectly agree, but this is just the general aspect. According to me the question should be handled more thoroughly so as to give it a broarder outlook.

JENNY

I am coming now to the second part which is merely a list of functions of organic matter which our group would like to see being handled by the other groups. We are listing what we think should be included:

Functions of organic matter:

1) to enable fixation of nitrogen and to protect the nitrogen fixed;
2) to improve soil structure;
3) to increase the exchange capacity of the soil and the absorption of mineral elements, macro- and micro-elements;
4) to increase the field capacity of the soil and thereby assist in water conservation;
5) to store energy available for microbial life;

6) exert physiological effects on plant growth including anti-toxic behaviour.

These are a minimum set of statements which should be included in the report.

The third part has to do with the recommendations for improving specific soil areas of the world. This part is, unfortunately, not ready until Dr. BRAMAO arrives.

BAVER

We have a philosophy in our 'umbrella' to point out the fact that agriculture means that you are going to have organic matter.

A. Origin and value of Organic Matter

1. Soil organic matter is a by-product of plant growth both past and present and the biological transformations of the residues that are produced.
2. It is a tool in the management of soils for greater plant and animal production that is able to modify deeply the natural properties of the mineral fraction of the soil, depending upon the specific soil, climate and plant situations involved.
3. The greater the production of the plant the higher the organic residues both tops and roots that are produced. In a well-fertilised soil this growth will result from nutrients supplied by both the organic matter and artificial fertilisers.
4. This agricultural production of crops can only be achieved by the formation of organic materials. There is no need to evaluate the use of such residues to the maximum economic potentialities in world food production.
5. Organic matter influences the biological, physical and chemical properties of soils. The extent of these actions depends upon as many variables of soil, climate and crop. It is recognised

that the majority of the nitrogen, phosphorus, and sulphur suplied by the soil in the worlds' annual harvest of the crops is derived from the soil organic matter.

B. The Physical Effects of the Soil Organic Matter:

The physical aspect of the influence of organic matter on soils may be divided into two major categories.

1. Its use as a mulch to protect the soil surface from:
   - *a*) the impact of raindrops and subsequent protection against the capping effect and prevention of water erosion;
   - *b*) the impact of wind and the prevention of wind erosion;
   - *c*) the impact of solar energy and subsequent evaporative losses of soil moisture or the detrimental effects of high temperature as may occur in the tropics.

2. The incorporation of organic residues in the soil through root systems, soil fauna activity or by mechanical means that changes the structural properties of the soil associated with soil aeration water-holding capacity, drainage and soil strength. This must be done as to avoid formation of pseudo-gley soils and subsurface mats. Now we thought it necessary to make a statement regarding the status of existing information with which we can agree. We have this to contribute:
   - *a*) With respect to organic mulches,
     - 1) their use for moisture conservation, erosion control and reduction of soil temperatures, has been adequately documented by research;
     - 2) mulch tillage has become an accepted agronomic practice in certain areas of the world, such as the Western Plains of the United States;

3) the protective effects of organic mulches is applicable to most soil situations except poorly drained cold soils or in areas of long periods of drought without irrigation. Care must be taken to prevent fires.

Those are the situations that we do think we have available information on.

b) With respect to the information concerning the incorporation of organic residues:

1) the amount of residues that can be incorporated is dependent upon the depth of the soil, the availability of machinery to accomplish burial and economic factors;

2) the production of humus and its resultant effect upon soil structure is a function of microbiological processing, the activity of certain soil fauna, such as earthworms and the root effects of vegetation;

3) beneficial effects of organic matter on soil structure are rarely obtained on well granulated soils such as the low humic latersols in the tropics;

4) the stable aggregating effects of organic matter are the results of the formation of clay organic complexes resulting from the products of microbic synthesis and the products of microbic decomposition;

5) cultivation of soils aggregated by clay organic complexes without proper organic management, eventually leads to the deterioration of soil structure through a decomposition of organic link in the clay organic complex.

Now those are things we thought we could agree upon, is what we know about the situations.

Basic research needed for a better understanding of the organic matter effect on soil physical properties.

First, we need to study the use of mulch tillage and sod seeding under different soil and environmental conditions as affecting soil properties and crop yields. This must include an evaluation of the fire, insect and rodent hazards. I know in our work in Ohio for example we are finding that we do not have all the know-how to do this yet, particularly in relationship to the management of the organic matter or to solve the insect and rodent problems that occur with it.

With respect to the incorporation of organic matter in the soil, we feel that the most important aspects are :

1) study of mechanisms of interaction of the constituents of humus with soil particles of different texture and mineral compositions;
2) we need standardized methods for characterising and determining the stability of soil aggregates. We all have our own methods for doing this, generally speaking. We think there are the two major research areas in the field of physical properties.

Now there are some general research problems. The first is the need to know what has been done and so we suggest the collection and interpretation of past and existing experiments in relation to environmental conditions, soil characteristics and soil and crop management. The second is the management of soil organic matter for achieving optimal results on soil physical properties; in other words, if we are bound to have this organic matter, how much are we going to handle from the standpoint of mulch tillage and how much from the standpoint of an incorporation.

In our group we also have to handle the chemical effects of soil organic matter. What is the status of existing information in this area:

a) soil organic matter is a mixture of fresh plant and animal residues and more or less transformed substances frequently considered as humus. The latter is a complex mixture of polymers of varying size, shape and chemical composition;

b) humus substantially contributes to the cation-exchange capacity of the soil system.

We thought that these were two points that everyone is pretty well agreed upon.

Basic research needed to clarify the differences of opinion:

1) improvement and development of methods for extraction and characterisation of soil organic matter. These should include the use of tagged plant materials for fractionation studies leading to identifying chemical groups;
2) further evaluation of the mechanisms involved in the formation and transformation of humus;
3) the effect of humus on the availability of mineral elements, their transportation and their immobilisation;
4) the organisation of properly integrated long term field studies, along with supplementary laboratory investigations, on the interaction of organic substances and mineral fertilisers.

We have one final general recommendation which is to suggest to the group that we recommend that an international organisation sponsor a soil bank of major soil groups for research purposes.

WAKSMAN

I think that here we have an ideal opportunity once and for all to decide whether this humic acid, a name that keeps popping up all the time in the study of organic matter, whether there is a place for it or not. I think we could easily have a committee or some group to consider this and present a recommendation at some gathering of this nature, perhaps before the next Congress of the

International Society of Soil Science, because it is really confusing between the concept of the organic constituents of the soil organic matter, on the one hand and these ephemeral concepts of humic acids.

BAVER

I think that our recommendations here lead to just what you are talking about.

BRAMAO

(Concerning the third part of the statement by Dr. JENNY).

Problems of tropical soils in South America, may be quite different from problems of tropical soils in Africa and in South East Asia. One difference is that many of the soils of tropical South America have a very low exchange capacity and low base saturation, very near the critical point.

BRADFIELD

May I suggest that instead of going into the details now that you prepare your statement and give it to us a little later. Boil it down, including only the essential points stated as concisely as possible. If you would do that and submit it to the group of Chairmen of the various Committees before they adjourn later this morning, that would be helpful. Are there any further comments from the floor before we go on to the Report from the Chairman of the Biology Committee.

NORMAN

We took a somewhat different approach in our Report, and commented rather briefly on what we think is known and what we think is not known. We did not write one of these 'umbrella' statements so that we do not have the problem of incorporating that into the material prepared by the other groups.

Report of microbiology sub-group

1. Importance of biological processes in soil evolution and fertility

Much is now known of the capabilities of organisms found in soils to accomplish the decomposition of plant residues, either under virgin or cropped conditions, and of the biochemical transformations involved. However the total ecology of such environments is inadequately comprehended, so that the extent of the control which man can exercise over the degradation of plant residues under practical conditions is quite limited. It is recognized that the decomposition process is an integral and essential part of the cycling of plant nutrients, especially nitrogen. The principles governing nitrogen turnover under aerobic conditions are relatively clear, though it must be admitted that data relating to tropical soil conditions are less substantial than those obtained under humid temperate conditions.

It is now understood that in the decomposition of plant residues the soil population may have effects on plant growth and crop yield other than through the release of major and minor nutrient elements. These effects, often subtle, are not yet fully understood or adequately explored, but they include both inhibitory or repressive responses in seed germination and root development, and growth stimulatory or modifying effects of a hormonal type. These responses may arise from the release of substances preformed in the residues or from the production of physiologically active compounds by individual species in the microbial population.

2. Practical applications of soil biology

In both developed and developing countries soil biologists can improve soil fertility and plant productivity by inoculating soil and seed with organisms, including bacteria, fungi and fauna.

a) The growth of legumes can often be greatly increased by inoculating seed with root nodule bacteria specially selected for their efficiency in fixing atmospheric nitrogen.

b) The growth of fruit and forest trees and also some crops can be improved, particularly in soils of low fertility, by inoculating them with mycorrhizal fungi, which enable the host plants to absorb more nutrients from soil minerals and organic matter.

c) Soils lacking in certain soil animals, such as earthworms and dung beetles, which are responsible for burying and comminuting animal manure and plant debris, can be improved by introducing these animals.

d) Plants may sometimes be stimulated, or pathogens suppressed, by inoculating seeds with selected micro-organisms; but more trials are needed before these become acceptable practices.

3. Recommendations

a) The management of crop residues, organic wastes, and of some organic industrial wastes through decomposition in soil is of importance to both rural and urban societies. Wider dissemination of established knowledge concerning organic matter breakdown and development of effective and economical new methods are needed. Emphasis should be placed on minimizing the labour requirements in organic matter management.

The humus or organic fraction vitally affects the characteristics of soils; agricultural productivity in most situations is positively influenced by its presence. This fraction in mature soils, though relatively resistant to biological change, may be easily destroyed by improper land use. It is a fragile asset that if lost can be rebuilt inadequately with great difficulty. Human activities that destroy this asset are often thoughtlessly undertaken. Uses that modify the soil character by introduction of materials that affect the soil population or the growth of plants on the soil should be more thoroughly examined.

b) Pesticides and other chemicals are now widely used in agriculture, but little is known of their transformation, persistence and effects on soil organisms.

c) Study is needed on the behavior, durability and means for the eradication of soil-borne plant pathogens inasmuch as such disease organisms constitute a major threat to food production in all regions of the world.

d) Our knowledge of the transformations of nitrogen, phosphorus, sulphur and of the other nutrient elements important in crop production, is still highly inadequate in some soils and is lacking in many others. The availability of these elements is often governed to a significant degree by the soil community.

e) It is recommended that long-term experiments be made on the influence of human actions on soil biology and organic matter in the soil. Attempts should be made to reclaim soils degraded by erosion, salt or flooding. New techniques should be developed for the study of natural and modified communities of soil organisms, including the microflora and fauna. Better methods are needed for the study of the ecology of soil organisms.

4. Training needs

Because it is likely that world food needs will require great changes in agricultural practices in many developing countries, it will be essential that training be provided in soil biology for individuals from these countries, and further that those who must be concerned with the management of crop production programs have understanding of the processes of organic matter transformations in soils.

BRADFIELD

Thank you very much Dr. NORMAN for this very excellent report. I am glad that you put in that last statement because I think it should be incorporated. I think however, the Committee of the Chairmen would do well to consider broadening the base of this statement because it applies not only to biology but to all aspects of our problem. Are there any comments or suggestions?

DHAR

Prof. NORMAN read about nitrogen phosphorus and transformation, but before that he referred to insufficient studies in developing countries, but I don't think that reference is needed. We are in an international group and other studies are needed but I don't think it is necessary to say that not much is known in the hot countries but more is known in the temperate countries.

NORMAN

The comment was made Prof. DHAR, out of a general feeling, which I sense is rather widely held here, that we know less about some of these processes in tropical soils or soils that maintain throughout the year rather high temperatures than we do on temperate soils, and it was not intended in any way to reflect the differences in the amount of work that had been done.

DHAR

The problem needs further studies all over the world.

BRADFIELD

Are there any other comments?

FRANZ

Mr. Chairman, I feel that it would be important to put in our paper at the end something about the responsibility of man, probably in this way: man of our technical period is able to interact much easier and much more powerful in the equilibrium of ecosystems than man on the first stage of evolution. So responsibility of man for conservation of nature in all the parts of our planet becomes much higher. Many people are not prepared to take this responsibility. Often technical methods are applied which do not correspond to the need of conserving natural resources. This can be the case because man has not enough information about the effect of his actions. This can, however also be because he tries to have the highest economical effect at the cost of conservation of nature and resources. There are many possibilities of land use which do not correspond to the conservation of the fertility of soils. Many methods of land use produce large decrease of humus-content in the soil, at least at a level which is too low for conservation of soil fertility. His methods must be substituted by better ones and for this an intensive research and an intensive education is needed.

BRADFIELD

Thank you for that statement. It has certain attributes of an umbrella, I wonder if it might not be more appropriately a sector of our large umbrella and suggest that it be handed to the committee for consideration for that purpose or for such disposal as they see fit. Will that be satisfactory? If there are no objections we shall handle it in that way. Are there other general comments now which you would like to make before handing this matter over to the committee for further study?

HENIN

Il me semble que nous devons être précis dans l'expression de notre pensée. Nous ne devons pas donner l'impression que nous souhaitons que les situations naturelles soient parfaitement conservées. En fait il y a une évolution du milieu quand on le cultive, ce qui est indispensable c'est de prévoir ce qui se passera à la fin de celle-ci pour éviter des situations défavorables. Dans chaque cas il y aura plus ou moins un équilibre qui peut être différent et nous devons en avoir conscience pour le modifier si on l'estime nécessaire. Il faut tenir compte aussi du fait que l'accroissement de la production agricole doit se plier aux exigences de l'économie; les agriculteurs ne peuvent donc pas se laisser enfermer dans des systèmes trop défavorables. Pour ces raisons on ne doit pas donner à penser qu'il est souhaitable d'enrichir les sols en matières organiques ou de les conserver sans autres considérations, ce n'est pas je crois notre opinion et cela risquerait de retarder le progrès.

BRADFIELD

I think that idea is well worth passing on to the committee. Are there other comments? It seems to me one of the things that is going to be rather difficult for us, and I would like to have statements about this from Profs. LORA-TAMAYO and HERNANDO who are more familiar with the report of previous study groups; about the amount of detail that should be included in this summary statement. The papers are going to be published in full, I take it that this summary statement should be rather brief, that it should contain the broad general principles and conclusions without including too many details. Would you care to comment on this Prof. Tamayo?

LORA TAMAYO

Il suis d'accord avec le point de vue qui vient de soutenir le Président. On ne peut pas faire de généralisation du critère sur les diverses conclusions des diverses semaines parce qu'elles sont tout à fait différentes. Mais dans notre cas qui est un problème d'une importance capitale et universelle, je pense tout d'abord qu'il ne faut pas faire des prévisions détaillées comme il vient de dire, mais des précisions très concrètes, et aussi, s'il est possible, de tâcher de donner quelques directions sur la recherche, qui doit être intensifié. Voilà mon avis : des conclusions très concrètes, pas détaillées, puisque nos travaux, comme vient de le dire Monsieur le Président, seront publiés en même temps. Mais des recommandations utiles, et en même temps, fixer quelques directives sur la recherche, pour l'intensifier.

BRADFIELD

Thank you very much for the statement. Now we will hear from Prof. HERNANDO.

HERNANDO

I have been discussing with the Chancellor the question of what might be the most important aspects. I agree with Prof. LORA-TAMAYO except for a few slight differences: we cannot come to conclusions without taking in careful consideration the practical aspects of the whole matter.

With regard to research, the conclusions should indicate certain directives.

The conclusions we are going to establish should recommend the most interesting aspects to work on from a practical point of view. We need not worry about the length of the conclusions; to make things very clear we can always add another page, and especially in practical problems, we can never say beforehand if a clear explanation needs one or two, or even more pages.

DHAR

Last night I saw a report of the previous Study Week on Molecular Forces organized by this Academy, Prof. LORA-TAMAYO, and many others of our people took part. I request the three Chairmen to have a look at that report, I thought that the summary was brief. This report is available in the room upstairs and I think the Chairmen should have a look at this report.

LORA-TAMAYO

La dernière Semaine a été certainement sur les Forces Moléculaires, mais le thème et les problèmes sont tout à fait différents. Par conséquent, les conclusion d'une Semaine si différente ne peuvent pas servir comme modèle.

BRADFIELD

Are there other comments? If there are none we will adjourn. Dr. NORMAN, would you serve as Chairman of the Committee ot Chairmen and present their report when we reconvene?

FRANZ

I mean that we could probably complete our work a little in discussing urgent scientific problems.

BRADFIELD

I am note sure that I understood all of your statement Dr. FRANZ; would you repeat it please?

FRANZ

I feel that we could probably complete a little our work discussing scientific work urgently needed about organic matter, soil productivity and soil conservation.

BRADFIELD

You have heard the suggestion. May I suggest that we take it up from the different stand points of the world represented here and see how our colleagues from other countries are looking at this problem. Since you raised the question would you speak first. What are the problems that you consider most urgent in your country.

FRANZ

I mean that there are problems which are important for the whole world and there are problems which have certain importance for certain areas. I think that a very interesting problem is a very general one. This would be the problem to find methods and substances which could substitute some of the functions of the organic matter in the soil. For instance, in America Krilium was offered for structure stabilation. I remember, that Prof. BRADFIELD was one of the first who reported about it on the Congress of Paris. Now I hear that industry is able to produce substances which have the quality of chelates and this would be another very important function of organic matter which could be substituted by artificial products. Probably in a certain time we will be able to put these substances into the soils which have no humus like the desert soils. The evolution of substances which are able to substitute humus would be a very important research.

FLAIG

In Texas there is a firm which produces leonardite. Have you any experience with this product?

REUSZER

We have not experimented with it. Some experimental work has been carried out in the States with it, I think at Clemson University in South Carolina and under greenhouse conditions, they have sometimes shown some benefit from it. It is most beneficial in soils very low in organic matter but I think that usually it has been necessary to add phosphate to this and I think there is actually a product being sold now in which it is combined with phosphate. I am not so sure whether they have used ammonia in this or not. It does not have a wide market but I understand that it is available. There is a deposit also available in Wyoming. The Martin Colloroid Company is looking for a market for it.

BRADFIELD

I have a feeling that most of these synthetic compounds will probably be too expensive for general use in agriculture but many of them have a very important use in research work. I have found for example that Krilium has very remarkable properties and for certain types of research its use can be justified.

REUSZER

Dr. BRADFIELD, is the product that Prof. FLAIG is referring to a natural product? The product I am referring to looks exactly and behaves as humic acid does.

BRADFIELD

There is no processing involved.

BREMNER

I believe that the company Prof. FLAIG mentioned is American Humates of Dallas, Texas, and that this company manufactures a fertilizer material by treating leonardite with phosphoric acid, ammonia, and potash. I think that leonardite is an oxidized lignite.

SWABY

I wonder if I could comment on this question of utilizing lignite. We have vast amounts of this in our country and though they use as much as they can for fuel, there is still a great deal left and so the agricultural people were asked if they could do something about this. Trials were made and as far as I can recall, the only improvement we got was not due to any fertilizers that were in there, but because it made the soil darker, it absorbed more sunlight and heat and it warmed the soil up.

I can add a little bit also, but not first hand, only from what I have read, of the work that PIRET's group has done at St. Paul, Minnesota. There, they have been ammoniating peat and while much of the ammonia is ionically bound, yet a great deal of it is extremely firmly bound in covalent forms and very nearly unavailable. I don't know how much of that is marketed in the States but in Australia, we don't market it at all.

BRADFIELD

There is one other product that I have wondered about and I hope some of our microbiologists have had experience with it The paper industry has enormous quantities of lignin to dispose of. There have been some experiments and talk about treating this to get a product of value in agriculture. I wonder what microbiologists think of that possibility? Has anyone any experience? Dr. WAKSMAN have you been involved with any of these matters?

WAKSMAN

I spent many years studying peat in New Jersey and peat utilization. First of all, it must be clearly understood that peat and peat are not the same things. They are quite different in every respect and therefore the ammoniation probably refers to sphagnum peat which is very acid in reaction. At the end of the 1920's and the beginning of the 1930's, we had an organization known WPA. I don't know how many of you are familiar with the WPA idea, but we had to give employment to a lot of unemployed people; we had to create work for them. In New Jersey we have about 8 to 10% of the total surface area as peat land. They asked me from the State Capital whether I can employ a large number of people, the more the better, for any problem or project which I may have in mind. I said, let us make a survey of the peat resources of our State. That was an ideal project on which we could employ a lot of people. We worked out methods for about 150, who conducted botanical, chemical and physical studies of the peat resources of the State. The survey was later published by the Soil Conservation Department of the State. Apparently it had some significance and that project was considered by the people in the State as one of the most fruitful projects.

FLAIG

But then of course for the moment, this is only in the pilot stage.

BRADFIELD

Does this appear to you to have economic possibilities?

WAKSMAN

Some people believe that it can be used economically but as the product itself, only in mixtures with organic fertilizers.

I believe that somebody asked a question about the use of peat materials as fertilizer. It was not answered — and I would like to answer that. The peat in our State is high in nitrogen and calcium, but very low in phosphorus and potassium. Some companies supplement this peat with mineral fertilizers. It is being used extensively in dressing of lawns. It is very effective when you mix it with seed when sowing the lawns, because their moisture content allows the seeds to germinate and to grow. The sphagnum peat is being used very expansively; notably German peat moss and Dutch peat moss, which is being brought into the United States in large quantities. It is used in stable manures to absorb the ammonia from the droppings of poultry and can make a very fine fertilizer. The peats have thus found extensive applications in specialized forms of agriculture in various ways.

Flaig

Speaking still of peat, we speak more or less about a slow acting nitrogen source. BASF in Ludwigshafen developed a new slow acting nitrogen source which is called Floranid. This is a condensation product of two molecules of urea with one molecule of crotonaldehyde. This product is decomposed by microorganisms according to their living conditions. I would like to ask you, have you also experience with this product, because I know that it is used in many countries, also in tropical countries, to prove it.

Bradfield

Can anyone answer this?

Henin

En France notre industrie a produit pendant quelque temps des urée-formol.

Flaig

Excuse me, ureaform is a condensation product of urea with formaldehyde. The product I mentioned has been a condensation product of two molecules of urea with one molecule of crotonaldehyde. This product has a defined chemical composition. The condensation product of urea with formaldehyde differs in its composition according to the conditions of formation.

HENIN

Peut-être en dépit de ces différences la fin de ma remarque peut avoir quelque importance, malgré l'efficacité de ces produits il semble que le prix de revient en soit trop élevé par rapport à leurs avantages pratiques.

SWABY

I would like to add another chemical to the list of slow acting nitrogen fertilizers. This is one that the Japanese supplied us with, diamide of oxalic acid, oxamide. In rice areas this is particularly good and they say that it is economical. We have not used it ourselves because we are still very satisfied with the fast acting fertilizers because our rice is grown in areas so high in clay that any ammonia we put in is immediately fixed and so we don't have to worry about any losses. However, there are many other variations on this oxamide theme, all of which have far too much carbon in my opinion, which is not very useful and so you have a very much higher freight charge for these useless carbon atoms. Though I think it is worthwhile looking for slow acting fertilizers, I think that many plants require three different types of nitrogen containing bonds. They first need a group in the molecule that can give its nitrogen up to the plant very quickly in the seedling stages. This has to provide a small quantity. Then as the plant grows a little faster, it needs faster and faster mineralizing forms of nitrogen. We thought of ways of making complexes in which there were three different bonds but when we submitted these ideas to the I.C.I., who do most of the work on nitrogen fertilizers in our country, they said on economic grounds that these would be impossible.

FRANZ

The substances about which you have spoken help to substitute organic fertilizers by artificial substances. I think now that the population of the world is concentrating more on the towns and the organic matter is wandering from the country to the towns and there we have a lot of trouble with the decay of the organic matter and it is lost. And not only the organic matter but also much mineral so that I think that the decomposition of these substances of the town and the bringing back to the soil is a very important thing in the point of view of economy of the resources of the world. I think some word should be incorporated in our paper about this also.

HENIN

Il me semble que nous avons déjà discuté ce point. Je crois qu'il faut bien préciser que dans ce cas, les éléments fertilisants sont si dilués que leur transport est très coûteux. Je suis tout à fait d'accord avec vous, cette perte d'éléments fertilisants est inquiètante car nos réserves en acide phosphorique et en potasse ne sont peut être pas inépuisables. On pourrait suggérer que, quand on brûle les résidus urbains on traite les cendres qui se présentent d'ailleurs sous la forme d'un mâchefer, de manière à récupérer ces produits, seul l'azote serait perdu.

WAKSMAN

Any further questions, Dr. BREMNER?

BREMNER

Much effort has been directed towards development of slow acting nitrogen fertilizers, and I was at one time very interested in the possibility of converting waste lignin and cellulose to slow-release nitrogen fertilizers. But, like most people who have worked on this topic, I became convinced that, whatever type of nitrogen carrier is used, slow acting nitrogenous organic fertilizers will be too expensive except for special purposes. Their use may be justified where they help dispose of a waste material causing disposal problems.

FLAIG

It is sure that the slow acting nitrogen fertilizer which are chemically synthesized are more expensive than ammonium sulphate, liquid ammonia or also urea. But in some cases certain products must be mentioned, for instance lignin sulphonic acids formed during cellulose production. The question is, whether it is cheaper to burn it or to use it for a synthesis of other products. It must be removed, it can't be given in the rivers. We have strong laws about this point and to burn it is also relatively expensive. Furthermore also residues of inorganic material remain.

A nitrogen fertilizer could be produced by oxidative ammonification of calcium or ammonium sulphite liquors from cellulose production. The nitrogen content is about 20%, it depends upon the conditions of formation. About 30-40% of total nitrogen in these products are NH_4-nitrogen, about 10-20% are bound in a form, which can be distilled with sodium hydroxide after distillation with magnesium oxide. The rest of nitrogen is bound in another organic form.

About 50% of the total nitrogen are bound in the colloidal part of the products and are not leached by rainfall.

Up to 70% of the nitrogen can be used during the first vegetation period in pot experiments. The rest of nitrogen is bound in such an organic form, that it is available only after some further vegetation periods.

In pot experiments with biologically active soils (e.g. chernozem) it could be shown that the yield of cereals can be increased by addition of these products to an extent which is higher than in the case of inorganic nitrogen fertilizers, but then also a higher amount of this organic nitrogen fertilizers must be given in comparison to inorganic nitrogen fertilizer.

The products have some special properties as lignin derived materials. The yesterday mentioned effects of physiologically active substances on plant growth and also an inhibition of nitrification are observed.

CONCLUSIONS

FINAL STATEMENT

I. INTRODUCTION

The soil and the vegetation it supports, together with the multitude of organisms in it — the protozoa, actinomycetes, fungi and bacteria, and the many small and larger animals associated with it — constitute the soil ecosystem in the broadest sense. It is an open system. Continually carbonaceous plant residues are added and carbon as CO_2 flows out and is lost. During any period of time, short or long, the change in soil organic matter equals the gain minus the loss. Under natural conditions a delicate dynamic equilibrium or steady state is reached, in which the gains by photosynthesis and nitrogen fixation, and the losses by decomposition balance each other. This equilibrium level, depending on climate, parent material, flora, fauna and other factors, varies enormously from the tropics to the frigid zones.

Man, by altering the plant cover and cultivating the soil, disturbs this ecological equilibrium. The humus losses are accelerated, the influx of carbon and nitrogen is changed, and the organic matter content declines, often reducing the fertility of the soil, or even destroying it. On the other hand, man may shift the balance of organic input and output in his favor, and often then may improve the crop-producing capacity of the land.

In the management of soils for the production of harvested crops or forage, organic matter is a vehicle by means of which the natural properties of the mineral fraction of the soil may be greatly modified. The presence of organic matter influences the physical, the chemical and the biological properties of soils. The extent of the modifications so effected depend on many variables of soil, climate and crop sequence. Moreover soil organic matter constitutes a reservoir of plant nutrients. Most of the nitrogen, phosphorus and sulphur found in the world's annual harvest of crops is in fact derived by decomposition from the organic fraction of the soil.

II. PHYSICAL AND CHEMICAL PROPERTIES OF SOIL ORGANIC MATTER

1. *Physical aspects*: There are two major ways in which organic residues may be used to influence the productivity of soils.

a) Plant residues used as a mulch will protect the soil surface from the impact of raindrops, which can lead to soil loss through erosion, or from the capping effect which reduces water infiltration. Mulches also prevent wind erosion by reducing the impact of wind, decrease evaporative loss of soil moisture and the detrimental effects of high temperatures, such as may occur through insolation, particularly in the tropics.

b) Plant residues incorporated in the soil through the action of soil fauna, or by mechanical means, or in the form of the root systems of the vegetation growth thereon, will bring about changes in the structural properties of the soil associated with aeration, moisture-holding capacity, drainage and soil stability through aggregation of mineral particles.

Basic research is needed on several areas for a better understanding of the effects of organic matter on soil physical properties. These should include:

a) the use of mulch tillage and sod seeding under different soil and environmental conditions as affecting soil characteristics and crop yields. This must include an evaluation of fire, insect and rodent hazards;

b) the mechanisms of interaction of the constituents of humus with soil particles of different textural and mineralogical compositions;

c) the development of standardized methods for characterizing and determining the stability of soil aggregates;

d) the collection and interpretation of past and existing experiments in relation to environmental conditions, soil characteristics and soil and crop management.

2. *Chemical aspects*: The chemistry of the transformations involved in the degradation of plant materials into soil organic matter is highly complex. There is much not yet known about the composition of humic residues in soils. Basic research is required to provide a clearer understanding of the chemistry of soil humus, and particularly:

a) development and improvement of more discriminating techniques for the extraction, separation and characterization of humic compounds. In order to identify the origin of particular chemical groupings, such studies could include the use of isotopically-tagged plant materials;

b) further evaluation and analysis of the mechanisms and reactions involved in the formation and transformation of humus under different conditions;

c) the effect of humus on the plant availability of mineral elements, their cycling through the biological domain, their transportation and immobilization.

Both the physical and chemical aspects of soil organic matter research would be aided by the organization of cooperative, integrated long-term field studies, supported by supplementary laboratory investigations. There are international governmental and international scientific organizations that could sponsor such research.

III. BIOLOGICAL ASPECTS

1. *Importance of biological processes in soil evolution and fertility*: Much is now known of the capabilities of organisms found in soils to accomplish the decomposition of plant residues, either under virgin or cropped conditions, and of the biochemical transformations involved. However, the total ecology of such environments is inadequately comprehended, so that the extent of the control which man can exercise over the degradation of plant residues under practical conditions is quite limited. It is recognized that the decomposition process is an integral and essential part of the cycling of plant nutrients, especially nitrogen. The principles governing nitrogen turnover under aerobic conditions are relatively clear, though it must be admitted that data relating to tropical soil conditions are less substantial than those obtained under humid temperate conditions.

It is now recognized that in the decomposition of plant residues, the soil population may have effects on plant growth and crop yield other than through the release of major and minor nutrient elements. These effects, often subtle, are not yet fully understood or adequately explored, but they include inhibitory or repressive responses in seed germination and root development, and subsequent growth stimulation or growth modification. Such responses may arise from the release of substances preformed in the residues or from the production of physiologically active compounds by individual species in the microbial population.

2. *Practical applications of soil biology*: In both developed and developing countries, soil biologists can improve soil fertility and plant productivity by inoculating soil and seed with organisms, including bacteria, fungi and fauna.

a) The growth of legumes can often be greatly increased by inoculating seed with root nodule bacteria specially selected for their efficiency in fixing atmospheric nitrogen.

b) The growth of fruit and forest trees and also some crops can be improved, particularly in soils of low fertility, by inoculating them with mycorrhizal fungi, which enable the host plants to absorb more nutrients from soil minerals and organic matter.

c) Soils lacking in certain soil animals, such as earthworms and dung beetles, which are responsible for burying and comminuting animal manure and plant debris, can be improved by introducing these animals.

d) Plants may sometimes be stimulated, or pathogens suppressed, by inoculating seeds with selected micro-organisms; but more trials are needed before these become acceptable practices.

3. *Contemporary problems*:

a) The management of crop residues, organic wastes, and of some organic industrial wastes through decomposition in soil, is of importance to both rural and urban societies. Wider dissemination of established knowledge concerning organic matter breakdown and development of effective and economical new methods are needed. Emphasis should be placed on minimizing the labor requirements in organic matter management.

b) Pesticides and other chemicals are now widely used in agriculture, but little is known of their transformation, persistence and effects on soil organisms.

c) Study is needed on the behavior, durability and means for the eradication of soil-borne plant pathogens, inasmuch as such disease organisms constitute a major threat to food production in all regions of the world.

d) New techniques are required for the examination of natural and modified communities of soil organisms, including the micro flora and fauna, and new methods of expression are needed for comparative studies of the ecology of these organisms.

IV. MANAGEMENT PRACTICES

The humus or organic fraction vitally affects the characteristics of soils; agricultural productivity in most situations is positively influenced by its presence. This fraction in mature soils, though relatively resistant to biological change, may be easily destroyed by improper land use. It is a fragile asset that if lost can be rebuilt only with great difficulty. Human activities that destroy this asset are often thoughtlessly undertaken.

Good management of soils to protect the organic matter component is an international responsibility, inasmuch as future food supplies for man depend upon the maintenance of productive soils. Priorities in land use should be established with this goal in mind. Whenever possible, developments that permanently withdraw land from agricultural uses should be located on the poorer soils. Uses that modify the soil character by the introduction of materials that affect the soil ecosystem should be more thoroughly reviewed. It is recommended that long-term experiments on the effect of man's activities on the soil population and organic matter levels be initiated.

Keeping in mind the principles of soil microbiology and soil biochemistry, as at present understood, it is tempting to formulate specific recommendations for augmenting the organic matter content of the various soils of the world. But this is not yet possible. Each individual soil has its own characteristics and its own particular problems that must be known and interpreted before its microbiological life can be manipulated with any hope of success. Thus, for the extensive areas of tropical and subtropical upland forest soils, the nature of the parent rock determines the vital base status, the vegetational history affecting today's humus equilibrium and the stage of soil exhaustion. As new cropping sequences are developed, it will concurrently be necessary to ascertain the optimum needs for macro and micro-nutrients, so that rational fertilizer policies are devised, both to maximize yields and to maintain or improve the organic matter status and soil fertility. To cool the surface soil and to reduce evaporative water losses, suitable mulching practices may have to be contrived. Crop rotations that are benefited by mulching can be adopted. To bring about improvement in soil structure, periods of grass sod or even afforestation may be required. New legumes should be selected, or bred, for efficiency in nitrogen fixation. Successful land-use management must integrate soil-science knowledge with agronomic practice.

V. GENERAL RECOMMENDATION ON TRAINING NEEDS

Because it is likely that world food needs will require extensive changes in agricultural practices in many countries, particularly the developing countries, it will be essential that available opportunities for training in all aspects of soil science and crop production, both basic and applied, be increased, and that the general principles of organic matter management be more widely understood by those who develop the strategies of world food production.

ALEXANDER, BAVER, BRADFIELD, BRAMAO, BREMNER, BROADBENT, CHAMINADE, DHAR, FLAIG, FRANZ, HAUSSMANN, HENIN, HERNANDO, JENNY, NORMAN, PRIMAVESI, REESE, REUSZER, SWABY, WAKSMAN.

DEBAT GENERAL FINAL

I. INTRODUCTION

Le sol et la végétation qu'il porte ainsi que les multiples organismes qui s'y trouvent — protozoaires, actinomycètes, champignons, bactéries et les nombreux animaux petits et grands qui lui sont associés — constituent l'écosystème du sol dans le sens le plus large de ce terme. C'est un système ouvert. Des résidus végétaux carbonés y sont continuellement apportés et le carbone sous forme de CO^2 s'en dégage et se perd. Pendant n'importe quel laps de temps, qu'il soit long ou court, les variations de matière organique du sol sont égales à la différence entre les gains et les pertes. Dans les conditions naturelles, il s'établit un équilibre dynamique fragile, ou un régime permanent, dans lequel les gains dus à la photosynthèse et à la fixation de l'azote et les pertes par décomposition s'équilibrent mutuellement. Le niveau de cet équilibre qui dépend du climat, du matériel initial, de la flore, de la faune et d'autres facteurs varie très largement des tropiques aux zones froides.

L'homme, en modifiant le couvert végétal et en cultivant le sol, perturbe cet équilibre écologique. Les déperditions d'humus sont accélérées, l'influx de carbone et d'azote est modifié et la teneur en matière organique diminue, en entraînant souvent une réduction de la fertilité du sol ou même en la détruisant totalement. D'autre part, l'homme peut modifier le bilan des matières organiques en sa faveur et arrive ainsi souvent à améliorer la capacité de production des terres.

Dans les systèmes d'exploitation destinés à produire des récoltes ou du fourrage, la matière organique constitue un agent permettant de modifier intensément les propriétés naturelles de la fraction minérale du sol. La présence de matière organique influence les propriétés physiques, chimiques et biologiques des sols. L'importance des modifications ainsi produites dépend de nombreuses variables liées au sol, au climat et à la succession des cultures. En outre, la matière organique du sol constitue un réservoir d'éléments nutritifs pour les végétaux. La majorité de l'azote, du phosphore et du soufre contenus dans la récolte annuelle mondiale des diverses cultures provient en effet de la décomposition de la fraction organique du sol.

II. PROPRIÉTÉS PHYSIQUES ET CHIMIQUES DE LA MATIÈRE ORGANIQUE DU SOL

1. *Aspects physiques.* Les résidus organiques peuvent être utilisés suivant deux voies différentes pour modifier la productivité des sols.

a) Les résidus de plantes utilisés sous forme de mulch protègent la surface du sol contre l'impact de la pluie qui peut entraîner des pertes par érosion et contre l'effet d'encroûtement qui réduit l'infiltration des eaux. Les mulch exercent aussi une action protectrice contre l'érosion éolienne en réduisant l'impact du vent, ils diminuent les pertes par évaporation de l'eau du sol ainsi que les effets nocifs des températures élevées résultant de l'insolation, en particulier sous les tropiques.

b) Les résidus de plantes incorporés au sol par l'intervention de la faune du sol, par des moyens mécaniques ou encore sous forme des systèmes racinaires de la végétation qui s'y développe entraînent la modification des propriétés structurales liées à l'aération, au pouvoir de rétention de l'eau, au drainage et à la stabilité du sol, par suite de l'agrégation des particules minérales.

Pour mieux comprendre les effets de la matière organique sur les propriétés physiques du sol il serait nécessaire d'effectuer des recherches fondamentales dans plusieurs domaines. Elles devraient porter sur:

a) les pratiques d'ameublissement du terrain sans enfouissement des chaumes, du semis sur gazon, dans différentes conditions de sol et de milieu, leur effet sur les caractéristiques du sol et les rendements des cultures. Ceci doit inclure une estimation des risques d'incendie, de la prolifération des insectes et des rongeurs;

b) les mécanismes d'interaction entre les constituants de l'humus et des particules de sols de composition minéralogique et texturale variée;

c) l'élaboration de méthodes standardisées permettant de caractériser et de déterminer la stabilité des agrégats du sol;

d) le regroupement et l'interprétation de données recueillies lors d'expériences, passées ou en cours de réalisation, portant sur les conditions du milieu, les caractéristiques et la conduite des sols et des cultures.

2. *Aspects chimiques*. La chimie des transformations intervenant dans la dégradation du matériel végétal en matière organique du sol est extrêmement complexe. On ignore encore beaucoup de choses sur la composition des résidus humiques. Une meilleure compréhension de la chimie de l'humus nécessite des recherches fondamentales portant en particulier sur les points suivants:

a) recherche et perfectionnement de méthodes permettant une extraction plus précise et plus spécifique. Afin d'identifier l'origine de groupements chimiques particuliers, ces travaux pourraient inclure l'emploi de matériel végétal marqué aux isotopes;

b) il faut poursuivre le recensement et l'analyse des mécanismes et des réactions intervenant dans la formation et la transformation de l'humus, dans différentes conditions;

c) étudier l'effet de l'humus sur la disponibilité des éléments minéraux à l'égard de la plante, leur cycle à travers le domaine biologique, leur transport et leur immobilisation.

Les études tant physiques que chimiques sur la matière organique du sol pourraient être rendues plus efficaces par l'organisation de recherches intégrées, comprenant des expériences in situ de longue durée, appuyées par des recherches complémentaires en laboratoire. Il existe des organisations gouvernementales et scientifiques internationales qui seraient susceptibles de patronner ce genre de travaux.

III. Aspects biologiques

1. *Importance des processus biologiques dans l'évolution du sol et de sa fertilité*: on connaît maintenant dans une large mesure l'aptitude des organismes du sol à réaliser la décomposition des résidus de plantes dans des sols soit vierges, soit cultivés, ainsi que les transformations biochimiques qui entrent en jeu. Toutefois, l'écologie globale de milieux de ce genre est insuffisamment connue, de sorte que l'importance du contrôle que l'homme peut exercer sur la dégradation des résidus végétaux dans des conditions pratiques est relativement limitée. On sait que le processus de décomposition constitue une partie

intégrante et essentielle du cycle des substances nutritives de la plante, en particulier de l'azote. Les principes qui régissent le renouvellement de l'azote en milieu aérobie sont assez bien définis, bien qu'il faille reconnaître que les données relatives aux conditions des sols tropicaux sont moins nombreuses que celles qui ont été obtenues dans des conditions tempérées humides.

On admet maintenant qu'en ce qui concerne la décomposition de résidus végétaux, la population du sol peut agir sur la croissance des plantes et le rendement des cultures d'une autre façon que par la libération d'éléments nutritifs majeurs et mineurs. Ces effets, souvent peu sensibles, ne sont pas encore parfaitement compris ni suffisamment étudiés, mais ils englobent des réactions d'inhibition ou de répression dans la germination des semences, le développement des racines et par là une stimulation ou une modification de la croissance. Des réactions de ce genre peuvent être dues à la libération de substances formées dans les résidus ou bien à la production de composés physiologiquement actifs par des espèces particulières de la population microbienne.

2. *Applications pratiques de la biologie du sol*: dans les pays actuellement développés ou en voie de développement, les biologistes peuvent améliorer la fertilité du sol et la productivité des plantes en inoculant des organismes appartenant à la microfaune et à la microflore dans le sol et les semences.

a) La croissance des légumineuses peut souvent être fortement accrue en inoculant aux semences des bactéries des nodosités de racines choisies spécialement pour leur efficacité dans la fixation de l'azote atmosphérique.

b) La croissance des arbres forestiers et fruitiers, ainsi que celle de certaines cultures, peut être améliorée, surtout dans des sols peu fertiles, en y inoculant des mycorrhizes qui permettent aux plantes hôtes d'absorber une plus grande quantité d'éléments nutritifs provenant des matières minérales et organiques du sol.

c) Des sols dépourvus de certains « animaux » tels que les vers de terre et les bousiers qui enfouissent et réduisent les déjections animales et les débris de plantes, peuvent être améliorés en y introduisant ces animaux.

d) Les plantes peuvent parfois être stimulées, ou la prolifération des organismes pathogènes inhibée, en inoculant aux semences des microorganismes choisis; mais il est nécessaire de poursuivre les expériences avant de pouvoir faire passer ces méthodes dans la pratique.

3. *Les problèmes actuels.*

a) L'utilisation des résidus de cultures, des déchets organiques et de certains déchets organiques industriels, par leur décomposition dans le sol, présente une grande importance pour les communautés rurales et urbaines. Il est nécessaire de diffuser plus largement les connaissances acquises sur la décomposition de la matière organique, et de mettre au point de nouvelles méthodes d'emploi efficaces et économiques. L'accent devrait être mis sur la réduction des besoins en main d'oeuvre, au cours du traitement ou des manipulations de ces substances.

b) Les pesticides et autres produits chimiques sont très largement utilisés en agriculture de nos jours, mais on ne sait que peu de choses sur leur transformation, leur persistance et leurs effets sur les organismes du sol.

c) Il convient d'étudier le comportement, la persistance et les moyens d'élimination des organismes pathogènes des plantes — organismes qui vivent dans le sol — dans la mesure où ceux-ci constituent un danger pour la production alimentaire dans toutes les parties du monde.

d) Il est nécessaire de mettre au point de nouvelles méthodes pour l'étude des communautés naturelles des organismes du sol et de leur modification, qu'il s'agisse de la microflore ou de la microfaune, et de nouveaux modes d'expression pour l'étude comparée de l'écologie de ces organismes.

IV. Technique d'utilisation

L'humus ou fraction organique a une influence essentielle sur les caractéristiques du sol; la productivité agricole est modifiée dans un sens favorable par sa présence dans la majorité des cas. Dans les sols évolués, cette fraction, bien qu'étant assez résistante aux transformations biologiques, peut être facilement détruite par suite d'une mauvaise exploitation. C'est un élément fragile qui, une fois perdu, ne peut être reconstitué que très difficilement. Des interventions humaines susceptibles de détruire cet atout sont souvent entreprises inconsidérément.

La bonne exploitation des sols destinée à protéger la matière organique implique une responsabilité à l'échelle internationale, dans la mesure où la production alimentaire future du monde dépend de l'entretien de sols productifs. Les priorités quant à l'utilisation des sols devront être établies en fonction de cet objectif. Dans tous les cas où il est possible de faire ce choix, la cessation permanente de l'exploitation agricole de certaines terres devrait être limitée aux sols les plus pauvres. Les techniques modifiant les caractères du sol par l'apport de matières pouvant affecter l'écosystème du sol devraient être réexaminées à fond. Il serait souhaitable de mettre en oeuvre des expériences de longue durée portant sur l'influence des activités humaines, sur l'abondance de la population et la teneur en matière organique des sols.

Compte tenu des principes de la microbiologie et de la biochimie du sol, tels qu'on les entend actuellement, on est tenté de formuler des recommandations précises sur l'augmentation de la teneur en matière organique dans les différents sols du monde. Mais ceci n'est pas encore possible. Chaque sol possède ses propres caractéristiques et ses problèmes particuliers qu'il faut connaître et interpréter avant de pouvoir intervenir dans sa vie biologique avec une chance de réussite. Ainsi, dans le cas des vastes étendues de sols forestiers de montagne, tropicaux et subtropicaux, la nature de la roche mère determine la situation de base, l'histoire de la végétation affectant l'équilibre actuel de l'humus et l'état d'épuisement du sol. A mesure que de nouvelles cultures sont entreprises, il est nécessaire, parallèlement, de déterminer les besoins optimaux en micro et macroéléments nutritifs, afin d'organiser les programmes rationnels de fertilisation, visant simultanément à obtenir des rendements maximaux et à conserver ou améliorer l'état de la matière organique et la fertilité du sol. Afin de refroidir la surface du sol et de réduire les pertes d'eau par évaporation, il sera nécessaire de trouver des méthodes de mulching appropriées. On peut adopter des types d'assolement pour lesquels le mulching exercera un effet favorable. Il pourra être nécessaire d'introduire des périodes d'engazonnement ou même de reboisement dans le but d'améliorer la structure du sol. Il faudrait aussi sélectionner ou créer de nouvelles variétés de légumineuses ayant une capacité élevée de fixation de l'azote. Une politique efficace d'exploitation des terres doit faire une synthèse des connaissances pédologiques et de la pratique agronomique.

V. RECOMMANDATIONS GÉNÉRALES CONCERNANT LA NÉCESSITÉ D'UNE ÉDUCATION

Etant donné que les besoins alimentaires mondiaux susciteront des transformations importantes dans la pratique agricole de nombreux pays, et en particulier dans les pays en voie de développement, il sera essentiel d'accroître les possibilités de formation des hommes dans tous les domaines de la science du sol et de la production des cultures, du point de vue théorique et pratique, et de faire connaître plus largement les principes généraux de l'utilisation de la matière organique à ceux qui établissent les programmes de production d'aliments à l'échelle mondiale.

ALEXANDER, BAVER, BRADFIELD, BRAMAO, BREMNER, BROADBENT, CHAMINADE, DHAR, FLAIG, FRANZ, HAUSSMANN, HENIN, HERNANDO, JENNY, NORMAN, PRIMAVESI, REESE, REUSZER, SWABY, WAKSMAN.

Traduit de l'anglais par Mr. le Prof. Stèphane Henin.

APPENDIX I

THE IMAGE OF SOIL IN LANDSCAPE ART, OLD AND NEW

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INTRODUCTION

The pygmy forest of California, an unusual ecosystem of spindly dwarf trees on podsol soil with snowhite surface layer and brilliant reddish subsoil deserves to be preserved for future generations of naturalists. Alas, the plea does not impress officials and the public, for they claim the landscape is not photogenic, not beautiful, and as for the soil, it has no aesthetic value. The same objections are raised against the preservation of natural grasslands and steppes. Scenic and beautiful — we are told — are the dark forests, the steep canyons, the natural rock sculptures, and of course the mighty redwood and the majestic oak.

Who is the arbiter of what is beautiful in nature? Who decides whether soils evoke aesthetic pleasure? The artists presumably, foremost the landscape painters, for they must choose what to put on the canvas. Taking up this lead and wandering as a sabbatical pedologist (student of soils) through art galleries here and abroad, we, my wife and I, encountered a fascinating story that deserves to be told. Be it understood that no value judgements on art per se are intended.

THE MEDIEVAL ROCKS

DUCCIO DI BUONINSEGNA's « Transfiguration » (Plate 1) was installed in the dome of Siena on June 9, 1311. Flanked by Moses and Elias and with three apostles resting, Christ stands on reddish ground. But « ground » is the wrong word. It is a flatish rock, a mountain top with ledges and crevasses that help separate foreground and background. There is no soil, no vegetation. The figures are placed into an unrealistic rock landscape of old Byzantine tradition. Medieval painters generally chose bare rock shelves and piles to heighten the divine in the religious scenes.

A century later, the strange rock structures still dominate in pictures, though other features have crept in. SASSETTA of Siena painted the « Journey of the Magi » during 1432-1436 (Plate 2). Three kings on horses and attendants descend a barren, grayish slope full of sharp-edged crevasses. There is sparse grass in the foreground, and two finches are seen. In the distance a town and castle are visible, and occasional trees mostly without foliage are stuck into the stony ground. Cranes fly in the sky. In other paintings SASSETTA inserted little woods, the Gothic forests, that are dense thickets of trees with their stubby trunks close together. In like manner and somewhat earlier, the LIMBOURG BROTHERS executed the French miniatures, the royal « Books of Hours » (1409-1415).

TWO LANDSCAPES OF THE RENAISSANCE (15th CENTURY)

Art historians single out GIOVANNI BELLINI in Venice and JAN VAN EYCK in the North, in what is now Belgium, as the innovators of landscape art. These painters placed religious historias into landscapes that seem highly realistic and that are judged by general consent as being very beautiful.

« The Agony in the Garden » (Plate 3) by ANDREA MANTEGNA, BELLINI's brother-in-law, may serve as a transition piece. It was painted about 1459 in Padua. The traditional gray rocks are now brown, they have more realistic contours, and their assembly is one of grandeur. The hill town is done with extraordinary precision. Rabbits, pelicans and cormorant are more conspicuous than vegetation. While Christ is praying to the angels, three disciples sleep on hard plates of rocks out of which small herbs mysteriously grow. They are interspersed with dainty pebbles that are a stylised ornamental design, perhaps symbolizing soil. It was used by many Renaissance painters.

The early masterpiece of GIOVANNI BELLINI the « Agony in the Garden » (Plate 4), painted shortly after MANTEGNA's, is similar in content and conception. What is novel is the immensity of space and perspective, and the creation of light and atmosphere, those very features of Renaissance art. The green slopes are gentle, the hill town is subdued, and a poetic sunrise shows the time of day.

The familiar defoliated tree is balanced on the right by a fence of slender sticks and poles, executed in ultrafine detail. The center rock has mellowed lines, and the weathered slab provides a softer base to kneel on. The sleepers rest on dune sand blown over from the river bank. At the edge of the distant quarry a dark green carpet of grass presses on the rock, with no soil between. This pattern is repeated and much overdone in BELLINI's « Transfiguration » of 1480 (National Museum, Naples), where literally a « fleece » of grass is thrown over a pile of rocks.

MORE ON THE FLEECE-ON-ROCK DESIGN

It has long been noted that Renaissance artists were meticulous with anatomical details of humans and animals, that they were less candid with the vegetable kingdom, and that their rendering of rocks amounted to geologic blasphemy.

The fleece-on-rock is a case in point. Though not commonly found in Nature — she prefers the sequence « grass on *soil* on rock » — the motif has been singularly popular with artists for centuries, as late as the 19th century (MORITZ VON SCHWIND). Perhaps the design has special artistic merits, but no one has disclosed them.

Already in the 15th century realism occasionally prevailed. From the STUDIO OF THE MASTER OF THE VIRGIN, the « Conversion of S. Hubert » in the National Gallery in London depicts a trail border consisting of green grass on brown soil that fades into a light-colored substratum. It looks suspiciously like a « soil profile » and it may be historically its first image (second-half of 15th century).

Like DUCCIO's crevasses and ledges, the grass-covered crags, cliffs and rock banks served as effective dividers of the picture plane into proximity and background. In the « Deer Hunt » (1529) by LUCAS GRANACH THE ELDER in the art museums of Vienna and Basel a conspicuous band of fleece-on-rock with brownish tint separates the gray-green meadow from the dark meandering river.

THE SCENE OF PLOWING

As symbolic gestures of the life-giving spring time, plowing with oxen or horses appears as early as the 1410's, in the delicate, precise paintings of « Les très riches heures du Duc de Berry » preserved in the Musée Condé in Chantilly (seen only in PAUL DURRIEU's reproductions).

One of the most famous plowmen in art is PETER BRUEGEL's in the « Fall of Icarus » (Plate 5), painted about 1555. The religious theme has disappeared, and even the Greek legend of the flying Icarus is but fleetingly drawn as a leg sticking out of the water that nobody seems to notice. The only people are peasants, and while the animals, trees, ships and sea are real, the luminous, spacious landscape is a fantasy, a pleasing artistic construction. The central motif is the ritual of the plowman who turns the fat earth glistening in the evening sun. The strong furrows « make » the picture even though their proportions are incongruous. BRUEGEL gives the lie to HAMERTON (1885) who felt that in a pretty vale nothing is uglier than freshly plowed land.

THE LANDSCAPE OF THE NOBLE MOODS

The 17th century was influenced by the newly-found laws of nature enunciated by physicists, mathematicians and astronomers. Sky, land and sea too were being viewed as parts of an infinite design, and artists responded to these trends. Landscape painting ceased to be mere setting and became an end in itself.

NICOLAS POUSSIN, a Frenchman living in Italy, created in his later years poetic landscapes in which the human element was largely subdued. In his « Travelers resting in the Roman Campagna » (Plate 6), painted about 1643-44, according to Sir Anthony Blunt, the road, the well-shaped rocks and the majestic trees are properly balanced, conveying order and permanence. There is harmony in color too, an overall tonality of dark brown earth, light brown rocks and olive brown foliage. The landscape is ideal rather than real, it is said to be « noble ».

JACOB VAN RUISDAEL discarded the irrational cliffs and mountains that were in vogue by his predecessors and contended himself with the gentle undulations of his native Holland. In his works white, bulging clouds tower over tall trees and dark-green thickets that are reflected in ponds and rivers. There is little room for people. His « Bank of a River » (Plate 7), painted about 1650 has a quiet grandeur and solitude, inviting contemplation. A whitish blowout in the middle sand dune gives the only clue to the hidden, supporting earth. RUISDAEL paintings and their equivalents are still popular today, appearing on magazine covers and calenders, and they continue to shape people's appreciation of nature in this western classic tradition.

A revival of the vogue of ideal and heroic landscapes took place during the Romantic Period in the early part of the 19th century. The « Waterfalls of Tivoli » by CARL PHILIPP FOHR of Heidelberg (Plate 8) show a beautiful Tivoli above aggrandized waterfalls framed by picturesque trees and rocks. The foreground is bathed in a warm reddish brown, a plausible soil color, but there is no soil. The copper tinge envelopes rocks and trees, even people's clothes. It is purely a color device to heighten contrast with the purple-blue of distant hills and sky.

TRENDS TOWARD NATURALISM

At the end of the 17th century the harmoneous landscape tended to become overly harmoneous with gardens and park scenary supplanting the natural woods and waters. Baroque turned into florid Rococo. In turn, the 18th century brought the Enlightment Period and JEAN JACQUES ROUSSEAU's plea of « back to nature ».

THOMAS GAINSBOROUGH of portrait fame (Blue Boy) chose to paint nature in its more modest segments, such as cattle drinking in a pond in the woods, peasants sitting along the roadside and, interestingly enough, eroding sand dunes on the coast (National Gallery, Dublin; not seen in the original). In « View near the Coast » (Christ Church Mansion, Ipswich), stock and herdsmen are idyllically resting besides a cottage, and nearby a mantle of grass covers a crumbling rock.

In the « Rocky Landscape » (about 1783) of Plate 9 a small river flows near well-proportioned sunlit rocks. Opposite is a steep, pink-brown bank that might be either soil or rock. Sheep are grazing in front of a dark monumental group of trees. There is much chiaroscuro, the dark and light of studio art. The painting gives an impression of flawless elegance, with a touch of his theatrical.

JOHN CONSTABLE, East Anglian, has been proclaimed the discoverer of the art of naturalistic landscape, whatever that means, for looking at a landscape involves a complex set of impressions. As with many romanticists of the early 19th century his love of nature had religious undertones: the divine shines through flowers, leaves and trees, waters and clouds, and maybe even through soils.

It has been said that Gainsborough thought no landscape worth painting outside Italy, whereas CONSTABLE found art under every hedge. His landscapes are devoid of the classic, noble and heroic frames. They have a new directness and simplicity. In « Weymouth Bay » 1816 (Plate 10) the trees — these conveyors of moods — are gone. Inspiration is created by the sky. Its racing clouds are balanced by the broad, restful stretches of base ground, their browns being mirrored in the waves.

Artists of the BARBIZON SCHOOL in France took to outdoors painting and did not shrink from electing occasionally the seamy side of nature, the swamps, old farm huts, a winter-shed with chickens, a desolate field, a pile of rocks, a quarry. By putting these ordinary subjects on canvas they elevated them to « art », at times to the horror of the public.

The « Quarry near Fontainebleau » by JEAN-BAPTISTE COROT (Plate 11), executed during the early 1830's, is stark and healthy realism. Time-less beauty has now given way to naturalness. The vertical cuts and banks expose soil sections here and there. Dark blotches in the surface soil could be humus; more likely they are shadows from overhanging sod.

The Barbizonians had not yet learned to appreciate soil color differentations, wittness the boresome browns in front of the church at Lormes (COROT, Wadsworth Atheneum, Harford, Conn.). Art had to be awakened by the impressionistic phase.

WILLIAM DYCE's « Pegwell Bay » of 1858, now at London's Tate Gallery, drew praise in his day from geologist Archibald Geikie for the great fidelity of the structure of the chalk cliff. Be it further recorded that DYCE's cliff is topped by a brown soil with pebbles in it, and overlayn by sod, the sort of layering one looks for in vain in the fleece-rock stereotypes.

THE MEDITERRANEAN EARTH PALETTE

It remained for Provence painter PAUL CÉZANNE to utilize the broad spectrum of the gray-browns, yellow-browns, orange-browns and reddish-browns, the ochres, chestnuts and terracottas that belong to the soils of the sunny Mediterranean region. Gone are the drabby grays and faded tans of the northern scenes. Soil color is related to climate, a pedalogic tenet of import to art interpretation.

One of CÉZANNE's first landscape pieces, the « Railroad Cut » with Mont Sainte Victoire (Plate 12) was painted in the late 1860's. It is an orchestration of lively ambers and browns. The work has other novel features. Perspective in the form of diagonals that lead the eye to the rear in a painting is largely dispensed with; instead the back — middle — and foregrounds are simulated by color contrasts, warm browns against cool blues.

A survey of CÉZANNE's work, as offered by the great collection is the Barnes Foundation near Philadelphia, Pa., provides a panorama of endless nuances of the Mediterranean earthy colors that repeat themselves in quarries, housewalls and tile roofs. Their prominence is accentuated by the greens of trees and the blues of sea and sky.

Today's California and Mexican artists (e.g. JOSÉ CLEMENTE OROZCO in the Los Angeles County Museum of Art) are likewise fascinated by the range of soil colors found in their Mediterranean-type climate, with its prolonged wet and dry, dessicating seasons. Geography of soil color and its impact on people is still waiting for an interpreter.

FINALLY, THE RED SOILS

In 1887 the French painter PAUL GAUGUIN spent a few months in Panama and on the island of Martinique. Upon his return to Paris the friends and critics noticed that his colors had become more intense and brilliant, which was attributed to the color-rich tropics that none of the commentators had actually seen. This change in chroma and hue became emphasized in subsequent sojourns in Tahiti.

Pedologists are grateful to GAUGUIN for he has supplanted the conventional soil colors of previous generation with rich yellows, pinks, purples and reds, the characteristics of many tropical soils (« The Summons », Cleveland, Ohio; « Martinique », Munich; « Nave, nave mahana », Lyon). Strangely enough, none of the many GAUGUIN books consulted by the writer ever comment on the unusual soil colors, and only two seem to be aware that red soils exist at all. Pola Gauguin notes that his father's hut stood on « red earth », and anthropologist Bengt Danielsson concludes his narrative with the lowering of Gauguin coffin into « red volcanic earth. »

« Jacob wrestling with the angel » (Plate 13) was painted in Brittany, shortly after GAUGUIN's first visit to the tropics. The picture caused great consternation for the wrestling takes place on a red background. Viewers couldn't decide whether the Breton girls were looking at a crazy red sky or at a still crazier red meadow. Even today writers « excuse » GAUGUIN by speculating that he had been under a mystical spell of red church windows. It is equally plausible to speculate that the wrestling takes place on red soil, the kind Gauguin was working in as a ditch digger for the Lesseps Canal Company in Panama. In this light the only artistic liberty Gauguin allowed himself was the hybridization of Brittany and Panama.

Ever since « Gauguin », the red soils have taken their place in landscape art, though it would be rash to postulate an intimate causal connection.

ERNST-LUDWIG KIRCHNER painted the « Böhmerwaldsee » (Pinakothek, Munich), dated 1908. It is a lake in the Bohemian forest in which dense green foliage and blue-green waters harmonize with purple-red soils. Whether or not fossil red soils do occur in the Böhmerwald, or whether the color combination is pure fantasy, is immaterial. Important is the fact that KINCHNER used the soil and its color as a principal artistic-coloristic element.

KIRCHNER's friend KARL SCHMIDT-ROTTLUFF another expressionist, painted orgies of red soil, real or not. At about the same time (1906) ANDRÉ DERAIN produced « Vineyard in Spring » (Art Museum, Basel) which is dominated by warm, red earth, redder than any found on soil color charts. An excitingly beautiful deep-red laterite landscape hangs in the Museum of Modern Art in New York. It is « Morro 1933 » of the brush of Brazilian CANDIDO PORTINARI.

THE ABSTRACT LANDSCAPE

In the Lenbach Gallery in Munich a special set of paintings unfolds a remarkable sequence of events. At the turn of the century, WASSILY KANDINSKY left his native Russia and settled in the prestigeous art center of Munich. In 1901 he painted the « Schleuse » (sluice) in western naturalistic manner with impressionistic color accents. Subsequently, at the neighboring artist colony of Murnau, his landscapes underwent a process of reduction to essentials. He would set horizontal blocks of plowed fields against distant, rectangular roofs, all in yellow, orange, brown and red, interspersed with blues and violets as shadows. In « Nature Study III », Murnau 1909, the design has simple geometric shapes that clearly denote a house (in brown), a road (light blue), mountains (ultramarine) and sundry fields in yellow, orange and siena. To have a road painted in sky-blue tint should not be upsetting because the color of an object depends on the kind of light that shines on it, as discovered by the impressionists and before them by the physicists.

The lavish profusion of pigments in the « Garden » of 1910 (Plate 14) feels like a blinding color storm. Soon, a patch of brown, bare ground emerges, surrounded by a green shed and four sunflowers. In the distance a castle and a country church can be made out. Our desire for identification of objects is lessened by the delight in the exuberance of color.

From this garden it is but a small step to the « Improvisation N. 26, 1912 » (Plate 15) which is abstract, non-objective art, or nearly so. Bits of nature still remain, the brown outlines of hills, clouds, an orange-yellow field placed next to a blue lake — or is it a window of sky? — and six incisive streaks that could be taken as furrows or roads.

Historically, KANDINSKY has freed landscape painting from the conventional shapes and positions of skies, waters and lands. He rearranged the natural elements into personal « scapes » that suited his artistic temperament and taste.

KANDINSKY's younger musician friend PAUL KLEE was an artist of great sensibility and imagination. He embellished abstruse alignments of dots and lines with « childlike » scrawls and produced thereby enchanting compositions. In the « Garden plan » (Oeuvre 1922, No. 150, Paul Klee Stiftung, Berne, seen in color print) the entire canvas is devoted to soil. It is a soilscape in which a few capriceous plants decorate queer-shaped garden beds that glow and radiate in hues of reddish grays and pinkish browns.

Abstraction has had an enormous influence on succeeding generations of painters and it has stimulated the appreciation of soil as non-objective art. Thus, compared GUIDO AUGUSTS in California put flame-colored radishes into dark humus soil having abstract seams of whitish lime (« Radish III », 1965), and into red earth with a phosphorescent deep-blue sky in physically wrong but aesthetically right position (« Radish IV », 1965). Both works are in the author's possession.

ARTISTS DISCOVER SOIL PROFILES

Most soils in art are surface soils, as a bird would see them. To pedologists the really pertinent soil features are underground, seen along riverbanks, in creek beds, in erosion gullies, on road cuts, in excavations, and sometimes exposed by creeps and landslides. The vertical sections are known as soil profiles and their subdivisions are the soil horizons, broadly labelled A, B, C.

That early painters may have been aware of soil profiles was suggested for the Master of the Life of the Virgin, for COROT (Plate II and for DYCE. The real profile painters are of our time.

American GRANT WOOD, the originator of controversial « American Gothic » and satirical « Daughters of the Revolution », and in his days an art professor in Iowa City, was also the portrayor of the Midwestern scene. His landscapes are both realistic and strangely stylized. « Arbor Day » 1932 (Plate 16) traces the undulating land configuration much better than any aerial photograph could ever hope to accomplish. The planting act of teacher and children conforms to the belief that trees beautify the landscape. Astonishing is the steep bank at the road fork. No doubt, it is a prairie soil (mollisol) divided into A, B, C horizons in pleasing though idealized fashion. Are these depth differentations purely artistic perceptions, or had WOOD been indoctrinated by Iowan pedologists? We have before us a striking fusion of art and science.

At the same time, in the far-away region of the Baltic Sea, in what is now East Germany, the previously mentioned KARL SCHMIDT-ROTTLUFF painted the « Pommersche Moorlandschaft 1931 », the Pommeranian bog landscape (Plate 17). As the gallery visitor approaches the large 4 × 5 foot canvas, his eyes can't help remaining focussed on the soil profile with its colorful horizons. The brilliant orange band is most likely an iron-stained B-horizon, as would be expected in a landscape rich in podsol soils. Lest we forget, it is the very soil that on the California coast was pronounced as being devoid of artistic merits.

SOIL IS COMING OF AGE

A soil painter of extraordinary stature is JEAN DUBUFFET, born 1901 in Le Havre, a sometime wine merchant, whose enigmatic compositions command prices in the five-digit range. It is difficult to describe his landscapes. Facetiously speaking, they are the kind one sees with eyes closed. DUBUFFET talks about mental landscapes, Peter Selz mentions dreamscapes. To many people his figures are revolting and disgusting. To pedologists, some of his art, like the *Sols et Terrains* and *Terres Radieuses,* is sheer delight.

An idea what DUBUFFET has in mind may be gleaned from the titles of his paintings and from his elaborations (in a lyric French that requires a dictionary): the kingdom of stones, soils and lands, landscape of soil, celebrations of the soil, theater of soil, element of soil, concretions of the earth, secrets of subsoil, the humus, the voice of the soil, the example set by the soil, person attached to the soil, etc. DUBUFFET would select a square meter of an abandoned roadway and patiently sketch the little stones, particles of earth, twigs, decayed leaves, wild thyme, moss and lichens, and later assemble the observations into « texturologies » and surface « topographies ». In the « Geologist 1950 » (seen in the book of Selz) a little man with a large head and a magnifying glass stands on a rough terrein or, DUBUFFET adds, as one desires, on a cross section of subsoil, both at the same time. The point is that in viewing a landscape our vision, unlike a camera, moves around. Some of the soil features depicted are seen through the eyes of mice and moles. Whatever, a fine sense of humor permeates the designs, and the color combinations and paint textures are exquisite.

It is not easy to pick out a pedologically meaningful illustration. The choice is « At the Foot of a Wall », 1956 (Plate 18). It is reproduced here upside-down to match the idea of vegetation on soil. Humus in brownish-black blotches is all-engulfing. Coming up between tiny pebbles are the lowly weeds, the dandelions and thistles, that DUBUFFET paints as little happy stars. The browns of the soil (or wall), caused by iron in multiple stages of oxidation and hydration, are a color world by themselves. It is the realm of rustiness, the poem of iron according to DUBUFFET.

If there is art in soils — abstract, to be sure — why not take a section of a soil profile, a monolith, frame it and submit it to an art gallery? The art-part lies in deciding which profile, and the writer never had the courage to do it. But, Prof. R. TÜXEN did. In 1964 an exhibit was arranged in Hannover, entitled: Script of Soil - Language of a new Art. On the walls were hanging natural soil sections (podsol, Plate 17) paired with abstractions by DUBUFFET, MUSIČ, DAHMEN, GIRKE and others. KARL FRED DAHMEN'S « Composition in Red, 1961 » (Plate 19) is executed on an inch-thick slab of sand-resin mixture imparted with modulations of yellow and red pigments. The design results from scratching, stroking crumbling, breaking and polishing. It appeals to the eye as well as to the sense of touch, just as a profile does. A lively discussion ensued on beauty of nature and beauty of art.

CONCLUSION

Beauty in a landscape is a many splendered thing. Its recognition is a psycho-sociological process with roots in history. The Poussins, Claudes, Ruisdaels, Hobbemas, and the Gainsboroughs and Constables and their imitators still have a hold of children's books and magazines and of public officials and conservation societies. Preservation of have-not landscapes, those lacking the spectaculars, will follow a broadening of nature appreciation in which the discerning artist, be he painter or photographer, is bound to play an important role.

And this widening may well include the soil. Many pedologists derive aesthetic pleasure from looking at soils and handling them, but out of modesty they keep it a secret. They need not, for many artists are intrigued by soil colors and textures and seek and paint them. Whoever said that soils lack beauty is behind the times. Soil in art has arrived. It is an enrichment of art that is here to stay.

Books on the famous painters are legion. Some of the less well known are described in the following sources:

DAHMEN K.R. In: « Das Kunstwerk », Vol. 10, 1956-57, p. 5 (article by K. GOERRES); also in: Schwind, M., Schrift des Bodens - Sprache neuer Malerei, Humboldtschule, Hannover 1964, 42 p.

DUBUFFET J. In: P. VOLBOUDT, *Les assemblages de Jean Dubuffet*. XX^e Siècle, F. Hazen, Paris, 1958, 121 pp. - P. SELZ, *The work of Jean Dubuffet*. The Museum of Modern Art, New York, 1962, 186 pp.

FOHR K.P. In: R. BENZ and A. VON SCHNEIDER, *Die Kunst der deutschen Romantik*. Munich, 1939, 227 pp.

SCHMIDT-ROTTLUFF K. Many illustrations in Katalog 1964, Frankfurter Kunstverein, Frankfurt, Germany.

WOOD G. In: P. RINARD and A. PYLE, *Grant Wood* « The Lakeside Press », Chicago, 1935, 36 pp.

Landscape art is discussed in the well-known books by Sir KENNETH CLARK (Landscape into Art. Paperback, 1961), and M.J. FRIEDLÄNDER (Landscape, Portrait, Still-Life. Paperback, 1963), but no reference or publication on soil in art could be found.

The following specific sources were cited in the text:

BLUNT Sir ANTHONY, *The heroic and the ideal landscape in the work of Nicolas Poussin*. « Journ. Warburg and Courtauld Inst », London, 7, 154-168 (1944).

DANIELSSON B., *Gauguin in the South Seas*. G. Allen and Unwin, London, 310 pp. (1964).

DURRIEU P., *Les très riches heures du Duc de Berry*. Plon-Nourrit et Co., Paris, 261 pp. (1904).

GAUGUIN POLA, *My father*. A. Knopf, New York, 300 pp. (1937).

HAMERTON P.G., *Landscape*. Roberts Broth., Boston, 440 pp. (1885).

LIST OF ARTISTS AND THEIR PICTURES IN THE ORDER AS THEY APPEAR IN THE TEXT

Fig. 1 — Duccio (c. 1255-1319): *Transfiguration.* National Gallery, London.

Fig. 2 — Sassetta (c. 1400-1450): *The journey of the Magi.* Metropolitan Museum of Art, New York.

Fig. 3 — Mantegna Andrea (1431-1506): *The agony in the garden.* National Gallery, London.

Fig. 4 — Bellini Giovanni (1428/30-1516): *The agony in the garden.* National Gallery, London.

Fig. 5 — Bruegel Peter (c. 1525-1569): *Paysage avec la chute d'Icare.* Musées Royaux des Beaux-Arts, Bruxelles.

Fig. 6 — Poussin Nicolas (1594-1665): *Landscape in the Roman Campagna.* Loan, National Gallery, London.

Fig. 7 — Ruisdael Jacob (van) (1628/29-1682): *The banks of a river.* National Gallery, Edinburgh.

Fig. 8 — Fohr Carl Philipp (1795-1818): *Wasserfälle von Tivoli.* Städelsches Kunst-institut, Frankfurt a.M.

Fig. 9 — Gainsborough Thomas (1727-1788): *A rocky landscape.* National Gallery, Edinburgh.

Fig. 10 — Constable John (1776-1837): *Weymouth Bay.* National Gallery, London.

Fig. 11 — Corot Jean-Baptiste (1796-1875): *Carrière à Fontainebleau.* M.V.S.K., Ghent.

Fig. 12 — Cézanne Paul (1839-1906): *Der Bahnrdurchstich.* Neue Pinakothek, München.

Fig. 13 — Gauguin Paul (1848-1903): *The vision after the sermon (Jacob wrestling with the angel).* National Gallery, Edinburgh.

Fig. 14 — Kandisky Wassily (1866-1944): *Garten.* Städt. Gallerie, München.

FIG. 15 — KANDISKY WASSILY (1866-1944): *Improvisation No. 26*. Städt. Gallerie, München.

FIG. 16 — WOOD GRANT (1892-1942): *Arbor Day*. Collection of Edwin Hewitt, U.S.A.

FIG. 17 — SCHMIDT-ROTTLUFF KARL (b. 1884): *Pommersche Moorlandschaft*. Saarland-Museum, Saarbrücken.

FIG. 18 — DUBUFFETT JEAN (b. 1901): *Au pied du mur*. In: « XX° Siècle ». P. Hazan, Paris, 1958.

FIG. 19 — DAHMEN KARL FRED (b. 1917): *Komposition in Rot*. In: « Schrift des Bodens - Sprache neuer Malerei ». Humboldtschule, Hannover, 1964.

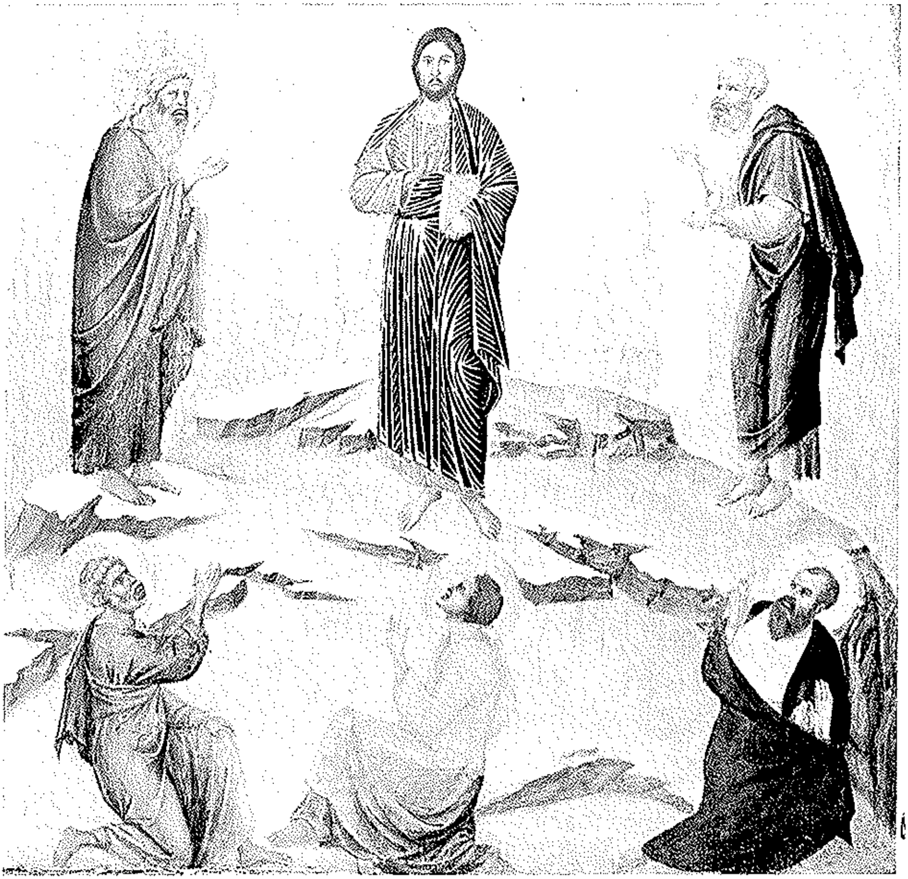


Fig. 1 - Duccio - *Transfiguration.*

Fig. 2 - Sassetta - *The journey of the Magi.*

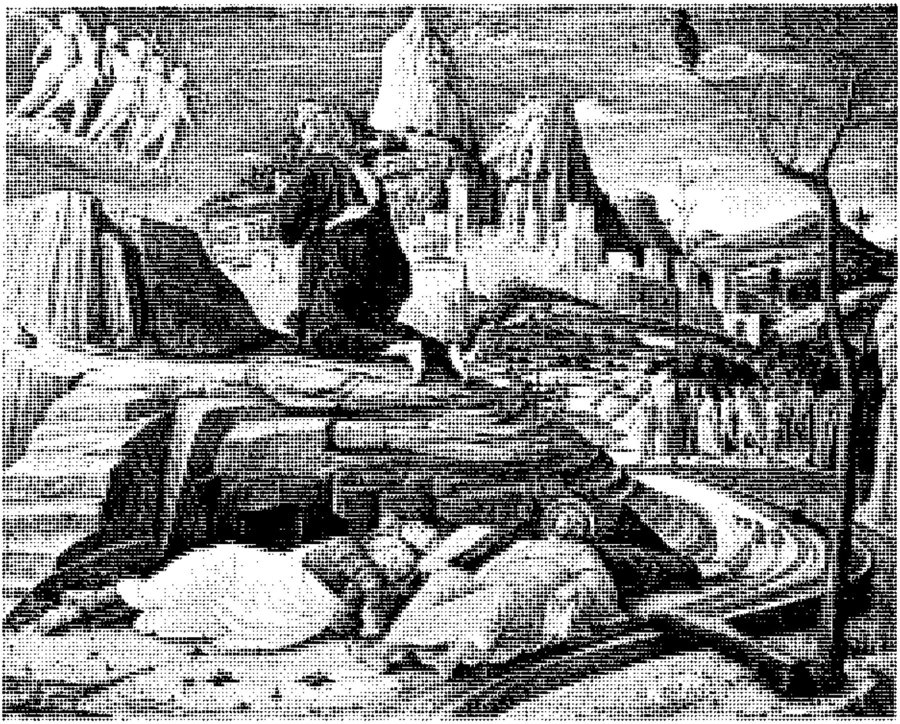


Fig. 3 - Mantegna - *The agony in the garden.*

Fig. 4 - Bellini - *The agony in the garden.*

Fig. 5 - Bruegel - *Paysage avec la chute d'Icare.*

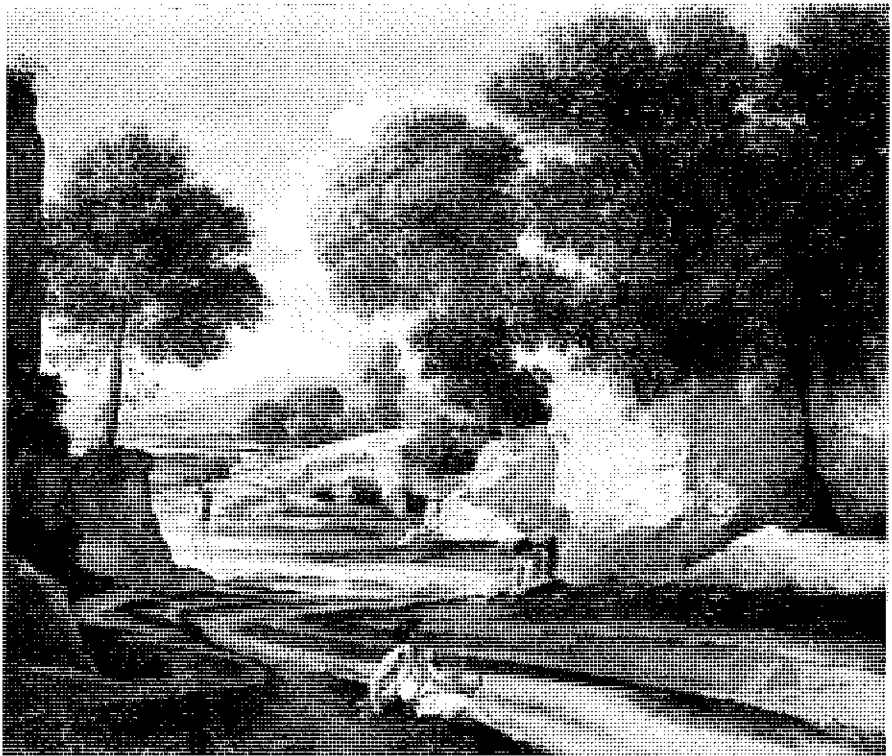


Fig. 6 - Poussin - *Landscape in the Roman Campagna.*

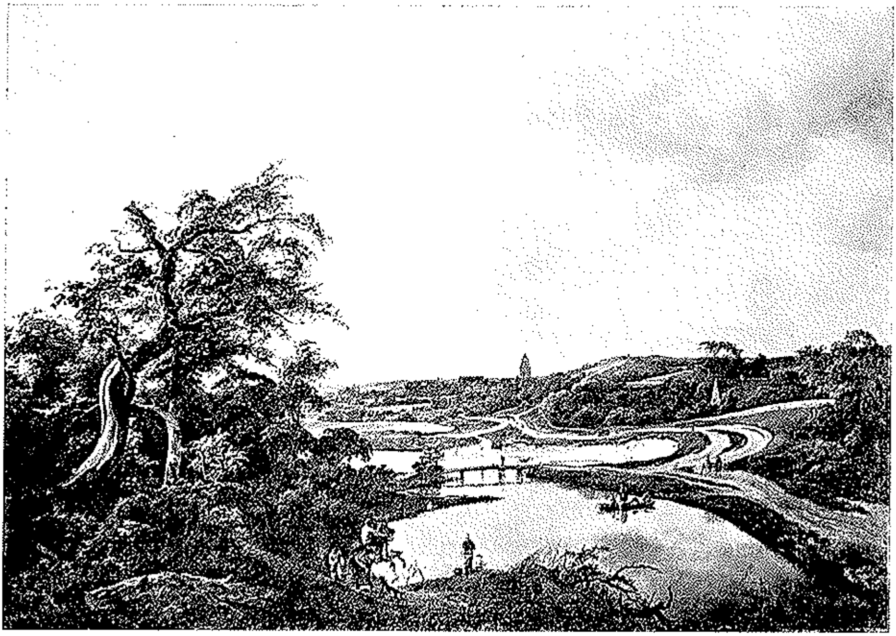


Fig. 7 - Ruisdael - *The banks of a river.*

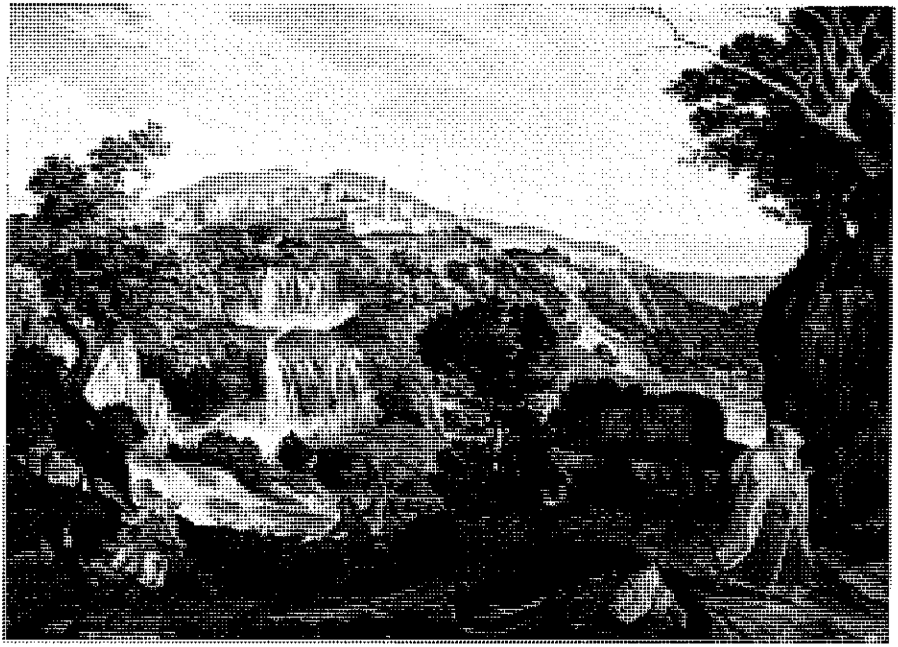


Fig. 8 - Fohr - *Wasserfälle von Tivoli.*

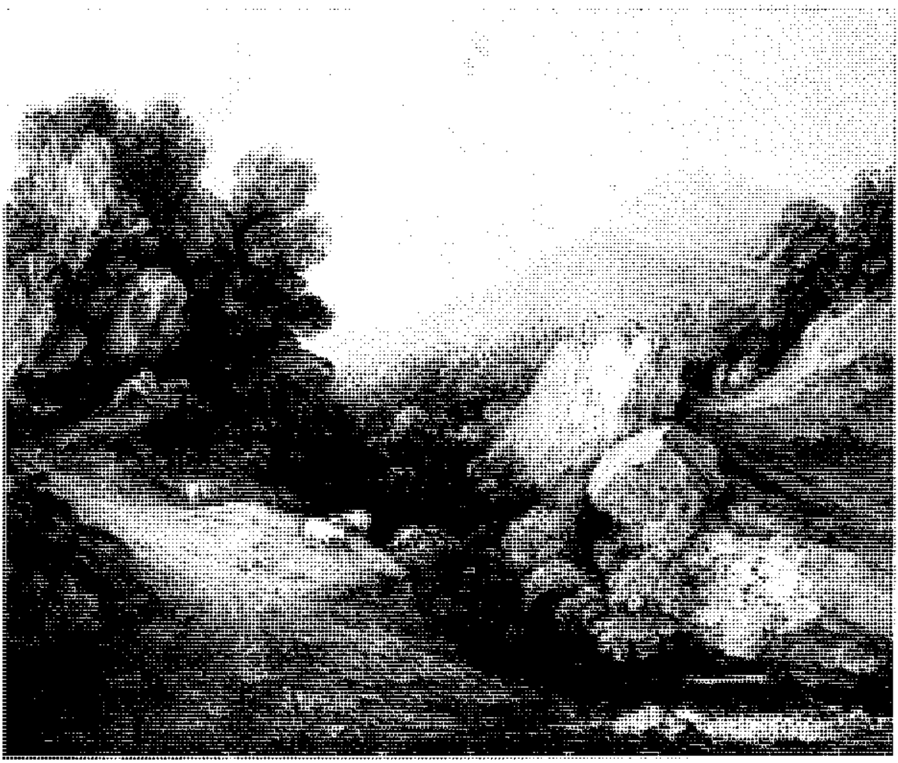


Fig. 9 - Gainsborough - *A rocky landscape.*

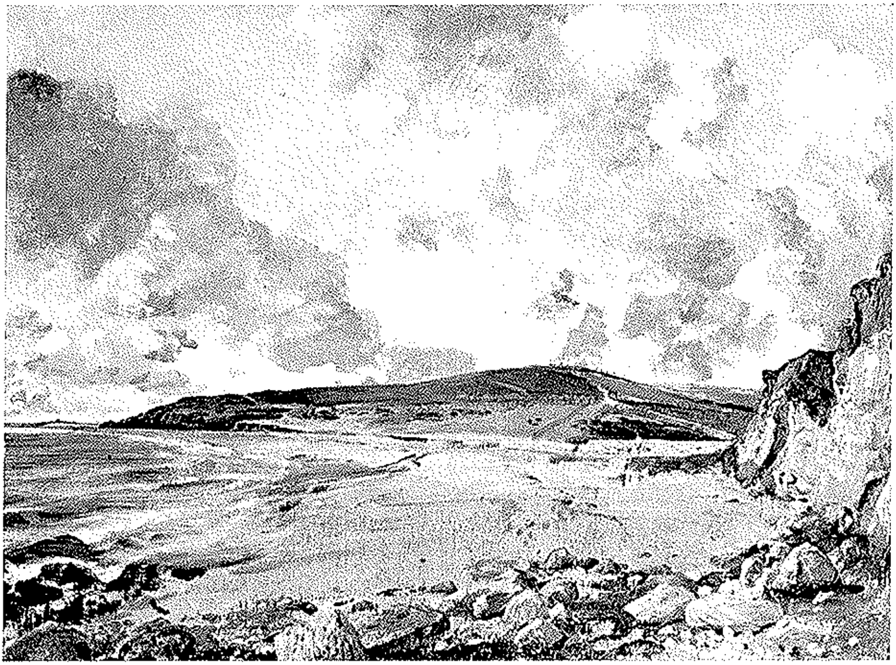


Fig. 10 - Constable - *Weymouth Bay*.

Fig. 11 - Corot - *Carrière à Fontainebleau*.

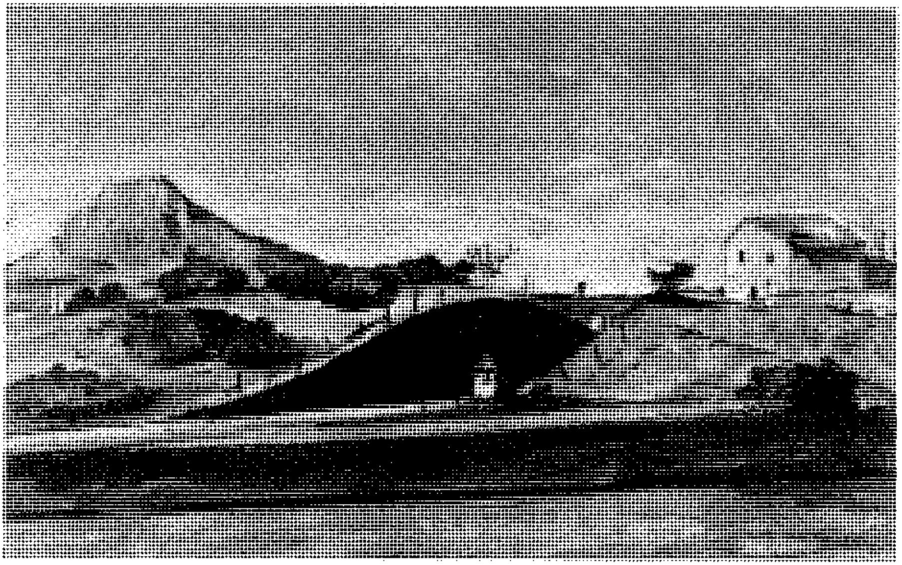


Fig. 12 - Cézanne - *Der Bahndurchstich.*

Fig. 13 - Gauguin - *The vision after the sermon.*

Fig. 14 - Kandisky - *Garten.*

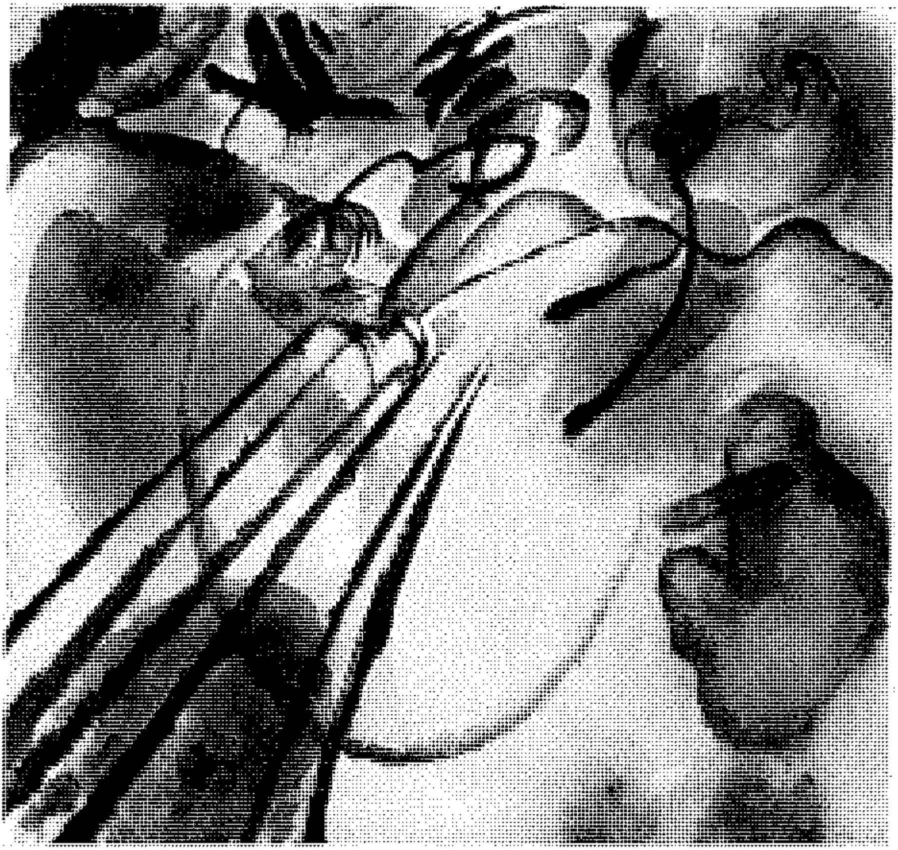


Fig. 15 - Kandisky - *Improvisation n.* 26.

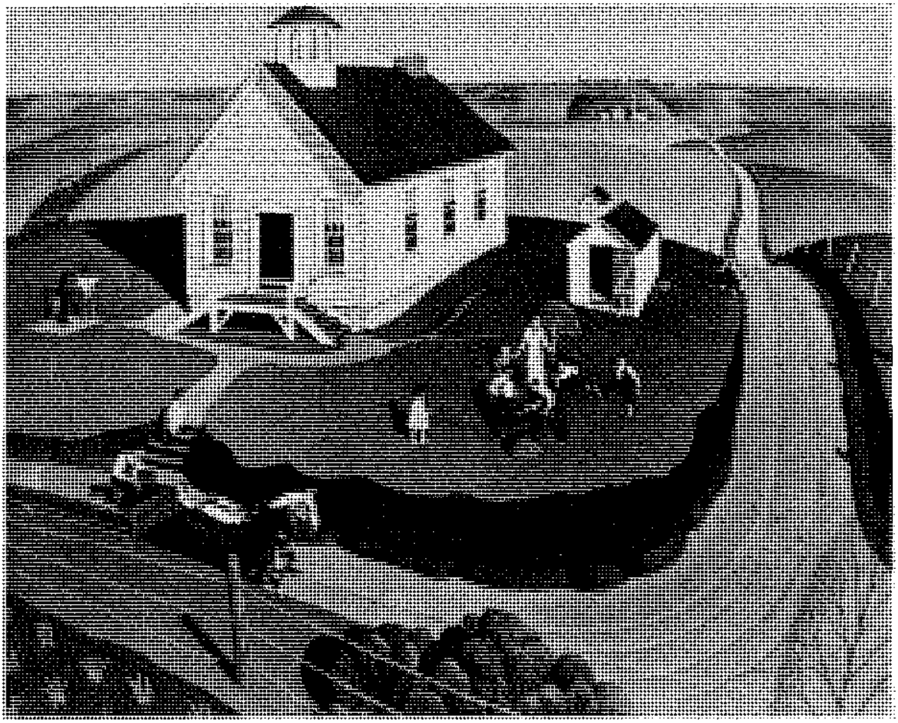


Fig. 16 - Wood - *Arbor day*.

Fig. 17 - Schmidt - Rottluff - *Pommersche Moorlandschaft.*

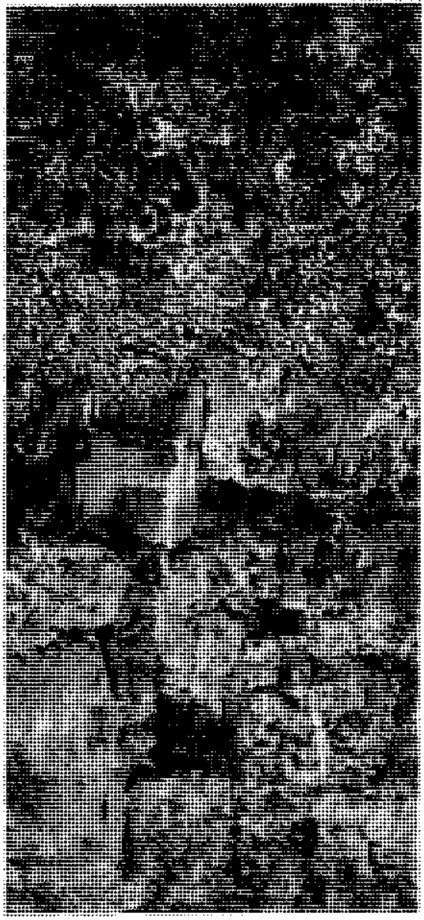


Fig. 18 - Dubuffet - *Au pied du mur.*

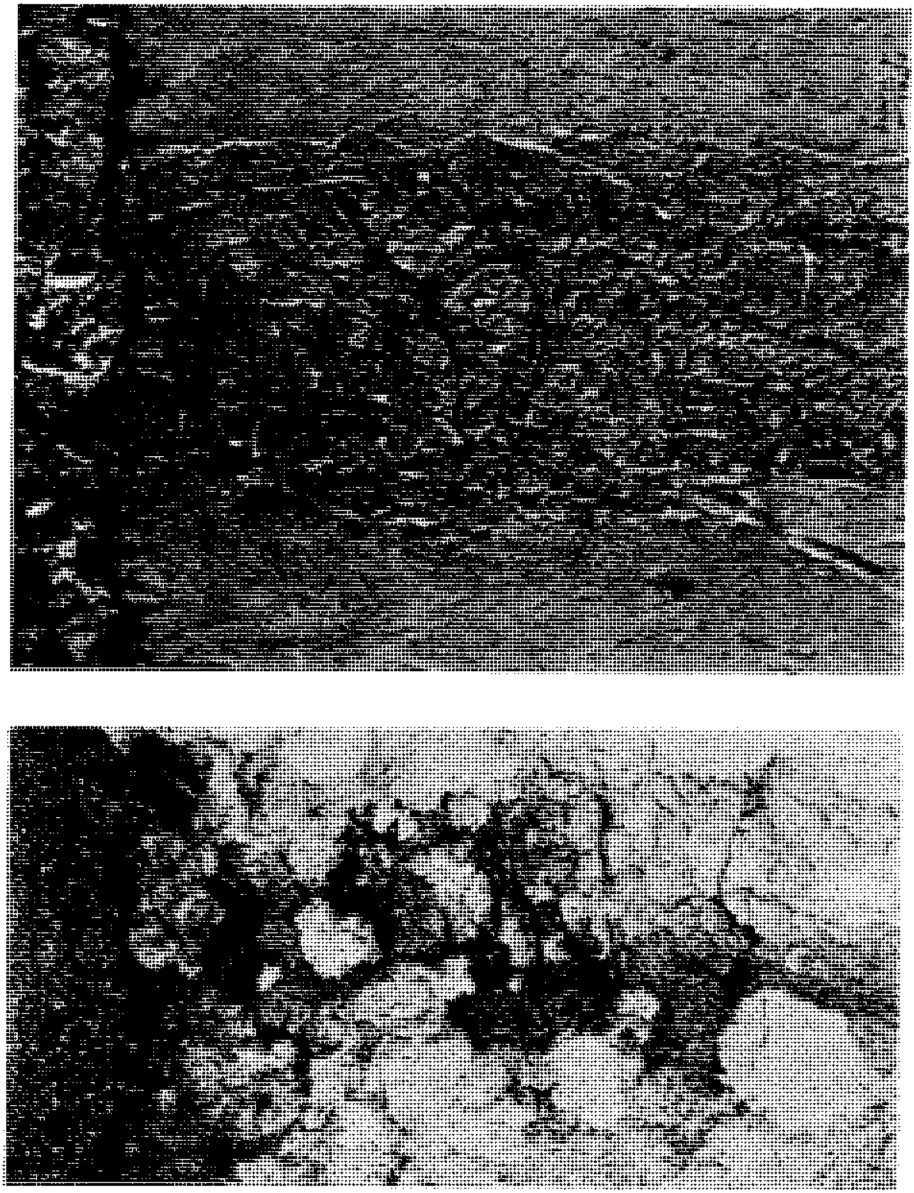
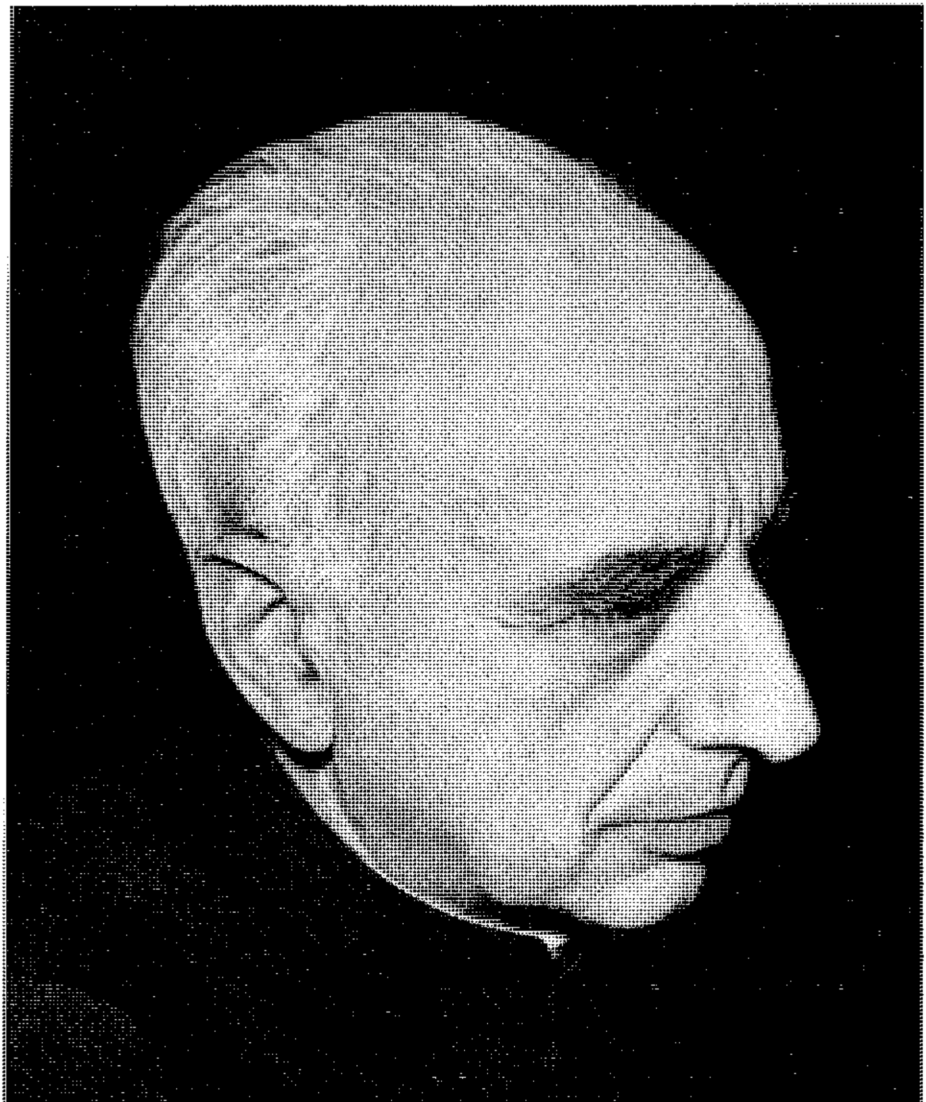


Fig. 19 - Dahmen - *Komposition in Rot.*

APPENDIX II

JOSE MARIA ALBAREDA HERRERA

15-IV-1902 27-III-1966



UN HOMBRE SABIO Y BUENO

por MANUEL LORA TAMAYO (*)

Hilvano estas líneas con el dolor de la impresión primera Le he visto morir y me resisto a creer en su falta.

Se no ha ido para siempre el José María Albareda de ayer, el padre Albareda de hoy, el hombre sabio y bueno de todo momento, y lo ha hecho, come vivió, discretamente, con sólo una docena de horas de angustiosa inquietud para los pocos que conocimos su mal, pasando inadvertido para los más hasta que lo inevitable tuvo que trascender. Por la misericordia de Dios gozará ya de la visión celestial, pero el dolor del desgarro nubla — por unos momentos nada mas, Señor — la visión de su dichosa eternidad.

Aqui deja una obra de gigante, con la que soñaba desde los días de nuestra guerra de Liberación. Para él, en el futuro glorioso que se preveía, la ciencia española tenía que adquirir superiores dimensiones y se hacía preciso realizar un órgano propulsor de la investigación que la articulara y diera empuje. La cuadrícula que trazara, al ver creado el Consejo Superior de Investigaciones Científicas, ha ido cubriéndose de denso contenído hasta alcanzar la fecunda realidad de hoy.

Una inercia de viejos procederes, una cerril negación de las realidades presentes y, en no pocos casos, una crítica aviesa, ligera e ignorante, ha pretendido en ocasiones, y siempre dentro

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(*) « A.B.C. » Madrid, 29 de marzo 1966. Edición de la mañana, pag. 71.

de casa, desvalorizar el rendimiento y magnitud de la empresa; pero, en el exterior, se valora en toda su dimensión y dignifica a España en el concierto científico universal. Los defectos de una obra grande no suelen ser los que la maledícencia señala, con espíritu destructivo, sino los que quienes la viven a diario aprecian bien en su permanente afán de superarlos.

Pero esa visión amplia y completa de lo que había que articular en el orden científico no le privó de concentrarse en la propia parcela de su investigación personal. Dentro de ella creó y desarrolló en España la investigación edafológica, con una clara y perspicaz proyección, aplicada al mejoramiento de nuestra producción agricola, cuya dirección, potenciada hoy por un crecido número de discípulos y colaboradores, multíplíca su eficacia en diversas regiones españolas a través de Centros y organizaciones que él creó y dió impulso.

En la figura humana de Albareda se conjuntan aspectos de coincidencias poco frecuentes: muy cerebral en sus concepciones, pero muy cordial en sus afectos, serio y profundo en su discurrir, siempre trascendente, y al propío tiempo capaz de mantener con un niño un sencillo diálogo impregnado de ternura; riguroso consigo mismo y abierto en ancha transigencia con los demás. Sufrío fisica y moralmente sin quejarse nunca, sin reaccionar contra la notoria injusticia.

La actual generación de investigadores, a los que dedicó en 1951 sus "Consideraciones sobre la investigación científica", magnífica obra no suficientemente difundida, debe a la iniciativa y las preocupaciones de Albareda su orgánica existencia de hoy y sus halagüeñas perspectivas de futuro.

Por su universalidad de saberes, su ciencia específica, sus dotes de creación y la extraordinaria calidad humana de su persona, José María Albareda deja en la ciencia española un hueco dificilmente reparable. Dios ayudará para la continuidad de su obra y él podra ser, sin duda, su mejor abogado.

RECUERDOS SENCILLOS DE JOSE MARIA ALBAREDA

por LORENZO VILAS (*)

Han de ser sencillos para que sean auténticos. Los que le trataron saben que su acción no hacia ruido, su pensamiento no tenia complejidades y su vida era franciscana. Fue humilde, pobre, sabio y generoso de amor al prójimo, cualidades que hizo fecundas por su triple canal de investigador, profesor y sacerdote. Vivió predicando con su ejemplo; cayó cuando predicaba la palabra de Dios. Vida utíl, muerte brillante.

Le conoci de estudiante, cuando tenia veintiún años y se matriculó en la Facultad de Ciencias de Zaragoza, graduado ya en Farmacia por Madrid, para estudiar con el famoso trío profesoral zaragozano Rocasolano, Saviron y Calamita. Una fotografía de laboratorio con Rocasolano y un célebre coloidequímico elamán nos recuerda el momento en que prendió su llama investigadora. Su habitación de patrona, en la calle de San Miguel, no tenía más sitio despejado que la mesa de trabajo, presidida por un pequeño crucifijo; el resto, incluso la cama, surgía donde los libros lo permitían. Ese crucifijo iba a ser el centro de su vida. Su padre, farmacéutico de Caspe, hombre de espíritu sólido y cuerpo recio, le enseñó con éxito a ser cristiano; cuando, en plena guerra, estando en Madrid, un primo suyo le dio la noticia de que su padre y su hermano

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(*) « Ya » Madrid, 30 de marzo de 1966.

habían sido fusilados en la plaza pública por los componentes de las columnas que pasaban de Barcelona hacia Zaragoza no oyó de sus labios ni una sola queja; oró y perdonó. Nadie le oyó hablar de esta herida de su alma, ni tomó actitud vindicatoria, ni influyó jamás en sus decisiones la posible comunidad de ideas con aquellos victimarios; antes bien, acogió en el Consejo de Investigaciones a personas expulsadas de sus cargos por la depuración. La tolerancia, que hoy se ensalza justamente como deseable, fue superada siempre en Albareda por el amor.

No vi nacer su afición política, en su acepción de pasión para ayudar al pueblo a alcanzar sus objetivos humanos y trascendentes, porque antes de entrar en quintas ya había publicado su primer libro, titulado « Biología política ». Era notoria su afición por el célebre profesor y crítico Juan Moneva, licenciado en Ciencias y catedrático de Derecho Canónico, de quien heredó, como un símbolo, la muceta universitaria, que le llevó a la similitud de estilo literario y a la doble condición de científico y rector de una universidad con facultad de cánones.

Con estas premisas, ci desarrollo de los tres frentes de su espíritu científico, político y religioso fue fulgurante. En el campo científico ennobleció la cátedra de agricultura de institutos, buscando el fundamento científico de sus enseñanzas, pues ganó la cátedra del Instituto de Huesca en 1929. Con este objeto frecuentó las mejores universidades y laboratorios de Europa, principalmente en Suiza, Inglaterra y Alemania, y se hizo « edafólogo », palabra acuñada por el español Huget del Villar cuando no había españoles a quienes aplicársela; Albareda los fabricó después. La cátedra de la Fundación del conde de Cartagena y sus numerosas publicaciones de investigación le trajeron por concurso a un instituto de Madrid, en donde le sorprendió el 18 de julio, pasándose algún tiempo después a pie, por el Pirineo, a la zona nacional, donde colaboró en Vitoria a la organización de la educación. En los primeros días de la victoria regresó a Madrid con el mandato de no perder la brillante herencia del instituto-escuela y fundó el Instituto Ramiro de Maeztu, del que fue organizador y primer director. Pasó pronto a la Universidad; opositó a la cátedra de Geología de la Facultad de Farmacia, que desempeñó hasta su nombramiento de rector de la Universidad de Navarra. En el Consejo de Investigaciones fundó el Instituto de Edafología, que ha dirigido hasta su muerte y que ha servido para alumbrar en la juventud universitaria una fecunda vena de actividad en el campo de las ciencias aplicadas al suelo y a las plantas. El extraordinario trabajo que hoy se hace en este campo en Madrid, Barcelona, Murcia, Granada, Salamanca y Santiago, entre otros lugares, a él se debe. Los doctorados honoríficos, sillones de academias, premios y presidencias relatados en las notas necrológicas son pocos para premiar al iniciador de este movimiento científico. Era una lástima que no los luciera, porque su obra estaba a la vista, pero su autor procuraba esfumarse en la humilde oscuridad.

En la faceta política actuó en forma parecida. Nunca apareció como autor de las cosas, pero fue el inspirador de muchas de las creaciones que se hicieron en Educación Nacional en los años de la reconstrucción. Ya hemos citado la fundación del Instituto Ramiro de Maeztu, que ha desarrollado su línea primera con evidente eficacia; la ley Universitaria del año 1943, con un acierto tan claro en la Facultad de Farmacia, por poner un ejemplo ligado a él, que ha producido en estos años más hombres de ciencia y investigadores que en toda su historia anterior; el Consejo Superior de Investigaciones Científicas, cuyos estatutos planeó y desarrolló como secretario general, alentando la creación de los distintos patronatos, que hoy actúan con efecto ambiental para la preparación de hombres y real para el avance de las ciencias. Este solo aspecto basta para la perduración de su nombre y para el agradecimiento, por acción directa o indirecta, de todos los españoles.

Pocos pueden sospechar ahora el beneficioso efecto de la contemplación de la España asediada de los años 40 por los mejores científicos extranjeros, cargados de prejuicios, a través de la rendija del Consejo de Investigaciones, invitados por la figura serena y transparente de Albareda.

Mucho deben a su acción la llamada enseñanza media y profesional, la primera junta asesora de las Universidades Luborales que presidió Coca de la Piñera, el Consejo Nacional de Educación y otras muchas instituciones.

Su faceta religiosa es de todos conocida. Se hizo socio del « Opus Dei » en los primeros años de la existencia de esta institución, porque encuadraba perfectamente su ideal de vida; muchos años después, en 1959, fue ordenado sacerdote y ocupó el rectorado de la Universidad Pontificia de Navarra, a cargo del « Opus Dei ». Cuando viajaba o esperaba en antesalas meditaba y oraba. Viajé miles de kilómetros con él por gran parte de la Tierra y nunca le vi perder el tiempo.

Algunos dirán que erró en tal cosa o no acertó en tal otra. Bien; tengan en cuenta que estamos recordando a un hombre y no a un ángel, por lo que les invito a superarle, ya que todos los humanos somos del mismo barro.

NOTA BIOGRAFICA

DE D. JOSÉ MARÍA ALBAREDA HERRERA

Nació el 15 de abril de 1902, en Caspe (Zaragoza).

Cursó estudios en la Facultad de Farmacia de Madrid y en la Facultad de Ciencias, Sección de Químicas, de la Universidad de Zaragoza.

Se doctoró en Farmacia en 1927, y en Ciencias en 1931, con Premio Extraordinario.

De 1926 a 1928 trabajó en el Instituto de Bioquímica del Profesor Rocasolano, y en el Laboratorio de Electroquímica del Profesor Ríus Miró, en la Universidad de Zaragoza.

Catedrático de Agricultura por oposición, del Instituto di Enseñanza Media de Huesca. 1928.

De 1928 a 1929 trabaja en el Institut für Chemie der Land. Hochschule de Bonn, con el Profesor Kappen.

De 1929 a 1930, trabaja en el Agrikulturschemischen Laboratorium de la Eidg. Tech. Hochschule con el Profesor Wiegner, y en el Pflanzenbau-Institut de la Universidad de Königsberg, con el Profesor Mitscherich.

En 1932 fué nombrado becario de la Fundación « Ramsay », por la Real Academia de Ciencias, y trabajó durante dos años en la Rothamsted Experimental Station (Inglaterra), y en Bangor (Gales) y Aberdeen (Escocia).

Transladado, por Concurso, al Instituto Velázquez de Madrid. 1935.

De 1935 a 1936 dio un curso de Ciencia del Suelo en la Cátedra « Conde de Cartagena » de la Real Academia de Ciencias de España.

Director del Instituto « Ramiro de Maeztu » de Madrid. 1939.

Secretario General del Consejo Superior de Investigaciones Científicas. 1939.

Catedrático de Mineralogía y Zoología de la Facultad de Farmacia de la Universidad de Madrid (Cátedra que en 1944 pasa a ser de Geología Aplicada). 1940.

Jefe de la Sección de Química Agrícola del Instituto de Química del Consejo Superior de Investigaciones Científicas. 1940.

Director del Instituto de Edafología y Fisiología Vegetal del Consejo Superior de Investigaciones Científicas. 1942.

Rector de la Universidad de Navarra. 1960.

Vicepresidente del Patronato « Alonso de Herrera » del Consejo Superior de Investigaciones Científicas. 1946.

Presidente español del I Congreso de Estudios Pirenaicos, y Presidente español de la Unión Internacional respectiva. 1950.

Presidente de la Sociedad Española di Ciencia del Suelo. 1950.

Presidente del V Congreso Internacional del INQUA. 1955.

Forma parte de la Comisión Nacional de Cooperación con la UNESCO.

Procurador en Cortes. 1955.

Doctor Honoris Causa de la Universidad Católica de Lovaina. 1953. - Doctor Honoris Causa por la Universidad de Toulouse. 1955. - Académico titular de la Real Academia de Ciencias Exactas, Físicas y Naturales de Madrid, 1941. - Académico titular de la Real Academia de Farmacia de Madrid. 1941. - Socio correspondiente de la Real Academia de Ciencias y Artes de Barcelona. - Socio corresponsal del Museo Canario. 1944. - Miembro de la Internacional Society of Soil Science. 1945. - Miembro de la Mineralogical Society. 1947. - « Académico Pontificio », Pontificia Academia Scientiarum - Città del Vaticano. 1948. - Académico correspondiente de la Real Academia de Ciencias de Barcelona. 1948. - Académico correspondiente de la Academia de Ciencias Exactas y Físico-Químicas de Zaragoza. 1948. - Miembro colaborador del Instituto Internacional de Ciencias Políticas y Sociales Aplicadas a Países de Civilización diferente (I.N.C.I.D.I.) de Bélgica. 1949. - Miembro de la British Society of Soil Science. - Miembro colaborador del Instituto de Antropología de la Universidad Nacional de Tucumán (Argentina). 1950. - Miembro correspondiente del Forschungsanstalt für Landwirtschaft, de Braunschweig. 1950. - Académico titular de la Real Academia de Medicina de Madrid. 1952. - Miembro de la American Society of Agronomy. - Miembro de la American Society of Soil Science. - Miembro de la Ingeniörs Vetenskaps Akademien, de Estocolmo. 1954. - Miembro correspondiente de la Arbeitsgemeinschaft für Forschung. 1954. - Miembro correspondiente de la Braunschweigische Wissenschaftliche Gësellschaft. 1955. - Miembro de la Deutsche Bodenkundliche Gësellschaft. - Académico correspondiente de la Real Academia de Farmacia. Barcelona. - Miembro de la Internacional Association of Sedimentologists. 1962. - Miembro de la Academia de Agricultura de Francia. 1964. - Miembro de la Asociation française pour l'Etude du Sol.

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