PONTIFICIAE ACADEMIAE SCIENTIARVM SCRIPTA VARIA

38

SEMAINE D'ETUDE

SUR LE THEME

L'EMPLOI DES FERTILISANTS ET LEUR EFFET SUR L'ACCROISSEMENT DES RECOLTES, NOTAMMENT PAR RAPPORT A LA QUALITE ET A L'ECONOMIE

10-16 avril 1972

I[e] PARTIE

PONTIFICIA
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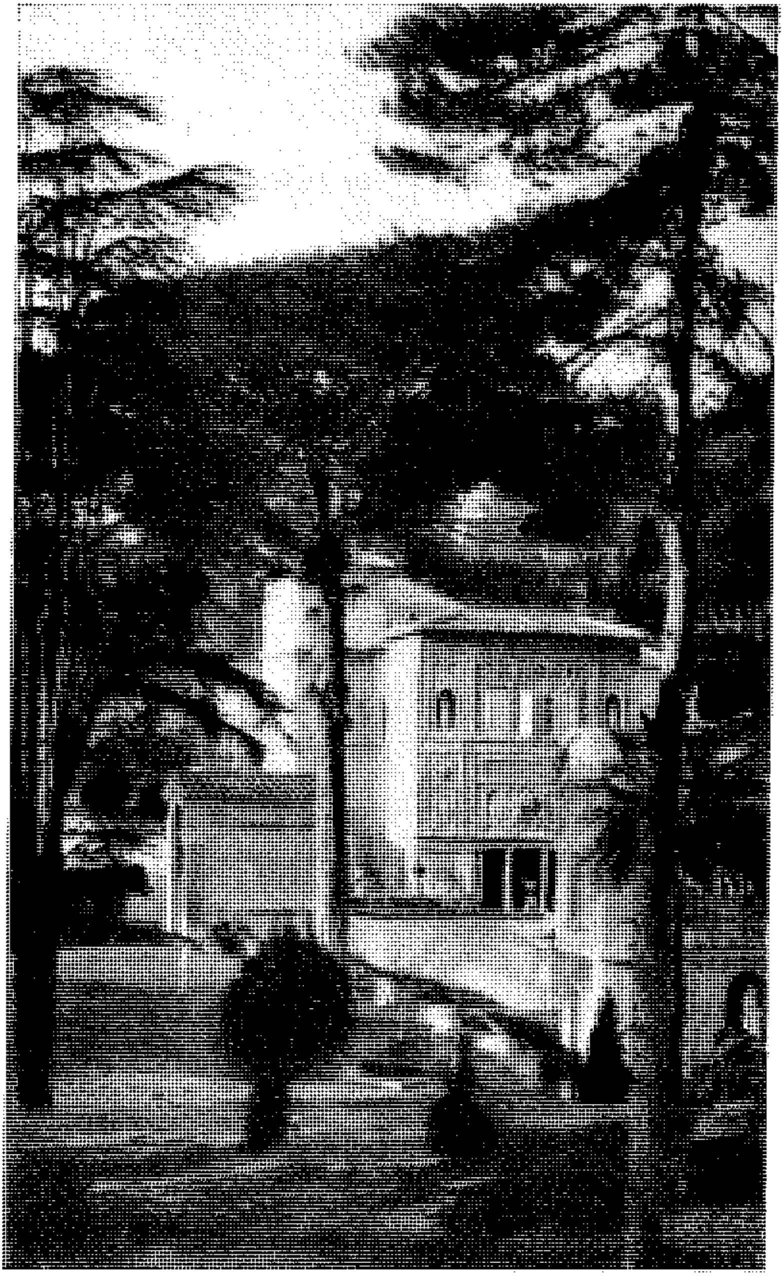

PONTIFICIAE ACADEMIAE SCIENTIARVM SCRIPTA VARIA

38

STUDY WEEK

ON

USE OF FERTILIZERS AND ITS EFFECT IN INCREASING YIELD WITH PARTICULAR ATTENTION TO QUALITY AND ECONOMY

April 10-16, 1972

FIRST PART

PONTIFICIA
ACADEMIA
SCIENTIARVM

EX AEDIBVS ACADEMICIS IN CIVITATE VATICANA

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PRESENTATION

Rien n'est plus utile que les rencontres de groupes de spécialistes attachés à l'examen d'un problème concret, quand leur formation est diverse et ils considèrent le sujet de points de vue ouvertement différents.

Affirmation valable également dans le domaine de l'édaphologie, à propos de laquelle nous avons le plaisir de présenter les Actes de la deuxième Semaine d'Etude organisée sur ce sujet par notre Académie, et qui fut exprimée déjà au cours de la première Semaine d'Etude, en 1968, à laquelle participèrent des spécialistes de physique, chimie, microbiologie des sols et agronomie: chacun d'eux, en soulignant un aspect différent du même sujet, permit d'atteindre des conclusions d'un énorme intérêt pratique, ce qui était le but visé.

A ces fins il est cependant indispensable que le nombre de participants soit limité et surtout que personne d'autre qu'eux *ne soit admis aux réunions, pas même les Académiciens Pontificaux.*

De telles rencontres, initiative originale de l'Académie Pontificale des Sciences, sont particulièrement appréciées dans les milieux scientifiques internationaux en raison de la contribution qu'apporte la publication intégrale de leurs discussions, et aujourd'hui, après plus de vingt ans d'expérience, on peut constater qu'elles sont le moyen le plus efficace pour obtenir des conclusions capables de contribuer au progrès de l'humanité.

Car, et il est aisé de l'observer, dans les grands Congrès, dont l'importance se réduit de jour en jour du point de vue que l'on pourrait appeler constructif bien qu'ils restent toujours valable sur le plan de l'information et de la connaissance, il n'est en premier lieu pas possible d'assister à toutes les discussions relatives aux sujet d'intérêt, et souvent on finit par tourner son attention vers des arguments de peu de poids tout en négligeant d'autres bien plus importants, car les réunions coïncident dans le temps et en outre on ne sait pas en réalité comment y seront traités les sujets.

D'autre part, vu la quantité et la densité des sujets outre que le grand nombre de participants, les spécialistes ne peuvent garder un contact suffisant pour atteindre des conclusions définitives et qui permettent de définir de nouvelles orientations pour l'étude du ou des sujets traités.

En outre la présence du public ne permet guère des jugements scientifiques qui, si d'une part ils comportent des appréciations personnelles dans le but de mieux éclaircir une question, *n'en sont pas moins d'une très grande utilité lors qu'il s'agit de définir des points sujets à controverses.*

Quand au contraire le nombre des participants est limité, et en particulier quand il est inférieur à trente, les possibilités de discussion et d'échange d'idées sont énormes, et, en général, moins d'une semaine suffit pour atteindre des résultats excellents, très constructifs et positifs à tous les points de vue.

Choisir dans le monde entier des spécialistes de tout premier ordre pour chacun des aspects du sujet, des spécialistes n'ayant pas la même formation et surtout pas la même façon d'affronter un problème donné, voilà la manière la plus efficace d'obtenir une vue d'ensemble sur les problèmes à examiner, et cela sous des angles complètement différents.

Tout cela permet, au cours des discussions de la Semaine d'Etudes, de comparer et souvent de soupeser les différents points de vue et d'arriver le plus souvent à des conclusions concrètes qui jettent un pont sur les différences de méthode, ce qui permet de définir un programme de recherches s'adaptant parfaitement au sujet proposé. De la même façon les conclusions ainsi obtenues sont tout à fait applicables en pratique, d'autant plus que l'organisation prévoit, bien avant le début de la Semaine d'Etudes, l'envoi des articles à chacun des participants, qui auront ainsi tout loisir d'étudier mutuellement leurs travaux et pourront ainsi, au cours de la Semaine, disposer de bien plus de temps pour les discussions proprement dites.

Pour la présente Semaine d'Etudes un choix rigoureux a été opéré parmi les spécialistes de la production de fertilisants, *de l'évaluation des besoins de fertilisants des plantes et des terrains, de l'emploi des isotopes pour déterminer ces besoins — méthode dont le rôle croît de jour en jour —, et enfin des problèmes économiques relatifs à l'emploi des fertilisants.*

A cette Semaine ont en outre participé des experts de cas concrets d'effets de l'emploi d'engrais dans les différents climats, qui ont examiner d'une façon approfondie les problèmes en matière. Cela a porté à des conclusions générales pour le futur en ce qui concerne les engrais dans les différentes zones climatiques, et spécialement dans les pays en voie de développement.

Les travaux de la Semaine d'Etudes ont également vu l'intervention de spécialistes qui ont souligné l'importance des ordinateurs dans l'interprétation des résultats des analyses des terrains et des plantes et dans celle des expériences conduites à ciel ouvert ou sous serre.

Il est permis d'affirmer que tout cela a contribué d'une façon valable à la définition d'un tableau complet et actuel de tous les aspects des recherches concernant le sujet proposé.

Quelques-uns des participants se sont en outre étendus sur les problèmes relatifs à la qualité de la récolte dans le cadre de l'économie de la production, argument dont l'importance ne pourra que croître, car le monde entier, et plus spécialement les pays en voie de développement, tendent au choix d'après la qualité. C'est de plus en plus la qualité qui prime sur la quantité.

Et il est évidemment nécessaire de savoir quels sont les aspects que considéreront ceux qui, vu la tendance à l'accroissement de la production, sauront et devront signaler les caractéristiques de l'application de ces engrais.

Un autre important sujet de discussion a été le rôle d'un emploi approprié et équilibré des engrais dans la réduction des effets des infestations de parasites, surtout maintenant que la pollution s'aggrave de jour en jour du fait de l'emploi toujours plus intense des insecticides.

On pourrait déplorer l'absence de spécialistes de sujets non moins importants, dont les interventions auraient pu compléter les travaux de la Semaine, mais en premier lieu cela nous a été impossible à cause du nombre limité de participants admis, et en outre de leurs domaines spécifiques, bien qu'ayant leur importance aux fins de la qualité et de la quantité des récoltes, n'a toutefois aucune relation directe avec le sujet fondamental de notre Semaine d'Etudes, l'emploi des fertilisants. Et le même raisonnement vaut pour la génétique.

PIETRO SALVIUCCI
Chancelier de l'Académie

INTRODUCTION

Le problème de la faim dans le monde est étroitement lié à l'emploi rationnel des fertilisants. Or, c'est justement dans les pays moins développés et où la population est la plus pauvre que les fertilisants ne sont pas employés ou le sont mal à propos.

Ce problème est devenu si harcelant qu'il retient l'attention de tous ceux qui peuvent contribuer en quelque manière à lui trouver une solution.

L'Académie Pontificale des Sciences a organisé dans ce secteur une Semaine d'étude sur le thème: « L'emploi des fertilisants et leur effet sur l'accroissement des récoltes, notamment par rapport à la qualité et à l'économie ». Les participants se sont attachés à parvenir à des conclusions pouvant contribuer à un meilleur emploi des fertilisants, soit en ce qui concerne leur application technique soit du point de vue économique, soucieux d'étendre les résultats des discussions et de la confrontation des diverses opinions au monde entier et plus spécialement aux conditions des pays moins développés.

Ainsi orientée, cette Semaine d'Etude eut un programme divisé en six sections pour faciliter la discussion de l'ensemble de la problématique par une analyse de ses aspects particuliers.

Pour chaque matière elle a fait appel à des spécialistes universellement connus, provenant de diverses parties du monde et ayant sur le sujet des points de vue différents, cherchant autant que possible à convier des ressortissants de pays appartenant aux zones géographiques qui présentent une problématique particulière quant au thème de la Semaine.

Voici dans l'ordre de leur discussion les six arguments pris en considération:

1. « Application des différents types de technique dans l'analyse du sol et des plantes pour déterminer leur besoin de fertilisants ».

La meilleure utilisation des fertilisants et l'emploi des techniques les plus modernes furent ici examinés par des spécialistes qui discutèrent des avantages et des inconvénients de chaque technique et de l'encadrement du problème pour lui donner la meilleure solution dans un futur immédiat.

2. « Emploi des fertilisants dans les régions du monde à conditions climatiques différentes ».

Les aspects traités furent ceux relatifs aux régions tropicales et subtropicales humides dans l'ensemble, les aspects particuliers de l'Amérique latine, de l'Afrique, des régions semi-arides et semi-humides, ainsi que l'ensemble des problèmes de la fertilisation des zones tempérées.

A la fin fut exposé le travail que la FAO a entrepris d'une manière générale pour améliorer l'emploi des fertilisants et intensifier la production des cultures alimentaires.

Les discussions qui suivirent amenèrent des considérations de grand intérêt.

3. « Aspects relatifs à l'écologie et aux conditions de la culture ».

La considération des conditions écologiques comme facteurs de rendement des fertilisants et limites de leur application a aujourd'hui beaucoup d'importance et en aura de plus en plus.

Les rapports présentés sur le sujet et les discussions qui suivirent ont fait valoir l'importance des facteurs écologiques limitatifs et leur action sur la potentialité des fertilisants.

L'expérience acquise à ce jour peut et doit servir à faire bénéficier le plus possible le reste du monde des résultats obtenus dans des zones très limitées de pays développés.

4. « Effet des fertilisants sur la qualité des récoltes ».

Cet aspect est très important parce qu'il comprend une thématique qui, même récemment, n'a pas encore la considération qu'elle mérite et qui acquerra certainement dans un proche avenir une plus grande importance.

Fut souligné comme facteur important la nécessité d'employer un plus grand nombre d'éléments fertilisants que ne le veut la composition classique (NPK), parce que se manifestent chaque jour les conséquences de l'emploi exclusif du NPK sur l'équilibre nutritif et la qualité des récoltes.

Au fur et à mesure que la production augmente grâce à de nouvelles variétés d'hybrides, à des méthodes plus adéquates de travail des sols, d'ensemencement et d'emploi des fertilisants, la nécessité de recourir à une gamme plus étendue d'éléments fertilisants s'impose avec plus d'acuité, si bien que l'application du fumier et d'autres engrais organiques a extraordinairement diminué.

Pour résoudre ces problèmes on a fait appel à de nouvelles techniques et développé des procédés de fertilisation équilibrée.

On discuta des possibilités de généralisation et des procédés à suivre dans un proche avenir.

On fit valoir combien il est important que les pays encouragent la qualité des récoltes en fixant des prix rémunérateurs, si l'on veut que l'agriculteur s'applique à obtenir des qualités supérieures, lesquelles rejailliront en de meilleures conditions de santé pour les individus.

5. « Nouveaux fertilisants et aspects spéciaux et futurs dans leur emploi ».

Furent ici examinées les perspectives de l'emploi de nouveaux fertilisants et leur probable importance économique dans l'avenir, ainsi que les résultats et prévisions possibles de ce qu'on appelle la « révolution verte »; les perspectives quant aux moyens futurs sont telles qu'aucun problème ne se pose dans ce secteur.

Les aspects économiques furent mis en premier plan et c'est à eux que la discussion donna le plus d'importance.

Nettement il fut bien établi que c'est fondamentalement un problème économique (achat et transport des fertilisants) qui, en réalité, limite la possibilité d'accroître les récoltes des pays sous-développés.

Par contre, il n'existe aucune limitation immédiate dans la possibilité de fabriquer des fertilisants, mais cette fabrication se concentre principalement dans les pays développés, qui sont exportateurs; de là le problème économique cité précédemment comme limitatif.

6. « Emploi de techniques de calcul et de nouveaux systèmes pour déterminer le besoin de fertilisants ».

Il s'agit de l'emploi des isotopes radioactifs dans les fertilisants, et des résultats obtenus pour connaître leur efficacité en serres ou en champs d'expérimentation.

On releva les possibilités futures dans l'emploi de ces méthodes spéciales, du point de vue de la fertilisation inorganique et organique.

Le plus important de tout ce qui fut dit autour de ce sixième argument eut trait aux possibilités qu'offre l'emploi des calculateurs modernes pour étudier l'influence de la quantité de facteurs qui interviennent dans la production végétale.

Sans ces calculateurs modernes il serait absolument impossible de tenir compte dans les expérimentations, et encore moins dans les cultures normales, du grand nombre de facteurs susceptibles d'influencer les récoltes, puisqu'il est pratiquement impossible d'obtenir une bonne corrélation entre la fertilisation et le rendement. On peut aujourd'hui considérer que ce problème est résolu d'une manière acceptable du fait de la possibilité de formuler un pronostic du rendement en fonction de la fertilisation, qui offre toute garantie d'une bonne précision.

Tous les thèmes furent repris dans une intense discussion finale qui devait préparer les « Conclusions ». Celles-ci ont retenu les points plus importants sur lesquels les participants parvirent à un accord: emergent ceux qui se réfèrent à la nécessité de futures investigations quant aux divers aspects du milieu, des cultures, des sols, de la santé de l'homme et des animaux, en vue d'augmenter dans chaque cas l'efficacité de l'emploi des fertilisants et de réduire au maximum la perte des ressources de la nature dans le monde.

Regardant le contrôle de la nécessité de fertilisants, fut mise en évidence l'importance de réaliser une bonne corrélation entre les analyses du terrain et des cultures et les résultats de l'expérience en terrain cultivé et surtout en serre.

On ne manqua pas de noter combien il est capital pour l'efficacité de tout ce qui a été dit de procéder à une divulgation des connaissances scientifiques, de manière qu'elles parviennent aux agriculteurs et puissent les convaincre des avantages économiques et sociaux qu'elles comportent.

Ne manquons pas de signaler l'optimisme avec lequel les scientifiques envisagent l'avenir de la production agricole dans le monde. C'est parce que le problème de la faim ne peut être enrayé que par une meilleure distribution des moyens de production, en particulier des fertilisants, ou, ce qui revient au même, par des aides économiques aux pays sous-développés accordées par des Organismes Internationaux ou des pays plus développés et économiquement plus forts, leur permettant de disposer des moyens nécessaires pour fertiliser comme il convient leurs cultures.

Nous voulons espérer que le bon sens l'emportera et qu'on parviendra dans un proche avenir à cette équitable distribution que nous avons proposée.

Puissions-nous avoir contribué, conformément au désir du Saint Père, à présenter des orientations pour résoudre ce problème de la faim qui se pose si cruellement à l'humanité. En substance, ces orientations constituent aussi de possibles solutions.

VALENTÍN HERNANDO FERNÁNDEZ

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

Le texte original espagnol se trouve a la pag. 1231.

SEMAINE D'ETUDE

SUR

L'EMPLOI DES FERTILISANTS ET LEUR EFFET SUR L'ACCROISSEMENT DES RECOLTES, NOTAMMENT PAR RAPPORT A LA QUALITE ET A L'ECONOMIE

Le but des « Semaines 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 en 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: « L'emploi des fertilisants et leur effet sur l'accroissement des récoltes notamment par rapport à la qualité et à l'économie » (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 restreint 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 promettantes, étant donné l'état actuel de la science.

A cet effet ont été invités des experts qualifiés en agriculture, en agronomie, en biochimie, en botanique, en édaphologie, en géologie, en microbiologie, en recherches agronomiques 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 « L'emploi des fertilisants et leur effet sur l'accroissement des récoltes notamment par rapport à la qualité et à l'économie » a été confié par le Président de l'Académie Pontificale des Sciences, S.E. le Rev. Père DANIEL O'CONNELL à l'Académicien Pontifical S.E. Don MANUEL LORA TAMAYO, Professeur de Chimie organique à l'Université de Madrid, et nomma Secrétaire technique de la dite Semaine M. le Prof. Dr. VALENTÍN HERNANDO FERNÁNDEZ, Sous directeur de l'Institut d'Edaphologie et Biologie Végétale de Madrid, aidé par M. le Prof.

(1) Voir la liste des « Semaines d'Etude » organisées par l'Académie Pontificale des Sciences à la page LXVII.

Dr. LUIS JIMENEZ, Chef adjoint du Département pour la fertilité des sols et par Mlle ANTONIA MARIA GONZALEZ, Bibliothécaire du même Institut d'Edaphologie de Madrid.

Ont été invités à la réunion les savants suivants:

Dr. YEHUDA ARATEN, Directeur de la division Nouveaux Engrais de l'Institut pour la recherche et le développement des Israël Mining Industries; Conseiller du Ministère du Développement pour les engrais - *Haifa* (Israël).

Prof. Dr. FRITZ BAADE, Directeur de l'Institut de Recherche sur les problèmes économiques des pays en voie de développement - *Kiel* (Rép. Féd. Allemande).

Dr. ROBERT BLANCHET, Directeur de la Station d'Agronomie de Toulouse - *Toulouse* (France).

Prof. Dr. ELEMER BORNEMISZA, Conseiller du Directeur Régional de l'Institut Interaméricain de Sciences Agricoles de l'OEA pour la Zone Andine - *Lima* (Pérou).

Prof. Dr. LOUIS BRAMÃO, Station agronomique Nationale du Portugal - *Oeiras* (Portugal).

Prof. Dr. WOLFGANG BUSSLER, Professeur de Nutrition des Plantes à la Faculté de Développement Agricole de l'Université Technique de Berlin - *Berlin, Dahlem* (Allemagne).

Dr. BERNARDO G. CAPÓ, Conseiller technique à la Station Agricole Expérimentale de l'Université de Puerto Rico - *Rio Piedras* (Puerto Rico).

Mr. YVES-MARIE-FRANÇOIS COÏC, Ingénieur agronome, Station Centrale de Physiologie végétale - *Versailles* (France).

Prof. Dr. JEFFREY DAVID COLWELL, Savant chargé de la recherche à la Division des Sols de la Commonwealth Scientific and Industrial Research Organisation - *Canberra* (Australie).

Prof. Dr. DAVID DAVIDESCU, Professeur de Chimie Agricole à l'Institut Agronomique Nicolae Bălcescu - *Bucarest* (Roumanie).

Prof. Dr. RAYMOND EWELL, Vice-président chargé de la recherche de l'Université de l'Etat de New York, Buffalo, N.Y., et Professeur de Chimie et de Chimie pour les Ingénieurs à la même Université - *Buffalo, N. Y.* (U.S.A.).

Prof. JAMES WALTER FITTS, Professeur à l'Université d'Etat de la Caroline du Nord, Directeur du programme international d'évaluation et amélioration de la fertilité des sols - *Raleigh, N. C.* (U.S.A.).

Dr. MAURICE FRIED, Directeur de la division conjointe « Emplois de l'Energie Atomique dans la production des aliments et l'agriculture » de la FAO et de l'AIEA - *Vienne* (Autriche).

Dr. GEORG F. HAUSER, Senior Technical Officer de fertilité et Chimie des Sols à la FAO - *Rome* (Italie).

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. MARCEL VICTOR LÉON HOMÈS, Professeur de Physiologie végétale et Prorecteur de l'Université Libre de Bruxelles; Directeur de l'Institut Botanique Leo Errera - *Bruxelles* (Belgique).

Dr. IRENE LATKOVICS, Directrice du laboratoire des radio-isotopes à l'Institut de Recherches de l'Académie Hongroise des Sciences sur la Science des Sols et la Chimie Agricole - *Budapest* (Hongrie).

S.E. Prof. Dr. MANUEL LORA TAMAYO, Académicien Pontifical - Professeur de Chimie Organique à la Faculté des Sciences de l'Université de Madrid et Directeur de l'Institut de Chimie du Conseil Supérieur de la Recherche scientifique d'Espagne - *Madrid* (Espagne).

Dr. HANS-ERICH OBERLÄNDER, Directeur du département Isotopes à la Station expérimentale fédérale de Chimie agricole de Vienne - *Vienne* (Autriche).

Prof. JOHN THOMAS PESEK, Jr., Chef du Département d'Agronomie de la Iowa University - *Ames, Iowa* (U.S.A.).

Prof. Dr. ARTURO PRIMAVESI, Directeur des cours de spécialisation en biodynamique et productivité des sols à l'Université Fédérale de Santa Maria - *Santa Maria, RGS* (Brésil).

Prof. Dr. ORFEO TURNO ROTINI, Professeur de Chimie Agricole à l'Université de Pise - *Pisa* (Italie).

Prof. Dr. EDWARD WALTER RUSSELL, Professeur émérite de Science des sols à l'Université de Reading - *Reading* (Grande-Bretagne).

Prof. Dr. EBERHART SAALBACH, Fondateur et Directeur du Centre de Recherches agricoles de la Ruhr-Stickstoff AG - *Dülmen/Westf.* (Rép. Féd. Allemande).

Prof. Dr. JACOBUS JOHANNES THERON, Doyen émérite de la Faculté d'Agriculture de l'Université de Pretoria - *Pretoria, Transvaal* (Rép. Sudafricaine).

Prof. FRANCISCUS VAN DER PAAUW, Directeur honoraire du département Nutrition des Plantes à l'Institut pour la Fertilité des Sols de Groningen-Haren et Lecteur honoraire d'Agronomie Botanique à l'Université de Groningue - *Groningue* (Pays-Bas).

Dr. THOMAS WALSH, Directeur de An Foras Taluntais, Institut d'Agriculture de l'Irlande - *Dublin* (Irlande).

Prof. Dr. ERWIN WELTE, Directeur de l'Institut de Chimie Agricole de l'Université de Göttingen - *Göttingen* (Rép. Féd. Allemande).

Tous les invités ont participé à la Semaine d'Etude.

Le « Règlement des Semaines d'Etude » selon 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 JEAN MCEVOY, Mlle CARMEN FERRARA, Mlle FLORE MITCHELL, Mlle HEATHER SAUNDERS et Mlle MARJORIE TAYLOR; en qualité de sténodactylographes polyglottes chargées des Procès-verbaux: Mlle MURIEL SADLIER, Mlle EITHNA RYAN, Mme SUSAN RUNECKLESS, Mlle ANN SAUNDERS, Mme RITA MANZO, Mme PAULETTA ROSSALDI; en qualité de traductrice simultanée Mme DONATELLA MONTERISI SINAGRA; en qualité de technicien pour l'enregistrement magnétophonique, Mr. MAURO ERCOLE, assisté par des opérateurs de Radio-Vatican, en qualité de technicien pour la projection Mr. NOBERTO LOSI, opérateur à la Faculté de Medicine de l'Université Catholique du Sacré-Coeur.

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, responsable du groupe; Mme MARIÙ PUNZI, les Comtesses ISABELLA et KARINA CALVI DI COENZO, Mme SABINE FASSIO, Mme PAOLA CIANCI, et Mr. NED FASSIO.

Le soir du dimanche 9 avril 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 été approuvé le programme définitif de la Semaine, dont à la page LXXXVII.

A l'ouverture des travaux de la Semaine d'Etude, le matin du lundi 10, le Président de l'Académie a eu pour les participants quelques mots de bienvenue auxquels le Président de la Semaine a répondu en remerciant avec des paroles très appropriées.

Le samedi 15 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 Prof. Dr. FRITZ BAADE, Participant à la Semaine d'Etude, a tenu une conférence des plus intéressantes sur le thème « Hundred years of increasing crops thanks to the use of commercial fertilizers - A retrospective view at the years 1900 and an outlook on the year 2000 », illustrée par de nombreuses projections de diagrammes.

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 soir du vendredi 14, les travaux scientifiques se poursuivirent sans interruption. Les discussions des différents rapports se déroulèrent groupées selon l'affinité des sujets.

Les séances se sont tenues deux fois par jour, le matin de 9 h. à 12 h. 30 et l'après midi de 16 h. à 20 h.; chaque séance a été 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 administration pour cette manifestation scientifique si réussie, en envoyant à l'Auguste Pontife PAUL VI le télegramme suivant:

We, the participants in the Study Week wish to express our deepest gratitude and thanks to His Holiness for the exclusive honor and opportunity to study together in this Eternal City, as part of the Pontificial Academy of Sciences, concerning the future material welfare of peoples of the world for which we know His Holiness has the deepest concern stop.

We also wish to communicate, to His Holiness, our humble commendation and sincere appreciation for selecting as the topic of discussion, « Use of Fertilizers and its Effect in Increasing Yield with Particular Attention to Quality and Economy », through which His Holiness has expressed an interest in the fundamentals, principles and application of production methods to increase crop yields stop Our own professional lives have been dedicated to this and we treasure this recognition stop

We are convinced that our knowledge of plant production technology gives us a basis for hope that the problem of hunger can be solved during this century if our scientific and technological experience can be applied wherever it is needed stop

It is our hope that the results of this Study Week will contribute to the untiring efforts of His Holiness to achieve the goals of freedom hunger and suffering, human dignity and peace and security in the world stop

ARATEN, BAADE, BLANCHET, BORNEMISZA, BRAMÃO, BUSSLER, CAPÓ, COÏC, COLWELL, DAVIDESCU, EWELL, FITTS, FRIED, HAUSER, HERNANDO FERNÁNDEZ, HOMÈS, LATKOVICS, LORA TAMAYO, OBERLÄNDER, PESEK, PRIMAVESI, ROTINI, RUSSELL, SAALBACH, THERON, VAN DER PAAUW, WALSH, WELTE.

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

Sa Sainteté agréant déférent message participants douzième semaine études Académie pontificale des sciences se réjouit contribution apportée au progrès scientifique et souhaite qu'une connaissance approfondie de la nature permette trouver solution efficace au problème angoissant faim dans le monde et ainsi mieux assurer dignité personne humaine. Invoque grand coeur divines Bénédictions sur tous signataires message.

En même temps a été envoyé au Président de l'Académie S. E. le Rév.me Père DANIEL O'CONNELL le télégramme suivant:

The participants of this Study Week on « Use of Fertilizers and its Effect in Increasing Yield with Particular Attention to Quality and Economy » wish to express, to your excellency, our sincerest appreciation and deepest gratitude for each having been selected by your excellency to take part in this important endeavor stop Each of us has experienced a renewed hope and conviction that hunger can be banished from the earth in this century if our knowledge and technology are applied wherever they are required stop.

We shall each forever be indebted to your excellency for this unique experience, for new friends made, for their fellowship and for a deeper insight into the multitude of concerns of the Holy Father. We shall cherish all of these stop.

Each of us extends to your excellency his sincerest hope that future Study Weeks will be as productive as we believe this one has been stop Again we wish to express our gratitude for being chosen from among many stop

ARATEN, BAADE, BLANCHET, BORNEMISZA, BRAMÃO, BUSSLER, CAPÓ, COÏC, COLWELL, DAVIDESCU, EWELL, FITTS, FRIED, HAUSER, HERNANDO FERNÁNDEZ, HOMÈS, LATKOVICS, LORA TAMAYO, OBERLÄNDER, PESEK, PRIMAVESI, ROTINI, RUSSELL, SAALBACH, THERON, VAN DER PAAUW, WALSH, WELTE.

Enfin le télégramme qui suit a été envoyé à Mr. le Prof. Dr. PIETRO SALVIUCCI, Chancelier de l'Académie.

The participants in this Study Week take this opportunity to recognize those who have made our presence here possible stop

We wish to express to you our grateful appreciation and sincerest thanks for the thoughtful way in which you have arranged this excellent program and for the accommodation for the entire group stop You showed your concern for our personal needs as well as study needs by providing a challenging schedule, yet allowing for fellowship outside of our study stop

Your staff should be singled out for particular recognition. They have been most helpful and efficient stop We also note the excellent environment of the conference Room, the transportation and our accommodation stop

A final expression of appreciation is made to you for your considerate correspondence leading to our final arrival and presence stop In this you showed understanding and kindness which we shall always remember stop

ARATEN, BAADE, BLANCHET, BORNEMISZA, BRAMÃO, BUSSLER, CAPÓ, COÏC, COLWELL, DAVIDESCU, EWELL, FITTS, FRIED, HAUSER, HERNANDO FERNÁNDEZ, HOMÈS, LATKOVICS, LORA TAMAYO, OBERLÄNDER, PESEK, PRIMAVESI, ROTINI, RUSSELL, SAALBACH, THERON, VAN DER PAAUW, WALSH, WELTE.

Les pages qui suivent contiennent, à la suite du compte-rendu de l'Audience du Saint-Père, du « Règlement des Semaines d'Etude », de la liste complète des Semaines d'Etude tenue par l'Academie et du Programme définitif de la présente Semaine, 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 page 1199.

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.

A 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 l'Observateur permanent du Saint-Siège auprès de la F.A.O., Monseigneur LUIGI LIGUTTI et Mr. le Dr. CARLO PONTI, Directeur des Villas Pontificales qui, dans une atmosphère de cordialité, se sont longuement attardés avec eux, exprimant leur satisfaction pour l'excellente réussite des travaux.

Enfin, le soir du samedi 15 avril, un dîner d'adieu a été offert par l'Académie, selon la coutume, aux savants participants à la « Semaine d'Etude ».

L'AUDIENCE

ET

LE DISCOURS DU SAINT-PERE

Le matin du samedi 15 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 « L'emploi des fertilisants et leur effet sur l'accroissement des récoltes notamment par rapport à la qualité et l'économie ». A la dite Audience ont participé aussi de nombreuses hautes personnalités.

Etaient présent Leurs Eminences les Cardinaux: AMLETO GIOVANNI CICOGNANI, Académicien Pontifical, LUIGI TRAGLIA, FERNANDO CENTO, GIUSEPPE FERRETTO, CARLO CONFALONIERI, PAOLO MARELLA, ARCADIO MARIA LARRAONA, JOSÉ DA COSTA-NUMES, ILDEBRANDO ANTONIUTTI, EFREM FORNI, FRANJO SEPER, JEAN VILLOT, CESARE ZERBA, ANGELO ROSSI, MAXIMILIEN DE FURSTENBERG, ANTONIO SAMORÈ, DINO STAFFA, ARTURO TABERA-ARAOZ, JOHN JOSEPH WRIGHT, EGIDIO VAGNOZZI, PERICLE FELICI, PAOLO BERTOLI, SILVIO ODDI, GIUSEPPE PAUPINI, JOHANNES WILLEBRANDS, MARIO NASALLI-ROCCA DI CORNELIANO, SERGIO GUERRI.

De nombreux Académiciens Pontificaux sont intervenus, et précisément Leurs Excellences: le Rév.me Père DANIEL JOSEPH KELLY O'CONNELL Président, CHARLES HERBERT BEST, HERMANN ALEXANDER BRÜCK, KEITH EDWARD BULLEN, CARLOS CHAGAS, GEORGES CHAUDRON, EDUARDO CRUZ COKE, ANTONIO DE ALMEIDA, CHRISTIAN DE DUVE, PAUL ADRIEN, MAURICE DIRAC, CIRIL CLAUDE GARNHAM, ERNESTO GHERZI, GERHARD HERZBERG, SVEN HÖRSTADIUS, JEAN LECOMTE, PIERRE LEPIN, LOUIS LEPRINCE-RINGUET, MANUEL LORA

TAMAYO, GIOVANNI BATTISTA MARINI BETTOLO, SAN-ICHIRO PAULO MIZUSHIMA, JAN HENDRIK OORT, MAURO PICONE, MARCEL ROCHE, SALIMUZZAMAN SIDDIQUI, ROBERT STONELEY, ALBERT SZENT-GYÖRGYI, ALFRED RENÉ UBBELOHDE, les Académiciens surnuméraires: Mgr. MARTINO GIUSTI, Père ALFONS STICKLER; 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 « l'emploi des fertilisants et leur effet sur l'accroissement des récoltes notamment par rapport à la qualité et à l'économie »: YEHUDA ARATEN, FRITZ BAADE, ROBERT BLANCHET, ELEMER BORNEMISZA, LUIS BRAMÃO, WOLFGANG BUSSLER, BERNARDO G. CAPÓ, YVES MARIE FRANÇOIS COÏC, JEFFREY DAVID COLWELL, DAVID DAVIDESCU, RAYMOND HENRY EWELL, JAMES WALTER FITTS, MAURICE FRIED, GEORGE F. HAUSER, VALENTÍN HERNANDO FERNÃNDEZ, MARCEL VICTOR LÉON HOMÈS, IRENE LATKOVICS, HANS ERICH OBERLÄNDER, JOHN THOMAS PESEK, ARTURO PRIMAVESI, ORFEO TURNO ROTINI, EDWARD WALTER RUSSELL, EBERHART SAALBACH, JACOBUS JOHANNES THERON, FRANCISCUS VAN DER PAAUW, THOMAS WALSH, ERWIN WELTE, et LUIS JIMENEZ, aide du Secrétaire technique.

A l'Audience outre le Corps Diplomatique au complet étaient présents S.E. Monseigneur GIOVANNI BENELLI, Substitut de la Secrétairerie d'Etat, S.E. Monseigneur AGOSTINO CASAROLI, Secrétaire du Conseil pour les affaires publiques de l'Eglise et Monseigneur SOTERO SANZ VILLALBA, Assesseur de la Secrétairerie d'Etat; les Membres du Corps Diplomatique furent reçus par M. MARIO BELARDO.

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 respectueusement à Votre Sainteté l'hommage de tous les membres de son Académie des Sciences réunis ici en session plénière.

Selon la coutume, nous avons, au cours de cette session, tenu en même temps une Semaine d'Etude, activité sans doute la plus féconde, comme la plus originale, de l'Académie Pontificale. Dans la liberté des rencontres privées — caractère propre de ces réunions — un petit groupe de savants réputés, choisis sans égard pour leur appartenance philosophique ou religieuse, discute de quelques problèmes de grande importance actuelle en cherchant un accord ou à préciser les raisons pour lesquelles on ne peut y parvenir. Cet accord est consigné dans une « Note collective finale » publiée dans le volume officiel des Acta, ainsi que les nombreuses discussions intervenues qui en constituent la partie la plus intéressante.

Most Holy Father,

I have the honour to present to Your Holiness the respectful homage of the members of Your Academy of Sciences gathered here in plenary session.

As usual we have, during this session, held at the same time a Study Week, without doubt the most fruitful, as it is also the most original, activity of the Pontifical Academy. In the freedam of private meetings a particular feature of these meetings, a small group of distinguished scientists, chosen irrespective of their philosophical or religious affiliations, discuss some problem of great actual import, trying either to come to agreed conclusions or, if that is not possible, to set forth the reasons for their disagreement. The result is presented in a final collective note, published in the volume of the Proceedings, together with the numerous discussions, often the most interesting part of the Study Week.

Dans la Semaine d'Etude précédente, nous avons essayé de pénétrer les secrets les plus profonds de l'univers et les découvertes les plus récentes de l'astronomie en étudiant l'origine et l'évolution des Galaxies et de l'Univers même. Déjà dans une autre Semaine nous nous étions dédiés au problème des populations stellaires. Cette fois nous sommes revenus à notre petit coin d'univers, la terre, bien petite en comparaison d'une galaxie.

Toutes ces dernières années l'Académie a, dans un travail fécond, affronté les grands problèmes de la science liés au développement et au bien-être de l'humanité. Et elle l'a fait non seulement grâce à la collaboration de ses membres, mais encore à celle de savants du monde entier. Parmi ces problèmes se pose celui de la faim dans le monde. Répondant aux préoccupations du Saint Père à ce sujet, en 1968 l'Académie a prévu une série de cinq Semaines d'Etude dont la première, qui eut lieu cette même année, se déroula autour du thème « Matière organique et fertilité du sol ».

In the preceding study week we attempted to penetrate the most profound secrets of the universe, and the most recent astronomical discoveries, in studying the origin and evolution of Galaxies and of the Universe itself. A previous study week had been dedicated to the problem of Stellar Populations. On this occasion we return to our own little corner of the universe, the Earth, small indeed compared to a galaxy.

For some years past the Academy has performed a fruitful task in facing the great scientific problems connected with the development and the well-being of mankind. It has done this, thanks to the collaboration not only of its members, but also of scientists all over the world. Among these problems is that of hunger in the world. In response to the preoccupation of the Holy Father with this matter the Academy in 1968 planned a series of five study weeks, the first of which, held that same year, was devoted to the theme « Organic matter and soil fertility ».

C'est le même argument qu'a repris aujourd'hui notre douzième Semaine d'Etude avec le thème « L'emploi des fertilisants et leur effet sur l'accroissement des récoltes, notamment par rapport à la qualité et à l'économie ». Elle compte ouvrir de nouvelles et utiles perspectives, en particulier pour les pays en voie de développement.

Il faut en outre rappeler avec quelle perspicacité l'Académie n'a pas hésité en 1962 à affronter dans sa Semaine d'Etude un thème comme « Problème du rayonnement cosmique dans l'espace interplanétaire », qui était alors d'avant-garde bien que fondamental pour la connaissance de l'Univers, du noyau de l'atome au cosmos. Nous pouvons aujourd'hui apprécier à sa valeur toute l'importance de cette Semaine d'Etude.

La connaissance intime de la nature de l'homme dans le champ de la biologie et des phénomènes physiologiques et pathologiques, fut l'objet d'un examen approfondi dans plusieurs Semaines d'Etude. Citons: le problème des macromolécules d'intérêt biologique, pré-

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Our twelfth study week has taken up the same argument, on the theme « The use of fertilizers and their effect on the growth of crops, especially in relation to their quality and the economy ». The aim is to open up new and useful perspectives, in particular for the developing countries.

It is well to recall with what foresight the Academy ventured, in a study week in 1962, to attack such a subject as « The problem of cosmic radiation in interplanetary space », then a very avant-garde topic, fundamental for the knowledge of the universe, from the atomic nucleus to the cosmos. We can to-day appreciate at its full value the importance of this study week.

The intimate knowledge of the nature of man in the field of biology, and of physiological and pathological phenomena, was the object of a thorough examination in several study weeks. For example: the problem of macromolecules of biological interest, forerunner of the problems of what is called nowadays molecular biology;

curseur de ceux posés par ce qu'on appelle aujourd'hui la biologie moléculaire; la biologie des tumeurs; les oligo-éléments dans la vie végétale et animale; les processus physiologiques du système nerveux centrale.

Dans tous ces domaines, en promouvant l'etablissement de contacts personnels entre hommes de science d'opinions différentes et leur rencontre en un cénacle fermé, l'Académie a grandement contribué, par cette forme d'activité originale et, comme on l'a dit, unique en son genre, non pas à fixer des connaissances acquises mais à stimuler la recherche vers de nouveaux objectifs offrant un intérêt aigu pour l'humanité entière.

Je voudrais encore rappeler que dans le champ des sciences de la terre, dès 1951 l'Académie appelait l'attention sur le problème des microséismes, problème d'intérêt primordial aujourd'hui puisqu'on lui doit une meilleure connaissance de la nature et des mouvements des variées strates de la terre.

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the biology of tumors; trace-elements in vegetable and animal life; the physiological processes of the central nervous system.

In all these fields, by promoting the establishment of personal contacts between scientists of different opinions, and their meeting in a closed circle, the Academy has contributed notably, in this original type of activity, unique in its field, not indeed by defining the knowledge already acquired, but by stimulating research towards new objectives of intense interest for all mankind.

I would also like to mention that, in the field of earth sciences, already in 1951 the Academy called the attention to the subject of microseisms, a problem of fundamental interest to-day, since to it is due our knowledge of the movements of the various strata of the earth.

The knowledge of matter is practically impossible without the study of the bonds which link the various types of molecules. A generation of illustrious scientists received from the Academy in

De même la connaissance de la matière est devenue aujourd'hui pratiquement impossible sans l'étude des liens qui unissent entre eux les différents types de molécules. L'exaltation enthousiaste d'une génération de savants illustres a reçu de l'Académie en 1966 une nouvelle élaboration en profondeur lors de la Semaine d'Etude dédiée aux « Forces moléculaires ».

Mais les sciences de l'homme ne se limitent pas à la seule connaissance de la matière inanimée ou vivante; connaître les rapports entre les hommes est tout aussi nécessaire. L'Académie s'est donc préoccupée en 1963 d'étudier sous tous ses aspects le « Rôle de l'analyse économétrique dans la formulation de plans de développement », contribuant ainsi à mieux préciser d'un point de vue quantitatif l'impact des sciences économiques sur les études qui traitent du développement des variés pays du monde.

Durant toutes ces années les académiciens pontificaux qui ont participé à l'organisation et au déroulement des Semaines d'Etude ont

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1966 a new examination in depth of this problem in the study week dedicated to « molecular forces ».

But the sciences of man are not confined simply to the knowledge of matter, living or inanimate. It is also necessary to know the relations between men. Thus, the Academy in 1963 devoted its attention to the study, in all its aspects, of the « Role of econometric analysis in the formulation of plans of development », thus helping to define more precisely, from a quantitative point of view, the impact to the economic sciences on those studies which deal with the development of the various countries of the world.

During all these years the pontifical academicians who have taken part in the organising and carrying out of the study weeks have also, in the Plenary Sessions, made their personal contributions to the life of the Academy. They have not only presented original scientific contributions, but also participated in fruitful discussions. Alle the meetings have indeed fulfilled their function by gathering *également offert dans les Sessions Plénières concomitantes leur concours personnel à la vie de l'Académie. Non seulement ils lui ont communiqué un apport scientifique original, mais les discussions furent fécondes. Toutes les rencontres ont vraiment rempli leur fonction de réunir des hommes de bonne volonté, dans un cadre magnifique et dans une ambiance particulièrement stimulante pour entraîner la recherche scientifique vers des objectifs toujours mieux et plus directement tournés au bien de l'homme. A ce propos je voudrais rappeler que les thèmes d'un intérêt plus général et plutôt interdisciplinaire, déterminant pour notre époque, furent récemment et fort opportunément discutés au siège de l'Académie: la science devant les problèmes que pose la pollution de l'air; la fonction de la science dans les pays en voie de développement; les nouveaux aspects de l'évolution cosmologique; enfin les grands interrogatifs de l'emploi des résultats scientifiques qui a ému le coeur et la conscience de plus d'un savant.*

Au nom des Académiciens ici réunis et de ces savants de divers

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together men of good will, in a splendid setting and in surroundings particularly conducive to promoting scientific research towards ever higher objectives, more directly aimed at the good of mankind.

In this connection, I should like to mention that interdisciplinary themes, of more general interest and of decisive importance for our time, have been recently, and very opportunely, discussed at the Academy: science and the problems of air pollution; the function of science in developing countries; new aspects of cosmological evolution; finally the great questions with regard to the use of scientific results, that have touched the heart and the conscience of more than one scientist.

In the name of the Academicians gathered here, and of the scientists from various lands who have participated in our Study Week, I wish to express our profound gratitude to Your Holiness for the munificence which has allowed us to carry out these important scientific activities.

pays qui ont participé à notre Semaine d'Etude, je tiens à exprimer à Votre Sainteté notre gratitude profonde pour Sa munificence qui nous a permis de réaliser ces importantes manifestations scientifiques.

L'Académie a décerné cette année la Médaille d'Or Pie XI au professeur György Némèthy, jeune chercheur hongrois du Biophysical Science Training Committee des Instituts nationaux de la Santé des USA. Le lauréat a réussi à appliquer les méthodologies mathématiques et thermodynamiques les plus avancées à l'étude et à l'interprétation des phénomènes liés à la nature de l'eau dans les systèmes biologiques.

Veuillez maintenant, Très Saint-Père, bénir les travaux de cette Académie des Sciences qui est Vôtre, tous ses académiciens et les participants à la Semaine d'Etude.

Daigne aussi Votre Sainteté remettre Elle-même au lauréat du Prix Pie XI la Médaille d'or qui lui a été décernée.

The Academy has awarded the Pius XI Gold Medal this year to Professor György Némèthy, a young Hungarian scientist of the Biophysical Sciences Training Committee of the National Institutes of Health of the USA. The medallist has succeeded in applying the most advanced mathematical and thermodynamical techniques to the interpretation of the phenomena connected with the nature of the water in biological systems.

May You now, Most Holy Father, bless the labours of this Your Academy of Sciences, together with the Academicians and the participants in the Study Week.

May Your Holiness also deign to present to the winner of the Pius XI prize the Gold Medal which has been awarded to him.

Le Saint-Père daigna répondre par le discours que nous reproduisons à la page suivante.

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 « Semaine 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 les plus chaleureux hommages se manifestèrent de nouveau au moment où, l'Audience terminée, le Souverain Pontife quitta la Salle du Consistoire.

Monsieur le Président et Messieurs les Académiciens,

Messieurs les Cardinaux, Messieurs les Ambassadeurs

et vous tous qui avez bien voulu nous honorer de votre présence.

Les nobles paroles que nous venons d'entendre ont déroulé sous nos yeux, dans un raccourci saisissant, les phases du fécond travail de l'Académie Pontificale des Sciences en ces dernières années, et elles suffiraient, à elles seules, à montrer la vitalité de cette institution. La remise de la médaille d'or

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Mr. President. Members of the Academy, Lords Cardinals, Messieurs Ambassadors, and all of you who have kindly honoured us with your presence.

The noble words we have just heard have given us a brief but striking picture of the phases of the fruitful work of the Pontifical Academy of Sciences in the last years, and they would suffice in themselves to show the vitality of this institution. The awarding of the Pius XI gold medal to Professor György Némethy is also a sign of this vitality. Il has become, as you know, a tradition to recognize in this way the merits of a scholar of international repute, in his specific field. Professor Némethy, a son of the noble Hungarian nation, has at present a chair at the Rockefeller University. He is, you know better than we do, a specialist in the physical chemistry of liquids and solutions, and we are happy to confer on him this

Pie XI au professeur György Némethy est, elle aussi, un signe de cette vitalité. C'est devenu, vous le savez, une tradition, de reconnaître ainsi les mérites, dans son domaine spécifique, d'un savant de classe internationale. Le professeur Némethy, fils de la noble nation hongroise, est actuellement titulaire d'une chaire à la Rockefeller University. Il est, vous le savez mieux que Nous, un spécialiste de la chimie physique des liquides et des solutions, et Nous sommes heureux de lui décerner cette marque d'estime et d'encouragement devant un auditoire aussi qualifié que le vôtre.

Un hommage à la science.

Votre présence ici. Messieurs, comme la nôtre, veut être un hommage à la science; et l'immensité des horizons que ce seul mot évoque aux yeux de l'esprit suscite des réflexions presque infinies.

Lorsqu'en 1936 notre grand Prédécesseur Pie XI institua l'Académie Pontificale des Sciences, il indiqua en ces termes

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mark of esteem and encouragement in the presence of such a highly qualified audience as yours.

A tribute to science

Your presence here, Gentlemen, like our own, is intended as a tribute to science; and the immensity of the horizons that this word itself conjures up before the mind's eye, gives rise to almost infinite reflections.

When in 1936 our great Predecessor Pius XI set up the Pontifical Academy of Sciences, he indicated the aim he proposed for it as follows: « Our wish and our hope is that, through this Institute, the "Pontifical Academicians" will contribute more and more and better and better to the progress of sciences. We do not ask *le but qu'Il lui proposait: « Notre voeu et Notre espérance c'est que, par cet Institut, les "Académiciens Pontificaux" contribuent toujours plus et mieux au progrès des sciences. Nous ne leur demandons pas autre chose: ce noble dessein, ce brillant labeur, tel est le service que Nous attendons d'hommes épris de vérité » (Motu Proprio* In multis solaciis, *A.A.S., 28 [1936], p. 424).*

En effet, la recherche désintéressée du vrai, la poursuite inlassable des secrets de l'univers, sont parmi les valeurs les plus élevées, les idéaux les plus passionnants auxquels un homme puisse consacrer sa vie. « Intellectum valde ama », disait Saint Augustin; et le géologue Pierre Termier (1859-1930), au siècle dernier, consacrait un ouvrage, que peut-être vous connaissez, à « La joie de connaître ». Les joies du savant vous sont familières, Messieurs: trouver soudain la solution de problèmes longuement étudiés; après des efforts prolongés, souvent douloureux, parfois infructueux, pénétrer plus avant dans les secrets de la nature; sur la base des résultats

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anything else of them: this noble intention, this brilliant labour, such is the service we expect from men enamoured of truth" (Motu Proprio, *In mutis solaciis*, A.A.S., 28 [1936], p. 424).

The disinterested search for truth, the tireless pursuit of the secrets of the universe are, in fact, among the highest values, the most enthralling ideals to which a man can devote his life, "Intellectum valde ama", St. Augustine said; and last century the geologist Pierre Termier (1859-1930) dedicated a book which perhaps you know, to "The joy of knowing". The scholar's joys are familiar to you, Gentlemen: suddenly to find the solution to problems after long study; after prolonged efforts, often painful, sometimes unavailing, to penetrate further into the secrets of nature; on the basis of ever more specialized researches, to construct suddenly a magnificent synthesis—sometimes seen in a flash—which gathers in a luminous theory a series of partial truths, apparently hetero-

de recherches toujours plus spécialisées, construire tout d'un coup une magnifique synthèse, aperçue parfois dans un éclair, qui rassemble en une théorie lumineuse un ensemble de vérités partielles, apparemment disparates, et s'écrier: « J'ai trouvé! »: vous avez connu ces minutes exaltantes.

Joie de l'intelligence, récompensée de son travail; jouissance esthétique, en présence d'un beau résultat; élévation morale, par la valorisation de l'effort: par tout cela le savant s'élève au-dessus de lui-même. Et par là aussi, il sert l'humanité. A mesure que se succèdent les générations, de nouvelles recherches prolongent les découvertes antérieures; les civilisations mûrissent; les progrès s'amplifient. On a pu parler avec raison de l'accélération de l'histoire. Elle est due, certes, aux enrichissements de la technique. Mais ceux-ci n'auraient pas été possibles, ou seraient demeurés ambivalents, si le chercheur désintéressé n'avait pas d'abord précédé, puis accompagné le technicien.

Le vrai savant va plus loin encore. Il sait que toute civi-

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geneous, and exclaim: "I have found it!"; you have known these moments of exaltation.

Joy of the intelligence, rewarded for its works; aesthetic enjoyment, in the presence of a fine result; moral elevation, through the emphasis of effort: in all these ways the scholar rises above himself. And in this way, too, he serves mankind. As generation follows generation, new researches prolong previous discoveries; civilizations mature; progress expands. People have rightly spoken of the acceleration of history: True, it is due to the achievements of technique. But these achievements would not have been possible, or would have remained ambivalent, if the disinterested seeker had not first preceded, then accompanied the technician.

The real scholar goes even further. He knows that all civilization presupposes wisdom. "The future of the world stands in peril, Vatican II says, unless wiser men are forthcoming". And it adds:

*lisation suppose une sagesse. « L'avenir du monde serait en péril, dit le IIe Concile du Vatican, si notre époque ne savait pas se donner des sages ». Et il ajoute: « De nombreux pays, pauvres en biens matériels, mais riches en sagesse, pourront puissamment aider les autres sur ce point » (*Gaudium et spes, *n. 15, § 3).*

Cette sagesse ne s'oppose pas à la culture de l'esprit: elles se conditionnent et s'intègrent mutuellement. Car la science n'est pas orgueil; elle n'y conduit que si on la dévie de son but. Elle est une leçon d'humilité: on ne conquiert la nature qu'en lui obéissant. On rencontre celle-ci d'abord comme un obstacle qu'il faut renverser, une nuit qu'il faut illuminer. Elle s'oppose à nos rêves et à nos fantaisies. Mais à mesure que nous nous soumettons à ses exigences, nous découvrons ses lois. Et nous pouvons peu à peu les utiliser, discerner les moyens de les mettre au service de l'homme. Ainsi le sage accompagne le savant; la nature, d'abord hostile, mais améliorée et transformée par le travail, devient une alliée et une amie.

"Many nations, poorer in economic goods, are quite rich in wisdom and can offer noteworthy advantages to others" (*Gaudium et Spes*, n. 15, 3).

This wisdom is not opposed to culture of the mind: they condition and complete each other. For science is not pride; it leads thereto only if deflected from its purpose. It is a lesson in humility: only by obeying nature is it possible to conquer it. Nature appears to us first of all as an obstacle to be overcome, darkness to be illuminated. It conflicts with our dreams and our fancies. But as we submit to its demands, we discover its laws. And we can gradually utilize them, discern means of putting them at the service of man. Thus the wise man accompanies the scholar; nature, at first hostile, but improved and transformed by work, becomes an ally and a friend.

Le mystère de la nature.

Cette rencontre du savant avec la nature le met sur une nouvelle voie. Une découverte appelle une autre découverte, qui en appelle une autre, mais l'esprit n'est jamais définitivement satisfait. S'agirait-il d'un progrès indéfini vers un but inaccessible? Mais ce serait l'abdication de l'intelligence! La nature, progressivement dominée, révèle un mystère plus grand qu'elle. Et ici le savant est invité à se faire philosophe. Soit à la source, soit au terme des énigmes qu'il rencontre sur sa route et qu'il travaille à résoudre, il est amené à reconnaître, ou du moins à pressentir, la présence d'une Sagesse d'un autre ordre, illimitée celle-là, transcendant les espaces et les temps, qui explique la présence de ces lois, d'abord résistantes, puis dominées et utilisées.

L'étincelle de lumière qu'est l'intelligence humaine, inégalement partagée mais présente en chacun de nous, apparaît

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The mystery of nature

This meeting of the scholar with nature sets him on a new path. One discovery leads to another, which in turn leads to yet another, but the spirit is never completely satisfied. Is it a case of indefinite progress towards an inaccessible goal? But this would be the abdication of intelligence! Nature, gradually dominated, reveals a mystery greater than itself. And here the scholar is invited to become a philosopher. Either at the beginning or at the end of the enigmas he meets with on his way and which he works to solve, he is led to recognize, or at least to divine, the presence of a Wisdom of another order, unlimited, transcending space and time, which explains the presence of these laws, at first unyielding, but, then mastered and utilized.

The spark of light of human intelligence, unequally distributed *alors au savant comme une participation à cette Lumière absolue et sans ténèbres. Chacun de nos progrès, chacune de nos synthèses, nous révèle quelque chose du plan qui préside à l'ordre universel des êtres, à l'effort tendu en avant de l'homme et de l'humanité. Nous voici « à la recherche d'un humanisme nouveau, qui permette à l'homme moderne de se retrouver lui-même, en assumant les valeurs supérieures d'amour, d'amitié, de prière et de contemplation » (*Populorum Progressio, *n. 20).*

Aussi bien la tâche du savant est-elle ardue, s'il prétend vaincre la nature en lui obéissant, progresser en la dominant. Mais cela requiert d'autres vertus spécifiques, qui vous sont familières: l'effort obstiné, malgré les échecs apparents ou provisoires, la patience malgré la lenteur des résultats, l'imagination créatrice en vue de découvrir les voies nouvelles, la passion de la recherche avec la volonté d'aboutir. Puis, vous l'avez deviné, cette alliance de réflexion profonde, d'interroga-

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but present in each of us, appears to the scholar as a participation in this absolute Light, where there is no darkness. Each step forward we take, each synthesis we make, reveals to us something of the plan that presides over the universal order of beings, over the forward effort of man and mankind. Here we are "in search of a new humanism which will enable modern man to find himself anew by embracing the ligher values of love and friendship, of prayer and contemplation" (*Populorum Progressio,* n. 20).

So the task of the scholar is a hard one, if he claims to conquer nature by obeying it, to progress by dominating it. But that calls for other specific virtues, which are familiar to you: obdurate effort, in spite of apparent or temporary failure, patience in spite of the slowness of results, creative imagination in order to discover new ways, the passion for research with the determination to succeed. Then, as you have guessed, out of this alliance of deep *tion sur soi, sur l'humanité et l'univers qui, unissant en symbiose le savant et le philosophe, fait le sage.*

La Semaine d'Etude de l'Académie Pontificale des Sciences.

A mesure qu'elle avance, la science est devenue plus complexe et plus spécialisée. Un esprit, fût-il génial, ne saurait la dominer seul, même dans son propre domaine. Une étude quelle qu'elle soit, suppose une problématique, des postulats initiaux, une ligne de recherche et sa propre logique. Tout ceci peut différer, non seulement à raison des découvertes antérieures propres à chacun ou des résultats acquis, mais suivant l'angle de vision qu'il a choisi. Appliqués à un même problème, des savants isolés pourront aboutir à des conclusions opposées. La collaboration, la confrontation, exigent alors entre eux des contacts personnels et suffisamment prolongés, sinon avec l'espoir de résoudre d'emblée les controverses, du moins

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reflection, of questioning about oneself, about mankind and the universe, which unites the scholar and the philosopher, there is born the wise man.

The study week of the Pontifical Academy of Sciences

As it advances, science has become more complex and specialized. Even a genius could not master it alone, not even in his own field. Any study whatsoever presupposes a series of problems, premises, a line of research and its own logic. All that may differ, not only according to previous individual discoveries or results, but depending on the angle of view chosen. Working on the same problem, isolated scholars may arrive at opposite conclusions. Collaboration, confrontation, call for personal and sufficiently prolonged contacts between them, if not with the hope of immediately solving the controversies, at least with the certainty of under-

avec la certitude de mieux comprendre les divergences et d'en tirer profit: le progrès de la science en deviendra plus rapide.

C'est pourquoi vous êtes ici. Presque dès sa fondation, l'Académie Pontificale des Sciences organisa des semaines d'études, la première en 1940. Elle invita quelques illustres savants, spécialisés dans une question bien délimitée, pas trop nombreux afin que le dialogue fût réellement fécond entre tous, et qu'ils puissent examiner en commun toutes les données du problème. Malgré les circonstances — le monde était alors en guerre — le succès répondit aux espoirs; la paix retrouvée, les semaines d'études se multiplièrent, comme on vient de nous le rappeler: la vôtre est la douzième.

« L'emploi des fertilisants et leur effet sur l'accroissement des récoltes, notamment par rapport à la qualité et à l'économie »: tel est votre thème. C'est avec un vif intérêt que Nous avons parcouru les résumés communiqués par chacun

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standing divergences better and taking advantage of them. Thus the progress of science will become all the more rapid.

That is why you are here. Almost from its foundation, the Pontifical Academy of Sciences organized study weeks, the first in 1940. It invited some eminent scholars, specialized in a clearly defined question, not too numerous in order that the dialogue would be really fruitful among them all, and that they could examine together all the facts relating to the problem. In spite of the circumstances—the world was then at war—the success measured up to the hopes. When peace was restored, the study weeks were multiplied, as we have just been reminded: yours is the twelfth.

"The use of the fertilizers and their effect on the increase of crops, particularly with regard to quality and economy": this is your subject. It was with keen interest that we read the summaries sent by each of you for the preparation of the work.

d'entre vous pour la préparation des travaux. Leur aspect technique ne relève pas de Notre compétence et n'appartient qu'à vous seuls. Mais le thème abordé comporte de tels retentissements humains que l'Eglise, préoccupée qu'elle est du développement de tout l'homme et de tous les hommes, angoissée par le drame de la faim dans le monde, soucieuse de l'abîme qui, loin de se combler, semble s'approfondir entre pays industriels et pays retenus encore dans l'économie rurale, l'Eglise, disons-Nous, attend beaucoup de vos recherches, pour contribuer à la solution de ces problèmes.

Le drame de la faim dans le monde.

Proportionner les ressources alimentaires à la population croissante du globe, vaincre la malnutrition, mettre enfin les pays peu industrialisés, apporteurs de produits agricoles, à même d'entrer en condition pas trop inférieure dans le commer-

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Their technical aspect is not within our competence and belongs to you alone. But the subject dealt with involves such human interests that the Church, concerned as she is with the development of the whole man and of all men, anguished by the drama of hunger in the world, anxious about the gap which, far from closing, seems to be widening between industrial countries and countries considered as being still in a rural economy, the Church, we say, expects a great deal from your researches, to contribute to the solution of these problems.

The drama of hunger in the world

To make food resource proportionate to the growing population of the globe, to overcome malnutrition, and finally to enable less industrialized countries, the producers of agricultural goods, to enter world commerce in conditions that are not too inferior: all *ce mondial: toutes ces ambitions sont d'abord humaines, et tendent à répondre de façon plus satisfaisante à la justice sociale, soit entre secteurs de production dans les régions de civilisation industrielle avancée, soit entre celles-ci et les populations principalement agraires.*

Du moins dans les premières, d'incontestables progrès sont acquis, grâce à vos travaux. Les nouvelles générations rurales savent l'écart qui les sépare encore de la vie urbaine, et les avantages qu'offre à celle-ci une technique avancée. Si elles n'en profitent pas dans la même mesure, elles en reçoivent les retombées, et les exploitent. Grâce à la mécanisation, elles ont pu étendre leurs emblavements. Par le recours aux fertilisants, elles ont accru et parfois doublé leurs rendements. Elles ont appris à faire analyser leurs sols, afin d'en connaître les aptitudes. Elles tendent à la spécialisation. Réduites en nombre, elles sont capables d'assurer la subsistance de populations plus denses et plus exigeantes. De traditionnelle et routinière, l'agri-

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these ambitions are human in the first place, and aim at meeting in a more satisfactory way the requirements of social justice, either between sectors of production in regions of advanced industrial civilization, or between the latter and populations that are mainly agrarian.

At least in the former unquestionable progress has been made, thanks to your work. The new rural generations are aware of the distance that still separates them from urban life, and the advantages that advanced technique offers the latter. If they do not benefit from them to the same extent, they receive the gleanings, and exploit them. Thanks to mechanization, they have been able to sow wider areas. By using fertilizers, they have increased and sometimes doubled their yields. They have learned to have their soil analysed in order to know what it is best suited for. They aim at specialization. Though their numbers are small, they are able *culture devient peu à peu savante et technicienne. Le paysan fait place à l'exploitant rural.*

Dès lors, une tâche profondément humaine vous attend. Vous êtes et serez de plus en plus les éducateurs de cet exploitant rural; il attend beaucoup de vos enseignements. Vous lui apprendrez à rechercher la qualité plus que la quantité, car il s'agit de l'alimentation des hommes; à équilibrer ses fertilisants, afin de ne pas épuiser sa terre en lui demandant plus qu'elle ne peut donner; à ne pas contribuer, par l'emploi abusif de pesticides mal contrôlés, à la pollution des eaux. Problème éminemment moral. Vous lui enseignerez que si le désir d'une plus juste rémunération de son travail, l'aspiration à une vie plus dignement humaine sont légitimes, il a aussi la noble mission d'apporter aux hommes une alimentation saine, qui ne soit pas contaminée par des artifices malsains, destinés seulement à hâter une production quantitative abondante.

Mais vous les savez, Notre sollecitude va d'abord aux plus

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to provide for the feeding of denser and more demanding populations. Agriculture, once traditional and following a customary pattern, gradually becomes expert and technical. The peasant is replaced by the rural cultivator.

This being so, a deeply human task awaits you. You are and will be to an increasing extent the educators of this rural cultivator; he expects a great deal from your teachings. You will teach him to seek quality more than quantity, for it is a question of the food of mankind; to make a well-balanced use of his fertilizers, in order not to exhaust his land by demanding from it more than it can give; not to contribute to the pollution of waters by an illegitimate use of uncontrolled pesticides. It is a highly moral problem. You will teach him that if the desire for a more just remuneration for his work, the aspiration for a more dignified human life, are legitimate, he has also the noble mission of bringing men wholesome foodstuffs, *pauvres qui, du fait de leur faiblesse économique, demeurent en condition d'infériorité dans le domaine des échanges internationaux. C'est pourquoi Nous Nous réjouissons de trouver dans votre programme des préoccupations identiques: emploi correct des fertilisants dans les régions tropicales et subtropicales humides, importance de la fertilité du sol en Amérique latine tropicale, rôle des fertilisants dans l'agriculture africaine. Ici encore vous serez des éducateurs indispensables, les seuls, peut-être, capables d'éveiller à de nouveaux horizons une population trop attachée à ses routines.*

L'activité de la F.A.O.

Beaucoup a déjà été entrepris. Depuis plus de vingt ans, la F.A.O. s'applique à ces problèmes, non sans difficultés, mais non sans résultats. Grâce à l'emploi de fertilisants plus adaptés, à une meilleure sélection des semences, à des techni-

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not contaminated by unhealthy articles, that serve only to hasten an abundant quantitative production.

But as you know, our concern goes first and foremost to the poorest, who, owing to their economic weakness, remain in a condition of inferiority in the field of international trade. That is why we rejoice to find in your programme identical concerns: the correct use of fertilizers in humid tropical and sub-tropical regions, the importance of soil fertility in tropical Latin America, the role of fertilizers in African agriculture. Here again you will be indispensable educators, the only ones, perhaps, capable of awakening to new horizons a population too much attached to its routines.

The activity of F.A.O.

A great deal has already been undertaken. For over twenty years, F.A.O. has been studying these problems, not without dif-

ques moins arriérées, des pays qui semblaient condamnés à la famine endémique ont considérablement amélioré le rendement de leur sol, accru leur production. Mais il reste beaucoup à faire. Vous aurez d'abord à faire oeuvre de persuasion, par des expérimentations variées, mais concluantes. Car le paysan, même peu instruit, voire illettré, croit à ce que ses yeux ont vu. Vos recherches lui apprendront à ne pas épuiser un sol déjà trop pauvre, en l'exploitant de manière trop brutale ou trop primitive, à équilibrer les rotations de ses cultures pour être moins victime des incertitudes climatiques, à adapter l'emploi des fertilisants aux conditions de la terre et du climat. Une chose est certaine: une trop grande partie du continent émergé n'est pas exploitée rationnellement. Le premier acte de la lutte contre la faim consiste à faire produire au sol tout ce qu'il peut donner: ceci est de votre compétence.

Si vous parvenez à convaincre, non seulement l'agriculteur penché sur sa terre désolé, mais d'abord les responsables

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ficulties, but not without results. Thanks to the use of more suitable fertilizers, to better seed selection, to less backward techniques, countries that seemed condemned to endemic famine have considerably improved the yield of their soil and increased their production. But there remains a great deal to be done. You will have to carry out, in the first place, a work of persuasion, by means of varied, but conclusive experimentation. For the peasant, even if uneducated, or even illiterate, believes in what he has seen. Your researches will teach him not to exhaust a soil that is already too poor, by exploiting it excessively or in too primitive a way, to balance the rotation of his crops in order to be less the victim of climatic uncertainties, to adapt the use of fertilizers to the conditions of the land and the climate. One thing is certain: too large a part of the earth is not rationally exploited. The first act of the struggle *de l'économie nationale, un grand progrès aura été accompli. Ayant amélioré ses conditions de vie matérielle, le paysan indien, africain, sud-américain pourra enfin accéder plus pleinement aux biens de l'esprit auxquels il aspire, à une culture qui ne soit point copiée sur d'autres mais qui lui soit propre, qui lui permettra de s'élever lui aussi au-dessus de lui-même et de devenir plus homme.*

Puissent vos recherches, parfois obscures mais efficientes, provoquer la conspiration de tous les hommes de bonne volonté pour employer les immenses ressources de leur esprit et de leurs mains à fertiliser la terre (cf. Discours du 16 novembre 1970 à la F.A.O., dans A.A.S., *1970, p. 837). N'est-ce pas en définitive la conclusion de l'un d'entre vous: « Les moyens techniques, écrit le professeur Baade: meilleure nourriture des plantes, recours aux fertilisants commerciaux, nous connaissons cela depuis cent cinquante ans. Mais la mise en oeuvre de ces moyens techniques, ceci relève du progrès dans*

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against hunger consists in getting the soil to produce everything it can: this is part of your duties.

If you succeed in convincing not only the farmer stooped over his desolate land, but first of all those in charge of the national economy, a great step forward will have been taken. Having improved his conditions of material life, the Indian, African, South American peasant will at least be able to acquire more fully the goods of the spirit to which he aspires, a culture that is not copied from others but is specifically his, which will allow him, too, to rise above himself and become more of a man.

May your researches, sometimes obscure but efficient, lead to a common effort of all men of goodwill to use the immense resources of brain and brawn to fertilize the land (cf. Address on 16 November 1970 to F.A.O., in A.A.S., 1970, p. 873). Is not that, after all, the conclusion of one of you: "Technical means, Professor *le domaine de la moralité humaine, en quoi consiste le véritable progrès des peuples, qui est déterminant » (Prof. Dr. F. Baade, Kiel, Deutschland: programme de la semaine d'études sur l'emploi des fertilisants: « Un siècle d'accroissement des récoltes, grâce à l'emploi des fertilisants commerciaux; vue rétrospective jusqu'à l'an 1900 et prospective jusqu'à l'an 2000 », p. 135).*

L'intérêt de l'Egise pour la recherche scientifique.

Ainsi, le discours sur la science s'achève, vous le voyez, Messieurs, en un discours sur l'homme, sur sa valeur spirituelle et morale, condition de véritable progrès, pour la personne comme pour la société: et c'est là toute la justification de l'intérêt profond que porte l'Eglise au travail scientifique.

Il ne nous reste plus, au terme de cet entretien, qu'à vous renouveler nos félicitations et nos voeux. Nous le faisons de

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Baade writes: better plant food, the use of commercial fertilizers, we have known all that for a hundred and fifty years. But the utilization of these technical means depends on progress in the field of human morality; and the real progress of peoples, which is determinant, consists in this" (Prof. Dr. F. Baade, Kiel, Germany: programme of the Study Week on the use of fertilizers: "A century of crop increase, thanks to the use of commercial fertilizers; looking back to the year 1900 and forward to the year 2000", p. 135).

The interest of the Church in scientific research

So, as you see, Gentlemen, what started out as a talk of science ends up as a talk on man, on his spiritual and moral value, the condition of real progress for the person as well as for society: this is the entire justification of the deep interest the Church takes in scientifis work.

grand coeur, en invoquant sur les activités de votre Académie, sur l'heureuse continuation de vos travaux, sur vos personnes, sur vos familles et sur tous ceux qui ont bien voulu rehausser par leur présence la solennité de cette audience, l'abondance des divines bénédictions.

There remains for us, at the end of this talk, only to express to you once more our congratulations and best wishes. We do so wholeheartedly, invoking the abundance of divine blessing on the activities of your Academy and the happy continuation of your work, on your persons, your families and all those who have kindly wished to emphasize the solemnity of this audience with their presence.

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LISTE
DES « SEMAINES D'ETUDE »
ORGANISEES PAR L'ACADEMIE

La première « Semaine d'Etude » a eu lieu du 6 au 13 juin 1940; elle a été dédiée au « PROBLEME 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 « PROBLEME DES MICROSEISMES », 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 24 avril au 2 mai 1955; elle a été dédiée au « PROBLEME DES OLIGOELEMENTS DANS LA VIE VEGETALE ET ANIMALE », et a été présidée par l'Académicien Pontifical S.E. JOSÉ MARIA ALBAREDA HERRERA, Directeur de l'Institut de Edaphologie et de Physiologie végétale de l'Université 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. Les 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 « PROBLEME DES POPULATIONS STELLAIRES » et a été présidée par l'Académicien Pontifical Surnuméraire le Rév.me Père DANIEL J. K. O'CONNELL, Directeur de la « Specola 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 « PROBLEME DES MACROMOLECULES D'INTERET BIOLOGIQUE AVEC REFERENCE SPECIALE AUX NUCLEOPROTEIDES », et a été présidée par l'Académicien Pontifical S.E. ARNE TISELIUS, Professeur de Biochimie à l'Université de Uppsala; y ont participé personnellement 18 savants. Les comptes-rendus de la « Semaine d'Etude » on 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 « PROBLEME DU RAYONNEMENT COSMIQUE DANS L'ESPACE INTERPLANETAIRE », et devait être présidée par l'Académicien Pontifical S.E. VICTOR FRANCIS HESS, qui 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 mathématique 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 au « ROLE DE L'ANALYSE ECONOMETRIQUE DANS LA FORMULATION DE PLANS DE DEVELOPPEMENT », 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 EXPERIENCE CONSCIENTE », et a été présidée par l'Académicien Pontifical S.E. Sir JOHN CAREW ECCLES, Professeur de Physiologie à l'Université de Canberra; y ont participé personnellement 18 savants. Les comptes-rendus de la « Semaine d'Etude » on 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 MOLECULAIRES », 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; il forment un volume de 824 pages.

La dixième « Semaine d'Etude » a eu lieu du 22 au 27 avril 1968; elle a été dédiée à la « MATIERE ORGANIQUE ET FERTILITE DU SOL » et devait être présidée par l'Académicien Pontifical 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; malheureusement l'Académicien Pontifical JOSÉ MARIA ALBAREDA HERRERA mourut et la Semaine d'Etude a été présidée par l'Académicien Pontifical S.E. MANUEL LORA TAMAYO, Professeur de Chimie organique à l'Université de Madrid. Y ont participé personnellement 21 savants, tandis que 3 autres ont envoyé des mémoires. Les comptes-rendus de la « Semaine d'Etude » ont été publiés dans le 32ème volume des « Scripta Varia » de l'Académie; ils forment un volume de 1092 pages.

La onzième « Semaine d'Etude » a eu lieu du 13 au 19 avril 1970; elle a été dédiée à « LES NOYAUX DES GALAXIES », et a été présidée par l'Académicien Pontifical S.E. le Rév.me Père DANIEL J. K. O'CONNELL, Directeur de la « Specola Vaticana » et Président de l'Académie. Y ont participé personnellement 25 savants. Les comptes-rendus de la « Semaine d'Etude » ont été publiés dans le 35ème volume des « Scripta Varia » de l'Académie; ils forment un volume de 870 pages.

La douzième « Semaine d'Etude » a eu lieu du 10 au 16 avril 1972; elle a été dédiée à « L'EMPLOI DES FERTILISANTS ET LEUR EFFET SUR L'ACCROISSEMENT DES RECOLTES NOTAMMENT PAR RAPPORT A LA QUALITE ET A L'ECONOMIE », et a été présidée par l'Académicien Pontifical S. E. MANUEL LORA TAMAYO, Professeur de Chimie organique à l'Université de Madrid. Y ont participé personnellement 28 savants. Les comptes-rendus de la « Semaine d'Etude » ont été publiés dans le 38ème volume des « Scripta Varia » de l'Académie; il forment un volume de 1424 pages.

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

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 toujonrs plns 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 sake and, raising his thoughts above all preoccupations of an utilitarian nature, asserted that all to 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 expérimentales 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 supra-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 sera réalisée par le Chancelier de l'Académie.

Ces rencontres, qu'on a appelées « Semaines 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 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 à l'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 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: these will be exclusively selected from amongst the specialists of the question being considered, either members of the Academy or not.

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 aussitôt 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 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. - Tous 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'Etude 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 CETTE DOUZIEME SEMAINE D'ETUDE

SUR

L'EMPLOI DES FERTILISANTS ET LEUR EFFET SUR L'ACCROISSEMENT DES RECOLTES, NOTAMMENT PAR RAPPORT A LA QUALITE ET A L'ECONOMIE

LUNDI 10 AVRIL

I. APPLICATION DES VARIÉS TYPES DE TECHNIQUES DANS L'ANALYSE DU SOL ET DES PLANTES POUR DÉTERMINER LEUR BESOIN DE FERTILISANTS

Matin: Président: WALSH

1. FITTS: *Proper soil fertility evaluation as an important key to increased crop yields.* - Discussion.
2. CAPÓ: *Optimum economic quantity of fertilizer based on plant tissue composition.* - Discussion.
3. HERNANDO: *Sap analysis as a fertilization index in several types of plants.* - Discussion.

II. EMPLOI DES FERTILISANTS DANS LES RÉGIONS DU MONDE À CONDITIONS CLIMATIQUES DIFFÉRENTES

Après-midi: Président: VAN DER PAAUW

1. PRIMAVESI: *Correct use of fertilizers in the humid tropics and subtropics and its effect on:* I - *Plant resistance to diseases,* II - *crop productivity.* - Discussion.
2. BORNEMISZA: *Problems of fertilizer use in Latin America.* - Discussion.
3. RUSSELL: *The role of fertilizers in African agriculture.* - Discussion.

MARDI 11 AVRIL

Matin: Président: HOMÈS

4. THERON: *Principles and practice of fertilizer in the semi-arid to sub-humid areas of the Republic of South Africa.* - Discussion.
5. WALSH: *The effective use of fertilizers under temperate conditions.* Discussion.
6. HAUSER: *FAO'S efforts to increase food production by promoting fertilizer use.* - Discussion.

III. ASPECTS RELATIFS ENTRE L'ECOLOGIE ET LES CONDITIONS DE LA CULTURE

Après-midi: Président: COLWELL

1. BLANCHET: *Fertilizer use and ecological factors.* - Discussion.
2. WELTE: *Profitability and optimal use of mineral fertilizers in farms of different cropping potential.* - Discussion.
3. VAN DER PAAUW: *Adjusting fertilizer rates to soil fertility level on the basis of soil testing.* - Discussion.

MERCREDI 12 AVRIL

IV. EFFETS DES FERTILISANTS SUR LA QUALITÉ DU RENDEMENT

Matin: Président: PESEK

1. HOMÈS: *Effect of the completely equilibrated fertilizer on the production of plants cultivated on large scale.* - Discussion.
2. BUSSLER: *The importance of « balanced fertilizers » with twelve mineral nutrients for higher yields of adequate quality.* - Discussion.
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VII CONCLUSIONS.

TRAVAUX SCIENTIFIQUES
ET
DISCUSSIONS

I

APPLICATION DES VARIES TYPES DE TECHNIQUES DANS L'ANALYSE DU SOL ET DES PLANTES POUR DETERMINER LEUR BESOIN DE FERTILISANTS

PROPER SOIL FERTILITY EVALUATION AS AN IMPORTANT KEY TO INCREASED CROP YIELDS

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The urgency of increasing world food production is well known. Many articles have been written and numerous speeches have been given on hunger and its relationship to the world's social and economic problems. During the past two decades much effort has been expended toward solving this problem and progress has been made. Nevertheless, there is no question but that a greater effort is needed if a hungry world is to be adequately fed during the years ahead.

Farming is Business

Farmers grow crops for one purpose and that is profit. This may be in the form of food as well as money but if the farmer involves himself in the production of a crop he anticipates a profitable return. At the dawn of civilization, man learned it was more profitable to gather seeds and plant them than to rely only upon gathering the seeds from wild plants. The sowing of seeds in easily cultivable land resulted in a low yield but was considerably better than production in the wild state. Man soon observed that some soils produced better crops than others, and he also noted that where manures, or residues from animals or plants were added to the soil the yields were improved. The rotation of crops and the inclusion of legumes in the cropping system as a source of nitrogen also had a beneficial effect. However, even today with the use of improved seeds, plant varieties and culture practices the "traditional" yields are relatively low. This is well illustrated by the average yields of wheat and maize in several countries around the world for the period of 1948-52 and 1965 as shown in Table 1 (FAO data). The average yields during the period 1948-52 are remarkably close for many of the countries even though they may be half a world apart with greatly different climatic conditions, different varieties and different races of people. The length of time which fields have been cultivated differ greatly too among the nations but this does not change the "traditional" yields obtained. For example, the average yield of maize for the 1948-52 period for USSR is 1310 kg/ha, for Turkey 1250, Greece 920, Afghanistan 1000, Panama 960, Pakistan 980, Paraguay 1210, Brazil 1260 and Bolivia 1390. During the same four-year period the average yields of wheat kg/ha, were USSR 840, Greece 1020, Turkey 1000, Afghanistan 850, Pakistan 870, Paraguay 670, Brazil 740 and Bolivia 610. During this period wheat was not an important crop in Paraguay or Bolivia and little acreage was planted. However, the yields in each of these countries are not too different; all are low. In Turkey and Afghanistan wheat has been grown for several thousand years and on the same fields that are being tilled today. Compared with this long period of cultivation is the yields of wheat or maize in the South American countries including Paraguay, Bolivia, Peru and Brazil where the crop production is relatively recent and most of the fields have not been cultivated for a period of more than one or two centuries.

TABLE 1 — *The average yields of maize and wheat for selected countries around the world during the 1948-52 and 1965 seasons.* (Data taken from FAO Production Yearbook Vol. 20, 1966).

Country	Maize kg/ha 1948-52	Maize kg/ha 1965	Wheat kg/ha 1948-52	Wheat kg/ha 1965
Bolivia	1390	1150	610	780
Brazil	1260	1380	740	760
Colombia	1070	910	710	900
Paraguay	1210	1300	670	660
Peru	1440	1470	920	990
Chile	1420	3030	1190	1500
Mexico	750	1140	880	2470
Panama	960	810	—	—
Afghanistan	1000	1440	850	970
India	650	990	660	910
Pakistan	980	990	870	860
Portugal	860	950	720	970
Turkey	1250	1530	1000	1070
Greece	920	2003	1020	1770
USSR	1310	2440	840	830
USA	2490	4630	1120	1790

The 1948-52 period was immediately following World War II and the use of commercial fertilizers was limited. Likewise, the acreage planted to hybrid maize and improved wheat varieties was limited. In the United States, however, the use of fertilizer was rapidly being adopted during this period, especially for maize. Since wheat is grown largely in the drier regions of the United States, fertilizers generally were not applied to wheat. During the 1948-52 period, the yield of wheat in the United States was about the same as for the other countries but the yield of maize was approximately double that of the other countries. Without doubt, the United States was growing more hybrid maize during this period than most other countries but also the use of fertilizers for maize was much more widely used in the United States.

During 1965, the change between countries is more marked. The average yield of maize in the United States was almost double that of the 1948-52 period. Many factors, of course, are responsible for this large increase, but the difference in acreage of hybrids or the potential yields of hybrids certainly cannot account for this huge increase. Other countries in which the yield of maize increased rapidly from the 1948-52 period to 1965 include: USSR (1310 to 2440); Greece (920 to 2003); and Chile from (1420 to 3030). The average yields in most of the other countries remained about the same. In each of the countries in which the yields greatly increased, the use of chemical fertilizers was also markedly increased.

The question might be raised as to the reason or reasons for the similarity of yields during the 1948-52 period in the widely scattered countries. One factor which will greatly influence the traditional yields is the availability of nitrogen to the growing plants. Native soil nitrogen occurs largely in the organic fraction and its availability is associated with the activity of micro-organisms which synthesize and decompose the organic matter. BARTHOLOMEW and KIRKHAM (1960) pointed out that organic matter in the soil is in a state of equilibrium. Following the introduction of cultivation on virgin soils, the organic matter content usually declines and nitrogen is released until eventually another equilibrium level is attained. Thus during the first years of cultivation nitrogen is released in soil due to the decline in organic matter. Sooner or later, however, the organic matter in the soil will reach a new equilibrium and then as much nitrogen must be added as removed; otherwise, the organic matter level in the soil would continue to decrease and eventually would reach zero. In crop production, nitrogen, above that in the state of equilibrium which is available to the growing plants, comes from microbial fixation from the atmosphere and from ammonia and nitrogen oxide in the air (mostly from lightning, etc.). The amounts of nitrogen from these sources is normally only sufficient to maintain the relatively low "traditional" yields such as shown in the 1948-52 yield data.

Farming is business and, like all businessman, the farmer operates his business for profit. In order to obtain a profit from the production of a crop, the farmer must concern himself with the various factors that influence yield and the inputs that should be involved with each of these factors. Furthermore, the modern farmer is interested not only in whether an input will return a profit but how the profit from one input compares with profit from another input.

When the farmer incorporates additional inputs into his farming operations in order to increase the crop yields he also must consider the risks involved. Long experience has taught farmers that many factors influence his crop yields; some can be controlled, others cannot. Therefore, he must be conservative in his selection of inputs to increase his crop yields unless he has information available to him which he has learned that he can rely upon.

Factors Affecting Yield

Crop yields, both quantity and quality, are a function of the soil ou which they are grown, the climate, the management factors and the crop itself. This may be expressed in an equation as proposed by Fitts (1959):

Yield = function (soil, crop, climate, management)

(Where yield refers to both quantity and quality).

Each of the factors in the equation has several components which must be considered in evaluating that factor. Although it is difficult if not impossible to obtain an exact value for any one factor, the equation illustrates the important principle that farmers are faced with a multitude of variables in producing a crop and these are further complicated by economic considerations. The equation also clearly illustrates the futility of attempting to predict yield from only one variable such as the availability of phosphorus in the soil. Nevertheless, each variable factor influences the degree to which the farmer can utilize an input in relation to the return that he can anticipate and obviously he should consider all of them.

Among the components in the soil factor of the yield equation, soil fertility and adverse conditions such as acidity or alkalinity are very important in crop production. Observations have been made by the International Soil Fertility Evaluation Project that of the additional inputs in which a farmer must invest in order to raise his crop yields above the traditional level, about 40 to 50 percent of the investment will be in fertilizers, lime or other soil amendments. Of course, soil water and aeration are very important too and should be considered along with soil fertility.

Plant Growth Environment

It is not necessary to reiterate the great importance of environment upon plant growth. Many studies have been conducted and much information is available about the effects of climate including precipitation (amount and distribution), temperature, light and wind upon the growth of plants. However, there is still much to be learned relative to the effect of these climatic conditions upon nutrient assimilation by plants and the influence upon soil fertility evaluation.

Plants growing in soil are relatively immobile but the environment about the plant may change quickly and markedly. This is true for both the above ground and below ground portions of the plant. Usually the greatest change in the root environment is in the plow zone because this is where management has its greatest influence. Generally, the largest changes in the environment of the plow zone is brought about by moisture fluctuations. Soluble materials including salts move into and out of the plow zones with changes in the moisture. Of course, the clay and organic matter content as well as the type of clay greatly influence the movement of nutrients and other materials. However, it should be poined out that plant roots assimilate the ions with which they are confronted. Plants cannot be selective in assimilating only the ions needed or the quantity of a given ion desired. Neither are plants able to assimilate only the elements essential for growth. In other words the plant is the victim of the soil environment in which it is growing and, whereas some adjustment can be made in the use of ions, the kinds and quantities of ions present in the soil solution largely determines what the plant will assimilate. Thus the concept of maintaining a proper balance of the essential elements should be followed in the evaluation of soil fertility requirements in order to obtain high yields of good quality crops. Not only the presence of the element must be determined but factors influencing the availability of each nutrient must be evaluated also. A good example is the effect of the amount of cations in the soil solution upon the uptake of those needed. The evaluation of exchangeable Ca, Mg and K should be made in terms of the quantity of each that is present or likely to become available. Of course, plants also assimilate non-essential elements as well as essential elements. Some of the ions may have a direct adverse effect upon the plants and others may influence plant growth indirectly by effecting the assimilation and transport of essential elements.

Soil Fertility Evaluation and Improvement

The purpose or goal of a soil fertility evaluation and improvement program is to obtain information which can be transmitted to farmers to guide them in the "proper use" of fertilizers, lime and other soil amendments (FITTS and NELSON, 1955). Success in achieving this goal will provide the farmer with the incentive needed to increase his crop yields. Sources of information for a soil fertility evaluation program include: (1) soil analysis, usually of the plow layer, (2) data on soil profile characteristics (mostly from soil survey reports), (3) plant analysis and (4) the correlation studies which relate the information from these three to yield responses from fertilizer or lime applications. Obtaining the data is important but interpreting it into terms of response from fertilizer or lime application is equally important. After the information has been obtained and interpreted, it still must be transmitted to the farmer in a manner that can be understood and followed so that he can put it into practical use. A soil fertility evaluation and improvement program involves both research and education. It is the collection of representative soil samples, transmitting them quickly to a laboratory for rapid and accurate analyses, interpretation of the results of the analyses, preparation of recommendations relative to good management practices including the proper use of fertilizer and lime, and the "putting into operation" of the recommendations.

Modern Laboratories

A good laboratory is the "backbone" of a soil fertility evaluation program. All other phases are directly or indirectly dependent upon the information derived from tbe laboratory. The two important ingredients of a successful laboratory are accuracy and speed or capacity. The cost per determination is important too, but this is greatly influenced by the volume of samples analyzed. The first major task of our International Soil Fertility Evaluation Project, which started in 1964, was the cooperative development and installation of multi-unit apparatus and improved laboratory techniques to permit the efficient handling of large numbers of samples with a high degree of precision. Emphasis in the development of apparatus and techniques was upon simplicity of design and operation. The law of the minimum applies in the logistics of analyzing a large volume of samples and the number of determinations completed per day is governed by the slowest step in the process. This includes transporting soil samples from the farm to the laboratory, sample preparation, analysis, the preparation of reports and returning the information to the farmer. All steps must be coordinated to assure speed and accuracy and to eliminate errors. One interesting observation is that a high capacity laboratory that tests many samples daily and includes a copious quantity of control samples (1 control with 10 unknowns) actually operates with more accuracy and fewer errors than most low capacity laboratories. The multiple unit apparatus designed by the project also removes many of the human errors frequently present in analytical work. It is not the purpose of this paper to discuss in detail the multiple unit apparatus and procedures developed by the project. (This information is presented in project annual reports). However, in Latin America where most of the project activities are directed, at least 50 laboratories now have the capacity to analyze more than 100 samples per day and about one fourth of these are handling over 500 samples per day during rush seasons.

Influence upon research capabilities: The capabilities of the analytical laboratory are based upon research but once the laboratory is established a high capacity laboratory can be very helpful in other research programs. Much information can be collected relative to diverse soil conditions over wide areas. This can serve as a basis of comparing soils under different conditions and also as a means of selecting problems which need further research. It is the philosophy of the International Soil Fertility Evaluation Project that no field trial should be established, either for fertility studies or variety tests, until as much information as possible about the site can be gained from various sources, including soil analysis.

The high capacity analytical laboratories also permit much more intensive studies of soil characteristics, either in soil mapping or in research on factors influencing nutrient availability and for adverse soil conditions such as acidity, alkalinity or salinity.

Correlation Data

Data obtained from either soil or plant analyses is rather meaningless until it is interpreted. The process of interpretation of the data involves the purpose or objective for which the information was collected. In the realm of prescribing soil and crop nutrient needs, soil and plant analyses are confined to procedures which will furnish information that will be valuable in determining the proper use of fertilizers, lime and other soil amendments. The information gained must be predictive in nature in order to be of value to farmers since they must use it to evaluate their alternatives as far as inputs for their crops are concerned. The analyses are not confined to providing measures of the availability of a given nutrient element or elements in the soil, but may be related to reactions that take place after the fertilizer comes in contact with the soil and thereby influence the availability of the added fertilizer element. Therefore, knowledge about clay minerals present, phosphorus fixation, the acidity or alkalinity, cation exchange properties, etc., are important in evaluating soil fertility requirements. The great number of types of soil, the wide range in climatic conditions, and the large variety of crops grown in most countries dictate that a considerable amount of research is needed for the correct interpretation of soil tests.

In the interpretation of soil and plant analyses many concepts have been proposed which range from using the test results as a psychological tool for selling fertilizer to using them as a single value cure-all (NELSON *et al.*, 1951). Obviously the correct role of soil fertility evaluation is somewhere between these extremes. Numerous extracting solutions and procedures are employed, too, in the removal of nutrient elements from the soil but none remove exactly the same amount that plant roots obtain. Most of the extractants remove certain portions of the various compounds and these extracted quantities may be related to the crop response obtained from fertilizers or lime applications. The interpretation of analytical data consists of two parts. The first is a statistical-biological approach which is used to estimate or predict the amount of crop responses that can be obtained from the proper application of fertilizers or lime to specific soils. The second is the economical interpretation of the possible use of fertilizers or lime to ascertain the feasibility of their application. There is also the problem of how to transmit the information to the farmer and with this comes the question of how many separations or groupings should be made of the data. In order to communicate with the farmer, a common practice was developed which consisted of making five separations of the data, very low, low, medium, high and very high. These connotations could be easily understood by the farmer, at least for the two extremes. However, the correlation problem became complex when critical values or division points were attempted between each class or group. The problem also becomes more difficult when attempting to justify specific rates of fertilizer for each group.

The National Soil Test Work Group in the United States (1949-56) recognized the great importance of soil correlation data and also the dearth of good data that could be used for correlation purposes. Although large numbers of field trials had been and were being conducted, very few were designed for correlation of soil analyses. Rates, methods and time of fertilizer application studies are very important for this type of information, especially when conducted on soils deficient in certain essential elements, but frequently the field sites are poorly chosen, poor samples taken if at all, etc. To emphasize the importance of soil test interpretation, the National Soil Test Work Group initiated a cooperative study between 55 laboratories in the United States. All laboratories tested a portion of 74 soil samples taken from fields where fertilizer trials had been conducted and also on which potted plant studies had been completed. The results of the study as reported in North Carolina Bul. 121, 1956, indicated the complexity of correlating data. The poor results of some extractants might be attributed in some instances to poor analytical work. However, the statistical procedures used are important too and the data should not be evaluated by simple linear regression. Difficulties are encountered too with curvilinear regression and quadratic equations. At the start of the International Soil Fertility Evaluation Project, the great importance of correlation interpretation was recognized but it was also realized that a simplified approach was needed in order that it would have wide adaptation and could be applied to a wide range of soil conditions. Likewise, a more rapid and direct approach was desirable in obtaining the correlation data through potted plant studies and field trials.

In plotting data the general custom has been to fit a curve to the various points on the graph and to include all points in one function or one population. Cate and NELSON (1965) point out that just as good, and often better, fits may be obtained by a simple discontinuous function. They first introduced a simple graphic technique in which scatter diagrams were separated into two populations by means of two perpendicular lines drawn on a clear sheet of plastic that was superimposed on the data. The line separating the two populations was established as a critical level. The soils below the critical level were likely to give a large increase from the application of fertilizer containing the element in question, but for those above the critical level the response would be small if any. Cate and NELSON have now refined this approach (1971) so that quite precise predictions can be made about relative responses using class means as predictors. The method involves many intermediate calculations before the final simple result is obtained. Thus the use of a computer is almost essential for making the calculations, especially if much data is available for the correlation study.

The more popular concept of soil analysis interpretation has been in relation to crop responses obtained from the application of fertilizers containing certain elements. In order to speed up the process of correlating soil analyses with crop response to fertilizers or lime the International Soil Fertility Evaluation Project reversed the usual procedure in getting data. Our procedures are outlined in Technical Bulletin 1 (1965), 3 (1966) and 5 (1969) of the Project series. The first step involves obtaining representative soil samples (about 50 kgms) from the plow zone of major cultivated soils of an area. The samples are first analyzed to obtain as much information as possible about the soils including nutrient availability; special conditions such as acidity, alkalinity or salinity, phosphorus fixation, and type of clay minerals present. The second step is potted plant studies to ascertain nutrient deficiencies. This is followed by plotted plant studies to determine critical levels for the various elements including phosphorus, potassium, calcium, magnesium, zinc, etc. The last step is testing the laboratory and potted plant data in field trials. The field plots are selected for conditions desired in testing the critical levels that have been established. Actually two basic types of field experiments are involved: (a) field correlation experiments at many sites to determine crop response to fertilizer application, using standard materials and cultural practices and (b) experiments on fields which are below the critical level to compare different controllable management and fertilizer practices, such as times, methods and rates of fertilizer application, and the most appropriate materials to use. Many factors (as shown in the yield equation presented previously), in addition to nutrient deficiencies, influence the crop yield and possible response to fertilizer. Some of these factors are uncontrollable but they should be considered and reported upon in field experimentation.

Optimum Ranges: If the concept of two populations with one critical level to separate the deficient and sufficient groups is followed, two questions arise: (1) at what level should be the various nutrients in the soil for obtaining high crop yields, and (2) how can the optimum level be maintained? In the CATE-NELSON approach of one critical level, the optimum range would appear to be just above the critical level, e.g. if the critical level is 6 to 8 ppm for phosphorus then the optimum level would be around 12 to 18 ppm. Studies conducted in North Carolina with both phosphorus and potassium since 1956 (KAMPRATH, 1964) indicate that high yields can be attained at nutrient levels just above the critical level, and that less fertilizer per year is needed to maintain the optimum level than where higher soil levels are attempted.

After the optimum range for a nutrient in the soil has been ascertained, the next question is how much fertilizer is needed to change the soil from its present low level (as ascertained by soil analyses) to the desired level. Several soil factors will influence the amount required. Losses of the nutrients by reactions within the soil (fixation or by leaching) are some of the factors that must be considered. Similar types of soils which are more or less homogeneous can be grouped together in respect to fixation properties. This information when coupled with soil analysis data can furnish the desired information relative to the rate of fertilizer needed. Of course, maintenance applications must be made periodically to keep the nutrient level within the optimum range.

Often soils within a field may be very heterogeneous in respect to levels of essential nutrients. The difference may not be large but great enough that the increase from fertilizer application ranges from slightly profitable to highly profitable. For example a portion of the field may return 1.5 dollars for every dollar invested in phosphate but another portion may return 3 for 1 and still another portion may return 5 for 1. The average for the field may fall to 2 to 1, which many economists consider marginal. Perhaps a solution to this dilemma is to build up all of the field to the optimum range and then apply a uniform maintenance application over all of the field in the future. Such an approach may be particularly significant when working with micronutrients.

Soil analyses are used in this concept as a source of information to develop an optimum balance of essential elements in the soil for good crop growth. This balance will have to be maintained by judicious fertilization practices but can be monitored by soil and plant analyses.

Economic Interpretation: Economic interpretation involves the question, will it pay to apply fertilizer or lime to a specific field growing a specific crop? If a soil is found to be deficient in a nutrient, then what materials and what rate should be applied? The question might be stated in another way. If a soil is known to be deficient how can you minimize the unit cost of the crop produced (i.e. cost per 100 kg. of crop) by the proper selection and use of fertilizer (Cate, 1969). Either applying a nutrient not needed or omitting one that is needed results in increasing the unit cost. Of the inputs that a farmer must consider in increasing his yield above the traditional level (including lime, fertilizers, improved seed, pest control, machinery and irrigation), fertilizer and lime involve a considerable portion. Cate and Vettori (1968) point out that many of the commercial farmers around the world invest 10 to 15 per cent of their gross income in fertilizers and lime. Thus information from soil fertility evaluation to place the soils above or below the critical level is very important in helping a farmer to decide whether his money will give the largest return from purchasing fertilizer or whether it should be invested elsewhere (CATE *et al.* 1971).

Two interesting studies on the economics of fertilizer use were conducted in Peru and are reported in the International Soil Fertility Evaluation 1967 Annual Report. One study included eight years of field trials with phosphate on potatoes in the Sierra or mountainous region and the results are presented in Table 2. When all fields are considered as a continuous

TABLE 2 — *Response of potatoes in the Sierra region of Peru to phosphorus fertilizer as a function of soil phosphorus level measured by soil test* (¹).

Rate of P applied	Net return per dollar invested
kg/ha P_2O_5	
All Soils	
80	$ 4.09
160	$ 2.85
Soils below the critical level (low)	
80	$ 7.25
160	$ 4.96
Soils above the critical level (high)	
80	$ 0.91
160	$ 0.75

(¹) Taken from 1967 Annual Report. ISFE Project. Average of 8 years of potato research carried out by S.I.P.A. - N.C. State University Mission in Peruvian Sierra.

function, the average return from an application of 80 kgm. P_2O_5 per hectare was $ 4.09 for each dollar invested in fertilizer. However, when the fields are separated into two groups, those below the critical level and those above it, much different results are obtained. On the soils below the critical level a return of $ 7.25 was obtained from each dollar invested for the 80 kgm. P_2O_5 per hectare rate but on the soils above the critical level a loss of nine cents was sustained on each dollar invested. When the rate of P_2O_5 was increased to 160 kgms. per hectare, the differences are approximately proportional; a greater loss is obtained on the high phosphate soils but the return on the low phosphate soils is reduced. The importance of separating the soils is readily seen in Fig. 1. Obviously the growth response curves for the two populations is much different with the average being in between.

Several important observations can be made from Table 2 and Fig. 1:

(1) Soil analysis does not indicate the rate of fertilizer to apply. The 160 kgm. rate of P_2O_5 was returning $ 4.96 for each dollar invested on the soils below the critical level and, although this is less than the 7.25 return at the 80 kgm. per hectare level, it is still highly profitable.

(2) By extrapolating the data in Fig. 1, rates of phosphate can be estimated which would give a return of 3 to 1 or even 2 to 1 for each dollar invested (shown by dotted line in Fig. 1). For the average of all soils the rate of P_2O_5 per hectare to get a 3 to 1 return would be about 150 kg/ha but for the soils below the critical level the rate would be about 230 kg/ha. This is one of the complaints that fertilizers companies often make about government operated laboratories which base recommendations on averages. When the soils are low in the element then the average suggested rate is too low and the farmer could afford a larger application.

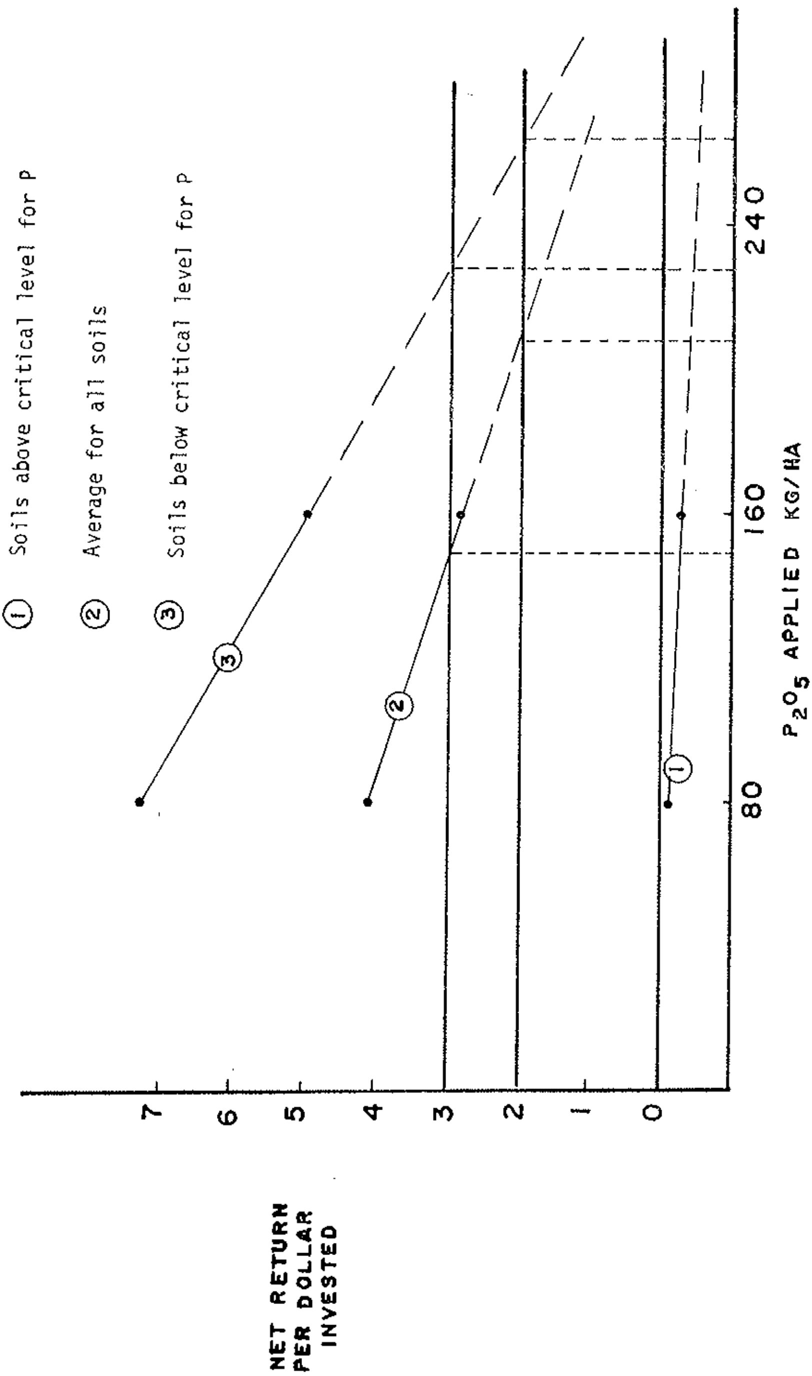

FIG. 1 — The net return from application of phosphate to potatoes in the Sierra region of Peru.

(3) Commercial farmers with greater financial support and better management capabilities will want to extend the fertilizer application rate as far as possible and may want to go to a level of 2 to 1 return or even 1.5 to 1. The subsistence farmer, on the other hand, cannot afford to take as much risk and he should select the point where the return is larger, although his yields will be less.

(4) The role of soil analysis is to separate soils into two (or possibly more) populations or groups about which growth response curves can be predicted. Soil analysis does not indicate methods or time of application nor material to use. This information should be obtained for the population of soils that are likely to respond to the nutrient in question.

(5) There rates of application, 0, 80 and 160 kg. P_2O_5 per hectare give good information relative to the response to phosphate application. However, for the soils below the critical level an additional one or two rates, say 240 and 320 kgm. per hectare would be desirable in order to extend the response curve to more precisely evaluate the 3 to 1 and the 2 to 1 return rate of fertilizer application.

Recti-linear programming: As previously pointed out, one of the goals of the International Soil Fertility Evaluation Project has been the simplification of procedures whenever and wherever possible. As a natural follow-up to the CATE-NELSON procedure for separating soils into two groups, below and above a critical point, Dr. CATE (1971) is now working with a computer program to utilize the concept of recti-linear response functions. This interesting concept is actually based on JUSTUS VON LIEBIG'S LAW of the Minimum and involves combinations of straight lines as illustrated in Fig. 2. The usual procedure would be to have one continuous curve to fit the four points of (a) as shown in (b). However, as Dr. CATE points out just as good or an even better fit may be obtained by two straight lines as in (c) which forms a

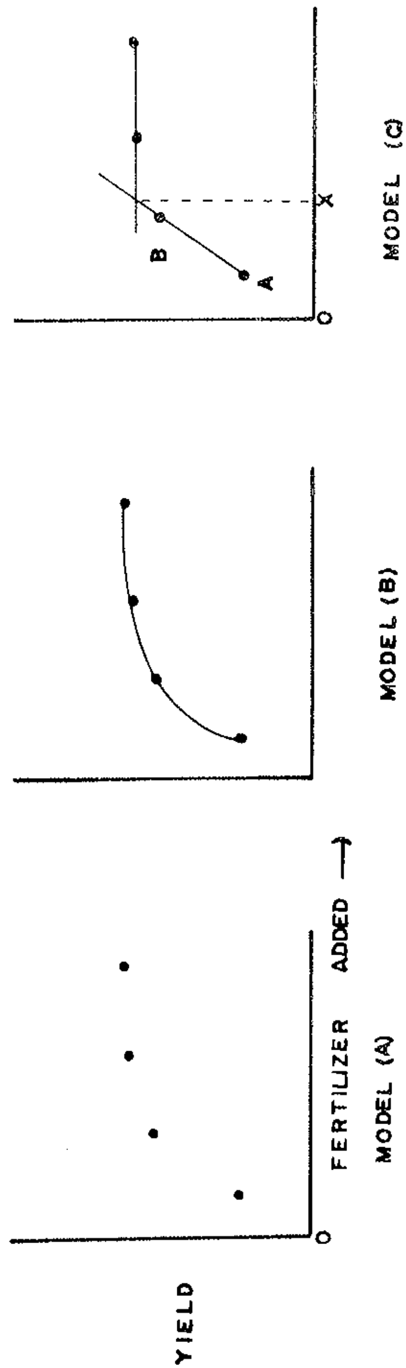

Fig. 2 — Diagramatic scheme for recti-linear compared with curvi-linear interpretation of response data. (After Cate)

simple discontinuous function. The advantage of this model (c) is that it facilitates economic decision making by establishing a relatively few fixed choices rather than the infinite number that are possible in curvilinear models. For example, in model c, the choice of fertilizer application would be either O or X since the slope of the line A-B is the same and if any portion is profitable all of it would be profitable. The higher rate would also decrease the risk factor since it tends to maximize the return from fertilizer application in relation to other necessary inputs in the production of the crop such as seed bed preparation, etc.

Combining the Information

Mention has been made of the use of information gained from soil analyses (usually of the plow zone), plant analyses and soil survey in a soil fertility evaluation and improvement program. This information not only must be correlated with crop response to the application of fertilizers, lime and other soil amendments, but also must be interpreted economically. Likewise, it must be integrated with the other variables that influence yield as outlined in the yield equation. Bringing all of these variables together necessitates simultaneous calculations and to do this a computer is virtually essential. However, before feeding the data to the computer it is desirable to consider the variables separately. It is for this reason that correlation studies with individual essential elements are important. Parameters can then be established for the element as it is combined with other variables. A problem of meshing extensive with intensive data is encountered when integrating soil testing information from soil survey. The soil mapping units are usually presented in great detail for a specific profile or soil type but soil testing data is more limited. Combining these two sources of information for predictive purposes is not simple bnt, again, perhaps the best approach to this will be through the use of a computer. This type of integration will be necessary in order to define and ascertain homogeneous soil conditions. Of course, homogeneous conditions are essential if production level possibilities and more general management practices are to be established.

Recommendations

Reporting to the farmer information as to whether the soil samples submitted for analysis are above or below the critical level is very valuable in aiding him to make decisions relative to the fertilizer or lime inputs needed to produce his crop; however, more information than this is usually desired and suggestions relative to management practices are often requested. The report should instruct the farmer on rates, time and methods of application of needed fertilizer although this information is not obtained by soil analysis. Likewise, the farmer should be reminded of improved crop varieties and the use of good seed as well as other good management practices. The soil fertility evaluation laboratory should not attempt expertise in all disciplines of agriculture, but it can be an excellent "vehicle" to sell a good soil and crop management program.

Farmers are interested in making a profit from the crop they are producing. The highest yields may not be the most profitable; in fact, often they are not. The question then may be asked. "What standard of yield should be established"? The standard (established yield goal) will differ with the different classes of farmers since ecological conditions, finances and administrative abilities differ (FITTS, 1971). In establishing the standard yield, the total quantity of crops needed within a region, the availability of land, the crop value and relative costs of inputs should be considered. Under some ecological conditions where cropland and labor are not limited but capital is scarce, it may not be economically feasible to establish a high standard yield level. In most areas, however, the traditional yields are not sufficient to meet the needs of the country. Then standard yields must be sufficiently greater than the traditional yields (usually more than double) to create interest in the various classes of farmers.

To be most effective the information sent to the farmer must be relative to his own farm and to his conditions. General recommendations based on averages may increase the production of a province but will do so at the expense of some farmers because averages are made up of both large and small increases. Thus recommendations should be both site specific and situation specific — site specific for the land upon which the farmer is producing his crops and situation specific relative to financial status and management capabilities. The latter is particularly important in respect to loans because loaning some farmers money may be a disservice rather than a service if he does not have adequate information or capabilities to use it.

Gathering More Information

Allusion has been made to use of the computer in the interpretation of soil fertility evaluation information and in making recommendations to farmers. If properly programmed the computer becomes a useful tool in the compilation and analyses of data. Much data is gathering dust in files around the world simply because persons gathering the data either do not have the facilities or capabilities of statistically analyzing it. Often reports are filed which indicate more information is needed when sufficient interpretation has not been given to existing data. Statistical calculations can be made, of course, with calculators but this is a time consuming, tedious operation, and as the fund of knowledge increases the clerical difficulties in analyzing data become immense. Thus the computer becomes an indispensable tool but must be properly used. Over-manipulating the data may result in a voluminous amount of computer print-out which may also inundate the research worker.

In order to simplify statistical analyses by computer, a computer program was recently developed at North Carolina State University which is referred to as S.A.S., Statistical Analysis System. This program is relatively simple and is a big asset to the average research worker in using a computer. S.A.S. is designed to permit an investigator to work with an IBM 360-75 computer which can handle a total of 256 variables at once with great flexibility and speed. The S.A.S. program has been made available to the International Soil Fertility Evaluation Project for use in cooperating countries.

The nucleus of a soil fertility evaluation bank consisting of over 200 sets of correlation data from the world literature has been initiated under the leadership of Dr. R. B. Cate, Jr. Since Dr. Cate works for the project with headquarters in Brasilia, Brasil, much of the activities of the project with S.A.S. programming will be taken care of by Dr. Cate in Brasil. The S.A.S. program is regarded as a real breakthrough in computer use for analyzing agricultural data. It will permit analysis of individual experiments and also aid in the interpretation of a mass of information. The soil fertility evaluation data bank should be of service to research workers around the world. Participation in the program is invited.

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DISCUSSION

Chairman: TH. WALSH

RUSSELL

I would like to comment on the last point raised by Dr. FITTS. Dr. BOYD at Rothamsted has also come to the same conclusion that fertilizer response curves can frequently be represented by two straight lines, though the upper one need not be horizontal.

However, the nitrogen response curve for wheat, following a grassclover or a lucerne pasture that was at least three years old, was curved near its maximum value with the yield dropping quite appreciably for higher levels of nitrogen. This behaviour was not shown if wheat followed wheat or other cereal crops.

PRIMAVESI

I approve everything you said and agree absolutely with you that it is not possible to make a fertilizer recommendation after making only soil analysis of merely two nutrients. Really, our experiences show that it is necessary to study physical-chemical-biological and ecological factors of the soil and the economical ones before a valid indication is obtained.

You said very well: « mention has been made of the use of information gained from soil analyses, plant analyses and soil survey in a soil fertility evaluation and improvement programme ».

and that the information « must be interpreted economically ». I think you are right in your exposition. What you said about Mr. Cate seems to come from you. It seems the simplification is very great. I recommend that you study the official publication about the work of Mr. Cate (Publication: FAO-ANDA-ABCAR Rio de Janeiro, September 1971).

He will use for all Brazil only one system, but Brazil is like a continent with very different soil types, climates, ecological factors, and so on, and besides it is necessary, as you said very well in your paper, to make the economical calculations and this also in relation with the given situation (commercial farmers, subsistence farmers, and so on).

Your concept seems excellent, but when you refer to Brazil you must see the reality.

Fitts

I appreciate your comments and agree with them very much. Prof. Cate is of course a member of our staff and he is working on a course in Brazil. They are working now with a computer system which they are hoping will bring all these data together from the different sources that they can and they ought to be able to interpret. If we try to bring together soil survey data and others it becomes quite a complex problem, and I think that with the computerised programme from all over Brasil, they will be able to get much more specific. This is our hope.

Colwell

I would like to ask questions of Dr. Fitts and Dr. Russell concerning this linear Liebig-type response function. I am quite impressed by the evidence that has been collected supporting this sort of curve, but I have noticed that most of the evidence does seem to be from response to nitrogen. Is this type of response peculiar to nitrogen rather than say phosphorus?

FITTS

I would like to talk about RUSSELL later, but as far as we are concerned we have nitrogen, phosphorus and potassium, and we have not found a lot of difference although I will agree that phosphorus does not do quite as well as nitrogen, but we will have both of them and they do agree the same way. I think that one of the things we have to watch though is, as you look at the so different nutrients, that all the other factors are taken care of and usually nitrogen is deficient, so if you do not take care of nitrogen properly then you do not get the curve like this in phosphorus.

RUSSELL

Dr. BOYD found that the response curve for phosphate is very similar to that for nitrogen, provided there is an adequate load of available nitrogen.

ARATEN

On one of the slides Professor FITTS showed us that the yield is a function of soil, climate and a few other factors, but he did not mention that it is a function of nutrients.

FITTS

You must excuse me, I should have pointed out that there are different factors in a yield equation as we had crop factors:

the kind of crop, the species, that is the variety, the population and many others, and coming to soil, we consider soil to be the nutrient in adverse soil conditions, physical conditions, the environment and general other soil characteristics and so forth, and getting to climate of course you would have precipitation, the temperature and light intensity. the duration of light and other factors. And a management part, as far as we look at it, is the control of pests, insects, diseases and so forth as well as cultural practices. We have found these are rather broad categories and we need to subdivide them, and I should have mentioned that as I presented the paper and thank you for calling attention.

WELTE

An additional remark in relation to the yield curve. You have divided the yield curve into two parts, below critical level and above critical level, and of course from an economical point of the individual farmer the low critical level is of utmost interest because the return is the highest, but on the other hand I would like to consider the situation in countries where planned economic programmes will be preferred instead of the optimum economic criteria of the individual farmer. Under these conditions the state is also interested in the part above the critical level and the value/cost = ratio may only be 1 to 1. This also will be economical for a government because more food will be produced for the population. You see, the interest of the individual farmer and the interest of governmental agricultural policy may be different.

OBERLÄNDER

I come back to the broken curve and my question to Prof. FITTS is what mechanism might be behind it; or, are there two mechanisms overlapping and what kind of mathematical equation would be fitting?

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FITTS

I am not sure, of course, as I said, I think it is based on Liebig's Law of the Minimum, and as far as mathematical formula, I am not sure offhand that I would want to answer that question.

HAUSER

I have just a small question. If these curves refer mainly to nitrogen, then I would be interested to know what type of nitrogen test has been used?

FITTS

We do not of course test much for nitrogen because there is difficulty in evaluation, and I mentioned that we think probably the best test is the one of the yield you are getting on regular farming conditions. I believe that is still the better test than any laboratory or biological test we can make.

HAUSER

But then these curves do not refer to nitrogen, but to phosphorus or potash. The correlation curves between the soils test and the yields are not referring to nitrogen. (Refer to paragraph 7 above).

FITTS

Yes, as far as those I have presented, those are phosphorus, potash and other elements. We do not try to correlate with nitrogen soil tests.

HERNANDO

I would like to ask a question in relation to the economical aspect. When you get a result from one year's field experiment, is it possible to use the economical result, in the following year, especially in areas with different climates? I think the problem of climate will be very troublesome for that aspect.

The difficulty being to find low level and high level, response level or no response separately. I think the value of the critical level is when there is an inflexion point that separates one side from another. It is very easy to prepare graphs of very similar soil and climatic conditions and a special crop variety, but when you use different types of crops, in different areas or the same crop but different varieties in different areas, with different climatic and soil conditions, the critical value will be variable and instead of one point you must have a wider range; in this case the difference between the curve and the two right lines is, I think, of major importance. That is my idea.

FITTS

I would like to point out that as far as the critical level is concerned that when we are above the critical level it does not mean that we would not be using fertilizer, all we are saying is that area would be maintenance because we do not have fertilizers and you are going to be dropping back below the critical level, and we like, if you want to call it the maintenance rate or medium rate, to be somewhere above that critical level. To us one of the things that has been very amazing was the similarity of the results that we are getting from different parts of the world, from different people, and the research, of how close that critical level comes if they are using the same procedure. For example, we have results from potatoes which I showed you here in Peru, and we just have a result now from about 100 trials with wheat and corn and potatoes in Bolivia, we have it on rice and sorghum from India, and if they are using the same extractant they would all fall between 7 and 9 parts per million of phosphorus. It is rather surprising that the different workers have come in with that same answer, and so I think that we can establish a criitcal level like that and come fairly close, but then whether you want to maintain the level of fertilizer nutrients is the one that we would like to know, and we try to think there is some way round 2 to 3 times above the critical level; in other words, if we worked on an area that would set our ranges somewhere between 20, 25 and 30, this would be a good level for our maintenance in that area, and if we dropped below that level phosphorus could become limiting.

HERNANDO

You have not answered my first question, only the second. The first question was about the application of the economical result from one year to another in areas with different climatic conditions. How far is it possible to apply these economical results you get in these trials for next year, I mean.

FITTS

Obviously there would be some difference, and I think that differences of value of crops you are producing will vary from one year to another as well as yield and cost involved, I do not know whether I can exactly answer that one, except that so far as we have looked at it from the standpoint of relationship of the cost of the product, because this will also vary with your cost of the nutrient you are adding as well as the cost of irrigation and other inputs, I think that you are going to have to relate it to whatever the other inputs you are involved with, if you find that irrigation is needed you are going to have to put in irrigation.

COLWELL

I wanted to just comment here that we were asked, if we could, to find controversial issues. I think we have one right at the beginning on the nature of response functions. I suggest there is need for research here. Fortunately, this is an issue which seems to be very easily resolved. It would seem to be simply a matter of carrying out experiments with many levels of fertilizer designed to decide whether response can be described by two straight lines, or whether it is better described by a curve. It is a rather important point because if it can be described by two straight lines we can use this very simple sort of approach that Dr. FITTS outlined for estimating fertilizer requirements. If the soil has a nutrient level corresponding to the steep curve you need fertilizer, if the soil corresponds to the flat curve at the top you don't; it's as simple as that, and you can also fall back on to this unit cost or cost/value ratio as a basis for estimating fertilizer requirements. If it is a curve the cost/value ratio should not be used to estimate requirements, and so it is important to distinguish between these two fertilizer response forms. Now a final point, it is quite inadequate to have a straight line drawn through two points to decide which is the appropriate form. You might recall the last curve we saw, the top part had a flat part which was just a line through two points. Now, statistically, you just can't decide from two points whether the response form is a straight line or a curve. This is why I say we have got to design experiments with many levels, say four or five points for the top part and four or five points for the steep line. In other words, about ten levels of fertilizer would seem to be a minimum to judge the relative adequacy of the Liebig type or the curvilinear type models.

WALSH

I think we will draw this session to a close. I want to emphasise what Dr. COLWELL has said, i.e. that the controversial issues

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here are the important ones. A number of them have been raised by Prof. FITTS. Another very important one is, do you fertilize for the rotation, i.e. do you fertilize for a period rather than for one crop. This point also obviously engages Prof. FITTS very much. Another matter which must be emphasised is that of the acceptability of research results to farmers and how farmers use them. This also of course decides the economic optimum use of fertilizers; the conditions under which economic optimum returns can be obtained is one thing, the social optimum is again another. Another point emphasised is that moving from subsistence agriculture to a high level agriculture changes many things, while the fourth one raised, and I would like to recommend it here for consideration later on, is the one about the situation under which you get loss of nutrients, giving rise to what ought to be described as a pollution situation, which has been rightly emphasised as being a soil situation. The last point which possibly we will get down to consider later on is the effect of soil type. Mitscherlich, and others prepared smooth flowing response courses. There is, however, no soil that I ever dealt with, where this holds in practice. There may indeed when some factor or complex in the soil is affected by the addition be a stop like change rather than a progressive, smooth response from one point to another. We should perhaps look on these effects in a totally different way at this point and maybe as Dr. COLWELL has said, the need for some more research is becoming very obvious.

EWELL

I hesitate to speak on this subject because I am not an agricultural scientist. I am a chemical engineer. However, I am accustomed to handling data and looking at curves as engineers are. In the process of my work in the fertilizer industry during the last 25 years, I have looked at about a million response curves. The agricultural scientists are developing response curves at an enormous and accelerating rate, and the main point that I wanted to make was that of these millions of response curves that have been developed, there do not seem to be any two that are the same. I am very suspicious of this two-straight-line intersection approach to it. Based on the many thousands of response curves that I have examined in India and several other countries, I personally feel that the curvilinear approach to it would be the more rational one. I would have to see a great deal more evidence to believe in this intersection of two straight lines, but I think it is very difficult to arrive at any all-encompassing conclusions, because as I said before, there appear to be no two response curves that are exactly the same.

RUSSELL

The individual points on a response curve are always subject to a considerable scatter due to soil variability and other causes, so it is not possible to discriminate between a number of possible response curves. It is possible that if one could reduce the standard error of each point on the curve to a really small figure, the response curve would be a uniform curve rather than two straight lines of very different slopes.

There is one other point about the response curve I wanted to make. The slope of the first part of the nitrogen response curve for a given crop should be very nearly constant if nitrogen is the only factor limiting yield but in so far as the slope in any particular experiment falls below this value, it shows that some other factor is limiting yield as well as nitrogen. If this factor can be recognized and eliminated, the slope of the nitrogen curve should then be raised to its theoretical maximum.

COLWELL

Yes, I have also looked at many response curves in Australia, and the first linear response part of this function is certainly not constant. The factor of course which is limiting is moisture.

WALSH

The only remark I would like to make about this situation is that what you say is right as we have had considerable experience along the same lines, moving with two different types of agriculture, need subsistence and commercial. Through the years I have never been able to fit a smooth curve to the data we have been getting. So in recent years we have gone away from curves to the straight line method of presentation. The other part of it is this. It makes more common-sense out of soil testing. There has been the approach down the years of thinking that you can fit a fertilizer recommendation accurately to a soil test in terms of so many parts per million of some nutrient. I think that people critical of soil testing, people like the late Dr. CROWTHER of Rothemsted, objected to soil testing because he did not see this possible. I would say against this new background he would be more satisfied - it is more realistic.

FITTS

If I may make one comment. I do not know Dr. RUSSELL if you find that in England what we find. If you interpret this rectilinear curve that the optimum rate you will make for a nutrient is considerably lower than on a curvilinear curve, and I think the fertilizer industry might object to it, but on the other hand we see on curvilinear relationships that they may be showing the optimum rate of application to be 200, 300, 400, or more kg per hectare of nitrogen. We know the needs of the plant probably will not be over 100-150 kg per hectare. Thus the rectilinear approach will give a more realistic value as far as the farmer is concerned. You can tell a farmer to put on 500 kilos of nitrogen per hectare but he is not going to do it if he has not had any experience to indicate it is profitable.

RUSSELL

We do not find the response curve for potash and phosphate of much practical value in Great Britain because the general tendency is to fertilize for the maintenance of a fairly high level of potash and phosphate in the soil.

FRIED

The comment I want to make is to bring the discussion back to the question that Dr. HAUSER mentioned. When we are talking about phosphorus we seem to be talking about a soil test of 8 parts per million or 7-9; when we talk about nitrogen we seem to be talking about actual field experiments, and I think we would better get ourselves straight a little as to what we are talking about when we talk about nitrogen. If we are talking about the general nature of the curve that is one thing. Are you trying to relate it to some kind of soil test or are you using actual field data for making your recommendations? I am throwing out the question, but I do not think we can generalize in relation to the different nutrients when we do not happen to have a decent soil test for nitrogen or at least the same kind of soil test for nitrogen that we have for some other nutrients.

WALSH

Dr. FRIED that is a very large question and I am hoping once again that it will come up at this meeting later on. It is in fact a crucial question as to how you can determine the nitrogen status of the soil. What nitrogen is released - what time is required? and so on comes very much into that picture as you all know very well.

FRIED

I just want to say it was not that I wanted an answer right now. I realise what an important question it is, but we seem to be talking about both of them at the same time. In one case we are talking about soil tests, and in the other case we are talking about field tests, and I think we would better keep clear what we are talking about.

FITTS

May I just comment on that, I think this is why we talk about soil fertility evaluation rather than soil tests, because we do not look on soil tests as our only source of information. Any information that can be interpreted in respect to optimum use of fertilizers will be used.

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OPTIMUM ECONOMIC QUANTITY OF FERTILIZER BASED ON PLANT TISSUE COMPOSITION

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Introduction

Agricultural soils differ in their capacity to provide the crops grown thereon with the nutrients they require. For successful crop production, therefore, there is need in many cases to use fertilizer materials to complement the available quantities of nutrients in the soil. To estimate the optimum quantity of a fertilizer material to add, it is necessary to know: (1) the actual level of the fertilizer material in the soil, that is, the quantity of the fertilizer material which, if present in the soil, would make the unfertilized soil behave as it does with regard to the quantity of the corresponding nutrient which it is able to provide to the crop; (2) the way in which the crop yield varies with the level of the fertilizer material as defined above; (3) the cost of the fertilizer material, including its cost of application; and (4) the net worth of one unit of the crop as it stands in the field ready for harvest, that is, its selling price less the cost of its harvesting and marketing. The possibility of making use of leaf analysis in making this estimate is discussed in what follows.

Available quantity of a fertilizer material in a soil.

Many methods have been proposed for the estimation of the quantities of nutrients which soils may provide to plants growing in them. These methods, both chemical and biological, differ as to whether: (1) no plant at all, a test plant or the actual crop plant is used; (2) the type of sample taken and the method of sampling used; (3) the way in which the sample is analyzed or in which the observations are made; and (4) the way in which the data are interpreted. The procedure to be here discussed is just another proposal in this connection.

In a number of fertilizer experiments with corn and sugar cane, in each of which 9 levels of only one fertilizer material were used, different types of leaf samples were gathered and analyzed for total content of the corresponding nutrient under study (3). The levels of application of the fertilizer materials under study in a given experiment varied from zero to a quantity excessively large, considered a priori to be harmful to the crop. Nitrogen was applied as ammonium sulfate, phosphorus as calcium superphosphate, potassium as muriate of potash, magnesium as magnesium sulfate and calcium as calcium carbonate.

The sugar cane leaf samples were taken at 4 and 7 months of age, and the leaves were divided into blades and sheaths. The corn samples were taken at 4 and 7 weeks of age.

Plotting of the leaf nutrient-content data against the corresponding levels of application indicated in general a diminishing-return type of increase of the nutrient in the leaf with an increase in the quantity of the corresponding fertilizer material applied to the soil. Three types of smooth curves were fitted to most of the data: the MITSCHERLICH or SPILLMAN diminishing-return equation [4, 7], the PEARL-REED logistic equation [6], and a fertilizer-yield equation to be discussed later on [1, 2].

Based on the values of the coefficients of determination of the fits of the equations to the leaf nutrient-content data, all

3 equations were about equally useful in explaining the relation between level of application of a nutrient and its content by the leaves. As examples, table 1 presents the coefficients of determination obtained in fitting the MITSCHERLICH and the fertilizer-yield equations to the data of the nitrogen experiments performed with corn and table 2 presents similar data when all 3 equations were fitted to the 3-month old leaf blade data of the phosphorus experiments with sugar cane. As may be seen in these tables, in some cases exceedingly good fits were obtained with all 3 equations, in other cases the fits were not at all good, but the 3 equations behaved similarly, that is, when a certain data was well fitted by one equation, the others also gave good fits, and likewise in the cases of poor fits.

TABLE 1 — *Coefficients of determination obtained on fitting the* MITSCHERLICH *and fertilizer-yield equation to the leaf nitrogen-content data of the corn experiments.*

Location	4 weeks		7 weeks	
	M.[1]	F.-Y.	M.	F.-Y.
Corozal	—	—	58	51
Guayama	96	93	—	—
Gurabo (T.)	87	82	65	64
Gurabo (Ma.)	97	44	96	44
Isabela	98	64	92	80
Lajas	55	37	51	38
Río Piedras (T.)	92	56	—	74
Río Piedras (V.A.)	40	39	2	—

(1) M = MITSCHERLICH equation. F.-Y. = fertilizer-yield equation.

TABLE 2 — *Coefficients of determination obtained on fitting the* MITSCHERLICH (*M*), PEARL-REED (*P.-R.*) *and fertilizer-yield* (*F.-Y.*) *equations to the leaf blade and sheath phosphorus-content data of the sugar cane experiments.*

Location	Blades						Sheaths					
	4 months			7 months			4 months			7 months		
	M.[1]	P.-R.	F.-Y.	M.	P.-R.	F.-Y.	M.	P.-R.	F.-Y.	M.	P.-R.	F.-Y.
Corozal	93	92	92	55	55	83	93	93	94	78	79	86
Guayama	85	96	97	60	61	66	74	78	78	53	53	72
Gurabo	85	—	93	39	39	36	83	91	90	73	73	72
Isabela	94	94	95	54	54	54	89	—	94	57	57	57
Lajas	97	99	98	85	85	84	98	99	99	81	79	80
Patillas	95	96	99	16	—	13	67	83	96	10	1	81
Río Piedras (T.)	50	50	51	24	24	20	60	60	60	68	67	65
Río Piedras (V.A.)	20	19	19	15	7	61	19	—	18	2	—	—

The general conclusions derived from these studies [3] were as follows:

1. The amount of a nutrient occurring in plant leaves, within certain limits, tends to increase with the increased availability of that nutrient in the soil upon which the plant is grown.

2. The relation between the available nutrient content of the soil and the leaf content of the nutrient is expressible by a smooth curve approaching a maximum value as an asymptote. The MITSCHERLICH equation, among others, may be used satisfactorily to represent this relation.

3. The precision of the fit of this equation to the corresponding amount of the nutrient applied and the leaf nutrient content data is higher when the corresponding calibrating experiments are performed in soils with relatively low available levels of the nutrient under study.

4. The relation between the available nutrient content of the soil and the respective nutrient content of the leaves is closer when the leaves are samples at a relatively early stage of growth rather than when sampled at a more advanced age.

5. The precision of the fits of the corresponding equations for sugarcane blades and sheaths are about equal for each of the various nutrients studied.

There seems no need to use different tissues for the diagnosis of adequacy of availability of different nutrients.

6. If MITSCHERLICH'S equation is used to express the relation between the available nutrient content of the soil and the leaf nutrient content, the equation may be transformed for use in estimating the quantity of fertilizer material representing the capacity of the soil to provide the crop with its respective nutrient. Thus, if X = quantity of fertilizer material applied, S = quantity of fertilizer material corresponding

to the capacity of the unfertilized soil to provide the crop with the respective nutrient, and M = total quantity of fertilizer material, then M = S + X.

The form of the MITSCHERLICH equation fitted to the data in this study was $L = A - BC^X$. In each soil studied, the leaf nutrient content was thus expressed as a function of the quantity of fertilizer material applied to the soil, X.

Now, to express the leaf nutrient content Y, as a function of the total, M, nutrient content of the soil, it is necessary to use a more commonly used form of the MITSCHERLICH equation, namely,

$$L = A\,(1 - C^{S+X}) = A\,(1 - C^{M}). \qquad \text{Eq. 1}$$

where, as indicated above, S = original content of the soil, X = quantity of fertilizer material applied, and M = total quantity of the nutrient in the soil expressed in units of the given fertilizer material. The relation $B = AC^S$ makes the two forms of the MITSCHERLICH equation identical.

This latter form of the equation may be used to estimate the nutrient content of the soil from the leaf nutrient content. Thus, solving for M, wo obtain:

$$M = \frac{\log\,(A - L) - \log A}{\log C}\,. \qquad \text{Eq. 2}$$

therefore, once the constants A and C of the corresponding MITSCHERLICH equation are determined for a given soil, crop variety, and fertilizer-material complex, the available soil content of the corresponding nutrient, expressed in units of the given fertilizer material, may be estimated for similar complexes from the respective nutrient content of a leaf sample.

taken at the stage of growth used to fit the soil-leaf nutrient relation.

7. The data of the calcium carbonate experiments, although not adequate to support the general conclusions mentioned above, need not necessarily be considered as contradictory.

This same type of relation seems to hold between the level of application, or if you wish, between the available content by the soil of a nutrient and its corresponding content by the leaves at a relatively early stage of the growth period in pineapples. Most probably it also holds true for other crops. If this is so, it should then be possible to assess the content by a soil of a certain nutrient available to a certain crop, in units of some fertilizer material, from the analysis of a leaf sample taken at a relatively early stage of growth of the plants of the crop growing in the given soil.

Influence of the available level of a fertilizer material on the yield of a crop.

Many types of mathematical functions have been suggested as approximations to the true nature of the relation between the available level of a nutrient in the soil and the yield of the crop growing thereon. These relations range from LIEBIG'S LAW of the Minimum assumption of a straight-line relation while the nutrient is supposed to be the limiting factor of growth to curves with even 2 points of inflexion such as the fertilizer-yield relation suggested by the author.

Theoretically, the nutrient-yield relation must be a curved line, since both at a zero level of an essential nutrient and at excessively high levels of the nutrient the yield must be zero, while experience indicates that for some levels of the nutrient within these limits the yield differs appreciably from zero, changing in value in the form of a smooth curve as the level of the nutrient in the soil or growth medium increases.

Plotting the yields obtained in the sugar cane and corn experiments previously mentioned, especially in the case of the potassium experiments, in which the quantity of potassium applied per acre reached up to a value of 10,000 pounds (11,205 kgs. per Ha.), it became evident that the nutrient-yield relation has a point of inflexion *beyond* the nutrient level which corresponds to the maximum yield. Since the presence of another point of inflexion *below* the nutrient level required for the maximum yield had been demonstrated as far back as 1890 by HELLRIEGEL, according to RUSSELL [5], the possibility of representing the nutrient-yield relation by a curve with 2 points of inflexion suggested itself.

This curve may be either symmetric or asymmetric, and may be simple or complex. Frequency distribution curves similar to the normal curve of error, or some asymmetric curves such as PEARSON'S curve no. 1, are possibilities. The quartic equation is also another possibility. After trying many such curves, the author came to the conclusion that the use of a simple 3-constant curve with 2 points of inflexion might be a satisfactory working tool for estimating the yields which might be expected from given nutrient levels in the soil. The equation suggested for this purpose is:

$$Y = \frac{T}{1 + D\,(M - G)^2}, \qquad \text{Eq. 3}$$

where Y is the crop yield, M is the available level of the nutrient in the soil, and T, D and G are constants representing respectively the maximum yield, an index of the curvilinearity or the curve, and the level of the nutrient in the soil which corresponds to the maximum yield. This equation cannot be fitted directly to the data of a fertilizer experiment in which different levels of a fertilizer material are tested, since the information available on the nutrient refers to the quantity of the fertilizer material applied. In this case the equation to be fitted to the data is:

$$Y = \frac{T}{1 + D\,(X - E)^2}\,, \qquad \text{Eq. 4}$$

where X is the quantity of fertilizer material applied, F is the level of application of the fertilizer material required for maximum yield, and the other symbols represent the same concepts as above.

Since it is obvious that $G = S + E$, and, as defined above, $M = S + X$, these 2 equations are equivalent to each other, since the differences to be squared in their denominators are equal, that is, $M - G = S + X - (S + E) = X - E$.

Equation 4 was fitted to the data of the above-mentioned experiments with variable results. In some cases the fits were good, in others not so good. The yield data in the latter cases, however, were of such a nature that, no matter how complex, no equation with relatively few constants would fit the data any better.

This same type of relation has been found to hold with a high degree of precision in the case of the influence of temperature on the growth of various isolates of some fungi, for which the coefficients of determination of the fits ranged from 0.87 to 0.96. It also offered a satisfactory explanation of the influence of the pH value of the growth medium on the growth of the same fungal isolates, although the coefficients of determination in these cases ranged from 0.69 to 0.89. In the cases of the influence of pH on fungus growth, the 5-constant PEARSON'S no. 1 equation, with 2 points of inflexion, provided much better explanations than Equation 4.

The drop in yield with excessive applications of fertilizer materials was observed especially with the highly soluble salts ammonium sulfate and potassium chloride, applied at maximum rates of 2,000 pounds of nitrogen and 10,000 pounds of potassium per acre (approximately 2,241 kgs. N and 11,205 kgs, K per Ha). With the slightly soluble calcium superphosphate and the practically insoluble calcium carbonate, with which the soluble concentration of phosphate and calcium ions in the soil solution is quite limited, the harmful influences of heavy doses of application might not be detected, although they might be in the cases of soluble phosphates and calcium salts. For slightly soluble salts, therefore, the relation between nutrient content and crop yield could perhaps be better represented by smooth curves approaching maximum values as asymptotes, such as the logistic equation or MITSCHERLICH'S. Calcium carbonate, of course, has an additional influence on the pH value of the soil, whose influence on crop yield may be far greater than the influence due to calcium as a nutrient.

Suggested procedure for estimating, based on the analysis of a leaf sample, the optimum economic application of a fertilizer material required for the production of a crop.

In a soil representative of that of the area to be dedicated to the commercial production of the crop, perform an experiment with the variety of the crop to be grown commercially. This experiment must include at least 3, and preferably many more levels of application of the fertilizer material to be tested, ranging from zero to quantities exceeding the usual commercial rates of application. The experiment should be located in a field for which there is evidence that its soil is deficient as regards the availability of the corresponding nutrient.

Leaf samples should be taken at a relatively early stage of the growth period and analyzed for the nutrient in question. By fitting to the fertilizer-leaf analysis data a smooth type curve similar to the MITSCHERLICH curve, the relation between the soil available nutrient content and the analysis of the leaves may be characterized. This equation is to be used later on in estimating the available content of the nutrient in the soils of the commercial fields from the analysis of leaf samples taken from the commercial field plants at the same stage of growth and time of the year as the experimental field samples.

After harvesting the experiment and determining the yield obtained with the various levels of application of the fertilizer material, the previously-mentioned fertilizer-yield equation should be fitted to the yield data. This equation indicates how does the crop yield vary with level of application of the fertilizer material and will be useful in estimating the optimum economic application of the material.

An example of the calculations to be performed follows.

Table 3 presents the results of the leaf analysis and the crop yield data of a fertilizer experiment performed with the Red Spanish variety of pineapples.

TABLE 3 — *Leaf-nitrogen content of leaves sampled at 3 months of age and yield of pineapples.*

Treatment		Percentage dry-weight nitrogen content of leaves		Treatment		Fruit yield in tons per acre	
No.	1,000-lb. units of urea applied	Actual	Calculated	No.	1,000-lb. units of urea applied	Actual	Calculated
1	0.000	2.520	2.419	1	0.000	12.91	12.55
2	0.075	2.455	2.555	2	0.225	14.28	13.30
3	0.150	2.645	2.679	3	0.450	12.05	13.96
4	0.225	2.785	2.787	4	0.675	14.22	14.50
5	0.300	2.870	2.872	5	0.900	15.14	14.88
6	0.375	2.955	2.930	6	1.050	15.31	15.03
7	0.450	3.030	2.958	7	1.200	14.97	15.09
8	0.525	2.905	2.953	8	1.350	17.31	15.07
9	0.600	2.905	2.915	9	1.500	13.14	14.95

TABLE 3 - (*continued*)

Statistics of the fitted equations

A = 2.96	T = 15.096
B = 0.987	D = 0.134
C = 0.476	E = 1.230
r^2 = 0.909	r^2 = 0.321
S = 1.479	E + S = 2.709

The MITSCHERLICH'S type equation fitted to the leaf-analysis data is:

$$L = A - BC^X = 2.96 - 0.987\,(0.476)^X \;,$$

where L is the nitrogen leaf content and X is the quantity of nitrogen applied to the soil, expressed in units of 1,000 lbs. of urea (U) per acre (equivalent to 1,120.5 kgs. U per Ha.).

Since $B = AC^S$, where S is the available nitrogen content of the unfertilized soil, expressed in units of nitrogen as defined above,

$$S = \frac{\log B - \log A}{\log C} = 1.479 \text{ units of N.}$$

The relation between *total* available nitrogen in the soil and the leaf nitrogen content is thus:

$$L = A - AC^SC^X = A - AC^{S+X} = A\,(1 - C^{1.479+X} =$$
$$A\,(1 - C^M) = 2.96\,(1 - 0.476^M).$$

This equation may be used to estimate the quantity of nitrogen available to the Red Spanish pineapple variety in a field with a soil similar to the one used in this experiment, from the analysis of a leaf sample taken at approximately 3 months of age and about the same time of the year in which the leaf samples were taken in the experiment.

The equation to estimate said quantity of nitrogen in the soil is:

$$M = \frac{\log (A - L) - \log A}{\log C} = \frac{\log (2.96 - L) - \log 2.96}{\log 0.476} .$$

Using this equation to estimate the available nitrogen in the unfertilized soil of the experimental field, one obtains:

$$M = \frac{\log (2.96 - 2.52) - \log 2.96}{\log 0.476} = 2.568 ,$$

as contrasted with 2.419 which was estimated by use of the fitted equation. The difference may be explained on the basis of the unavoidable experimental variation, since the "zero" application plots were not as fully representative of the soil of the experimental field as all the plots, the analysis of whose samples was used to fit the equation. In the case of a commercial field the fitted equation would not, of course, be available, but the leaf sample would be taken throughout all the field.

The relation between nitrogen applied and fruit tonnage is:

$$Y = \frac{T}{1 + D (E - X)^2} = \frac{15.096}{1 + 0.134 (1.230 - X)^2} ,$$

where Y is the fruit tonnage and X is the quantity of nitrogen applied to the soil, again in units of nitrogen. The relation between total available nitrogen in the soil and mean fruit weight is:

$$Y = \frac{T}{1 + D\,(G - M)^2} = \frac{15.096}{1 + 0.134\,(2.709 - M)^2}\,,$$

since $G = E + S$ and $M = S + X$.

To estimate the optimum economic quantity of available nitrogen in the soil for the production of this crop in a field where the above-mentioned equations apply, one may proceed as follows:

If P = profit per acre,

Y = yield of fruit in tons per acre, that is, mean fruit weight multiplied by the number of fruits produced per acre,

M = units of nutrient per acre,

F = cost of one unit of nutrient applied, that is, the cost of one unit of the nutrient plus its cost of application,

V = farm value of one ton of pineapple fruits ready for harvest, that is, the difference between its sale price and its cost of harvesting and marketing,

K = fixed costs per acre,

then the gross income per acre is YV and the expenditures are $MF + K$. Thus, the profit is:

$$P = YV - MF - K = \frac{TV}{1 + D\,(D - G)^2} - MF - K\,.$$

The total economic level of available nitrogen in the soil is the value of M which make the first derivative of P with respect to M equal to zero, and its second derivative positive in value. The first derivative of P, equated to zero, is:

$$\frac{dP}{dM} = D^2F\,(M - G)^4 + 2DF\,(M - G)^2 + 2VTD\,(M - G) + F = 0\,,$$

which, if one defines Z = M — G, becomes:

$$\frac{dP}{dM} = D^2FZ^4 + 2DFZ^2 + 2VTDZ + F = 0\,.$$

Now, if F = \$ 50 per unit of nitrogen, and V = \$ 23 per ton of fruit, the optimum economic value of M may be obtained by solving the equation:

$$\frac{dP}{dM} = (0.134)^2\,(50Z^4) + 2\,(0.134)\,(50Z^2) + 2\,(23)\,15.096\,(0.134)\,Z + 50 = 0\,,$$

$$= 0.8978Z^4 + 13.400Z^2 + 93.0517Z + 50 = 0\,.$$

The value of Z which makes this first derivative equal to zero and the second derivative positive is — 0.588. Since Z = M — G, then M = Z + G = — 0.588 + 2.709 = 2.121. Thus, the optimum economic quantity of available nitrogen in the soil of the experimental field or in similar soils is 2,121 pounds of urea per acre. By subtracting from this value the quantity estimated to be available from the nitrogen content of the corresponding 3-month leaf sample, one obtains the optimum economic application of nitrogen to apply.

In the case of the above-mentioned experimental field, where S was found to be 1,479 pounds of urea per acre, the optimum economic level of application would have been 2,121 — 1,479 = 642 pounds of urea per acre.

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DISCUSSION

Chairman: TH. WALSH

PRIMAVESI

Several times, before we worked with Dr. HERNANDO's sap analysis method, we have worked with leaf samples. In our 18th book, Deficiências Minerais em Culturas (Mineral Deficiencies in Crops), we treated this matter also. Prof. WALLACE, from the University of Bristol, remembers in his foreword (1964) the importance of this method for the Tropics and Subtropics.

With reference to your Table 3, it is really very interesting. It is an admirable approach of estimating data from crop yield data.

Furthermore, we have studied the optimum economic application of fertilizer and now we will apply the equations (fertilizer-yield equation) you mentioned in your paper.

OBERLÄNDER

I had some difficulties, Professor CAPÓ, with your equation 3. This might be due to my limited knowledge of mathematics, and since you are proposing that the fertilizer yield relationship may take the form of a frequency distribution curve, I was trying to fit equation 3 to what one usually calls a frequency distribution curve, but I was not successful, and now my question is: if one would apply the equation which is usually used for a frequency distribution curve, viz. $y = e^{-x^2}$, could it be converted into your equation 3?. But it is difficult for me to make a statement from my seat, with the Chairman's permission I would come out to the black-board to make just a short sketch.

If I had understood you correctly you would propose this type of curve. Did I understand you correctly? and how would you agree with this equation: $y = e^{-x^2}$ which is used for a frequency distribution curve. How would it be possible to transform this equation into your equation 3?.

Capó

You will notice that in the denominator of this equation there is the constant « one » so that when the amount of x is equal to the value of c, which makes that particular term zero, then the value of the maximum is the numerator. If you do not have that particular constant, then it would be infinity and then the equation would not fit, so that in order that the equation, which is similar to the normal curve, may have a value it needs the « one » appearing in the denominator of the equation. The constant « one », which could be ten or a hundred, is needed so that when x is equal to c, then the maximum yield is equal to the numerator.

Oberländer

Does it mean that your equation 3 and this one could easily be transformed one to the other?

Capó

Well, you will have to include that particular constant term. This term here is the one which enables the equation proposed to have the value of the numerator when x is equal to c, since this term, of course, becomes zero, so that A is the maximum value of the yield as observed. That is why that term is necessary. If you do not put any term there then it will be infinity and then you will not be able to fit the equation. In fact, that is an advantage, because you have already the maximum value of your experimental data, and you know that you are near your maximum. You can use this maximum value of experimental data as the first value for A. Now, the fitting of the equation is of course done by expanding this equation by Taylor's theorem. After the expansion, and substituting in the equation the values assumed for the constants, you establish the equations of differences between the observed and the calculated value. You have to assume values for the constants and then try to calculate the corrections for the different constants. Sometimes there is difficulty in solving the system of simultaneous equations when you try to calculate the corrections to all the constants at once. But, in our computer, we found that we could do this, when we calculated the correction of A first, then using that value we made a correction for B and then a correction for C, and having the computer doing it again, until we could get the best corrections or approximation to the best that can be obtained for the experimental data.

PESEK

I would like to ask a question relative to the application of the method. You dealt with some long season crops like sugarcane and pineapples and also with maize and you indicated, in the case of maize, to sample early. Do you propose that you use the results of your sampling and analyses in rectifying or correcting the fertilization practice for that particular crop or would this be for a future crop, growing in the same field.

CAPÓ

Use of the information to correct a previous basal application is of course correct, since we have found out that there is a good relation between the application of the fertilizer material and the contents of the elements in the leaves in the case of tobacco, even at only ten days of age of the plants. Now the precision of this relation tends to decrease with time, that is, as the plant grows. Apparently there is a dilution of the elements absorbed and when the plant is approaching maturity, then the relation between the content of the element by the soil and the yield and leaf content are not so good, so it is essential to get the leaves in an early stage of growth. Of course, for crops that have a short growth period maybe the method should be used to try to find whether you used a proper amount in the basic application, so that the following year you may correct the basal application if there is not enough time to make another application in that particular season.

WELTE

Only one additional question. First I would like to come back to Mitscherlich equation. I shall not use x generally, I would like to use x as a fertilizer material you have added to the soil, and what is available in the soil already should be here indicated as b. You showed up a relationship between the fertilizer applied and the content in the leaf. But then we have to ask what is the effect of b in the soil because b always differs from one soil to another. You can operate only with the fertilizer material if b is a constant, or if you use the same soils in a certain family. And therefore I think b maybe involved in your factor, that means, applied fertilizer plus the available amount in the soil, is that right? Otherwise you will get many curves and the content value of the leaf will vary very widely.

CAPÓ

If you apply your equation to a soil in which the relations of the different elements vary, the equation will not be very useful.

No. An experiment is made in the particular soil with its nutrient contents and you find out its constants. Now for that soil, or a similar soil; then your equation may be used to calculate how much there is in the soil, in that particular soil. I do not say that the calculation is true for other soils that differ from that one very much. Only for similar soils. That means the constants are only related to one soil. There is need to make a fertilizer experiment in every type of soil, let us say, that is used in the commercial production of the crop. You have to make an experiment to find the equation, both equations. First, the equation of the relation of the fertilizer material nutrient in the soil and the leaf content and, second of the nature of the response because, as you know, in some soils you may get a different response; say, in a sand with a potash deficiency you can supply the needs with less potash, whereas if it is a clay, there may be fixation of potash in the colloid and then you may need more. So that both types of curves have to be fitted to the particular soil that you are going to use in commercial production, or similar soils.

HERNANDO

You say in page 2, I read the paper already, that not only you, but many people say, that the curve is coming down because you use so high levels of one element that it will be toxic for the plant. Well, I think this is a problem generally not well understood; because often it is not true. The reality is that this element is not the deficient one that is involved in increasing the yield. But there is another element, and generally even more than one. Many people can answer to that. I think that normally in these experiments, if working with phosphate for instance, they apply enough nitrogen and potash, and we think that this is correct. More then a century ago Liebig said that it is necessary to apply to the soil that element that the plant took before from the soil in order to try to maintain the fertility. But people felt that only nitrogen and potash and phosphate were needed by the plant; but later we shall see in other papers that more elements are important and that sometimes, because of the increasing yields, there is more need of them for the plant growing. I think it would be more correct to say at this point that the element we are studying is not a deficient one, it will be another one, it will not be potash, not nitrogen, it may be a microelement. Only in few occasions, not generally, it is true that the element in question is really toxic.

Capó

Well, you know that in the research work done by Mitscherlich he found out that there is not only one limiting growth factor at a time, you may have a number of limiting factors. You may bring a certain element so that you can get a maximum yield under those conditions, that does not mean that at that particular moment there are no other limiting factors. In fact, that maximum is probably the state of optimum balance under those conditions and, as soon as you overpass that, then you have a sort of imbalance among the different growth factors, and taking that point of view, then all the growth factors would be in a sort of imbalance, because this one would be in excess of the other ones which would be deficient. So that the maximum value is just the point at which there is a balance of the particular elements, with respect to the condition of the growth medium, with respect to the other growth factors, not only fertilizer element, but temperature or carbon dioxide, or whatever it is. But of course, we wanted to characterize the response, and of course we wanted to use very high amounts, because in the past, the additions were stopped at what they called practical amounts of application, and under those conditions, of course, you get a diminishing type of response. You may recall that Mitscherlich amended his equation by applying a factor to take care of that particular situation. What our data seems to indicate is that it has two points of inflection.

COLWELL

I would like to raise a couple of points. First of all, let me comment on this estimation by extrapolation of the Mitscherlich equation. The extrapolated value depends on the value of A representing maximum yield being constant, otherwise, if it varies, the extrapolated value varies. That is just a small point.

Now, my main question is, how successful have you been in verifying this method of estimating fertilizer requirement. We understand that you have got correlations as shown in the paper. But have you shown, for example, that by this procedure you get a better estimate of fertilizer requirement than you would from an ordinary correlation between soil test and fertilizer requirement, or even simply between a tissue test and fertilizer requirement. Is it really necessary to go through this procedure of using a tissue test to estimate soil nutrient level and then coming back to estimate how much fertilizer should be applied.

Then, there are two things which need to be verified, one, if you sample a growing crop you can estimate what you have got to do to correct deficiencies in that crop. To do this you have to make a forecast, then check on the actual effect of the added fertilizer on that particular crop. I would suggest, a rather restricted application for estimating fertilizer requirements. Very rarely are we in a position to make a correction quickly to a growing crop. Rather we are interested in forecasting what we should do to the next crop. Have you looked at this aspect?

My point is that the actual A level has to be constant.

CAPÓ

With respect to the first question. Where you refer to a maximum yield in the case of the Mitscherlich equation, the Mitscherlich equation is not used in this connection, with respect to yields, but only as the relation between the amount of nutrient in the soil and the amount of the nutrient in the leaf. Now, as you increase indefinitely the amount of nutrient in the soil, of course, you get sometimes, a stable value, like that; the content of the element in the leaf does not decrease with increases of the element in the soil. That is why the Mitscherlich equation is useful for this purpose, since it approaches a maximum value.

If the other element, or growth factors are in the same relation, that value *is* constant. If you have a different soil in which the relation of the growth factors or other elements differ widely from that of the soil of the experiment, then you will not get that particular same level, that is why I say that you have to make an experiment in the soil, or a similar soil, to the one in which you are going to grow the crop commercially. Because if you have two soils that vary much in some other element or other factor, then that value will not be the same, it will differ, and that is why the experiment has to be made in the soil of the commercial field or a similar one, in order to be able to characterize the nature of the relation. In the second question which you asked, if you have a short-growing crop and you do not have time to correct the fertilization of that particular crop, the procedure may be useful in finding out whether your basic application of fertilizer to start with was enough to provide the nutrients required by the crop. If you cannot correct that one, that means that the next time you plant you may either raise or lower your basic application, but this will check with what was applied right and certain.

COLWELL

My question was, whether, in fact, have you verified it in this way?

CAPÓ

We have made this experiment which I mentioned there with pineapples, in which we applied heavy doses of the different elements and showed that we could get an optimum economic yield with an application of about 650 lbs of urea, in the case of nitrogen. This result was in line with other sorts of experiments which have been made in the past showing that about that concentration was a practical one, that is, in the particular place where this experiment was made were using 1,100 lbs or urea per acre, and this enabled the reduction of the amount of nitrogen applied, the amount of urea, and they are using the 650 lbs at present in their production.

WALSH

We have reached the end of this lecture. There will be some time available in the general discussion session, after Professor HERNANDO's paper, and maybe Dr. PESEK you will hold your question until then. In the meantime I would like to thank you Dr. CAPÓ for the very fine presentation of your subject, particularly for your answering. Thank you. Now, Professor HERNANDO is going to deal with sap analysis as a fertilizing index in several types of plant. These subjects are related, of course, and when we come to questions after Prof. HERNANDO's paper we can deal with this whole subject so that in the end we will have some definite conclusions about this matter. It is a very difficult field to cover. Prof. HERNANDO, I need not tell, has been organizing this meeting along with the people in Rome, and he is responsible to a very considerable extent for our programme here. So I won't say more than that at present. Professor HERNANDO, thank you.

SAP ANALYSIS AS FERTILIZATION INDEX IN SEVERAL TYPES OF PLANTS

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INTRODUCTION.

When leaf analysis is used to obtain information on the nutrional state of a plant, the results are practically never accurate enough. The reason for this is that leaves furnish primarily cumulative information on all the nutritional states of the plant from the budding time of the leaves in question until they are selected for analysis.

While the objective in most cases when leaf analysis is used is to find fertilization needs at the time in question, the results of such analyses, as presently conducted, are never conclusive in this sense, precisely for the reason mentioned in the preceding paragraph.

This is why we have been led to develop an analysis technique which can give a real indication of fertilizer needs at any given time. The technique we use is sap analysis, which does not have the disadvantages of leaf analysis.

Since the need to find a more accurate method arose in the course of work on nutrition control in the growing season of winter tomato plants, we have worked with this plant in developing and testing the validity of our method, but later the technique has been used with other types of plants and also it provided useful and conclusive results.

Theoretical aspects.

From the scientific standpoint, the advantages to sap analysis are unquestionably considerable when the inorganic part is analized separately from the organic one, as we do.

The reason for this is that, with this method, the amount of an element found in inorganic form in a conducting tissue (the kind of tissue used for these analyses) is a direct function of the absorption going on in the roots, or rather, of the supplies available in the plant's environment; although the latter formulation is not theoretically exact, this is the actual situation.

As a matter of fact, the nutrients uptaken by the roots are carried by the conducting tissues to the leaves and fruits; however, the inorganic ions not used in the process of photosynthesis also descend through these same tissues (which are very hard to separate from one another), and are transferred by translocation to other parts of the plant where they are more in demand. However, these substances are very small in quantity in comparison with the rising ones, and may thus be considered small, especially when, in the case of some elements such as boron and iron, translocation is practically nil. Thus, the results obtained from direct analysis of the inorganic content of sap yield a very clear picture of the current nutritional status of the plant, information which is extremly valuable for adjusting fertilization.

The reasoning we have followed is unquestionably theoretically accurate and logical from the physiological standpoint, but it would be meaningless if much more satisfactory results from those furnished by leaf analysis could not be obtained in practice.

We have tested the validity of this technique over a period of about ten years, during which time we have been using it with greenhouse and field plants, while perfecting our procedure by simplifying it and making it apt for routine laboratory use and even for quick field tests. In view of the practical importance of this technique in farming, we set forth hereafter its most important features, and some of the results obtained which demonstrate its usefulness.

Methods.

Hereunder appears a synoptic table (Chart I) of the entire method we presently follow, which is more complete and perfect than the one published previously. This table refers to the laboratory technique. Naturally the technique followed in the field is much more simplified. The method of separation is the same, however.

To prevent metabolic changes in the plant's petioles, they are stored in dry-ice refrigerators whose interior temperature is less than $-40°C$, after being out and placed in plastic hags to keep the specimens from each field or farm separate. This precaution is essential to prevent changes in the inorganic and organic composition of the plant's tissues.

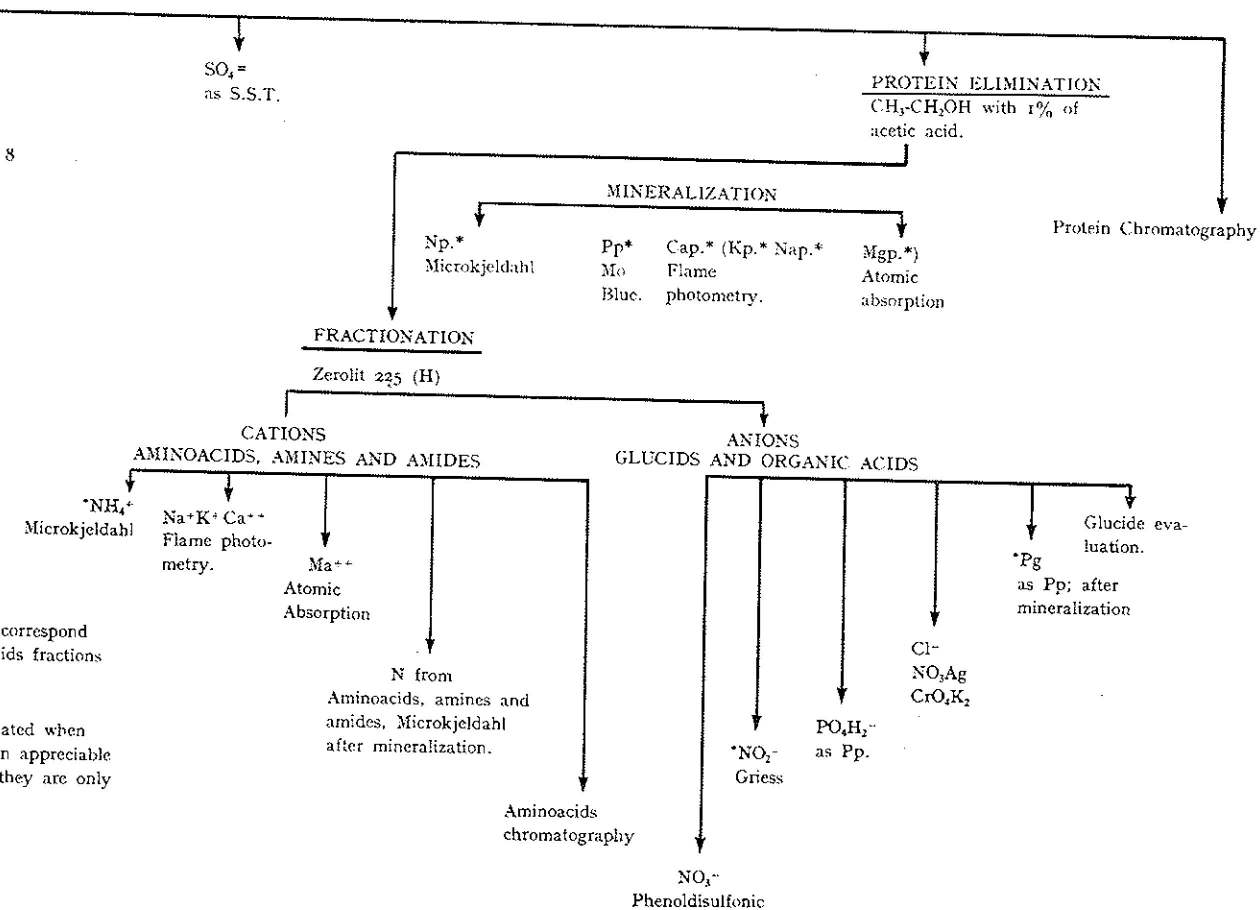
Ussing this method, we can learn at any given time what the percentage of an element in inorganic form is with respect to the total amount or to its organic form. The press shown in fig. 1 is used to extract sap.

Routchencko and Cadahía use this method to learn the deficiency level of an element: and on the basis of the ratio of the inorganic to organic form, and from the changes this variable undergoes, they deduce whether an element may be accounted deficient or not in the plant's nutritional system.

In this way, it is possible to recognize cases of accumulation of an element in inorganic form, which might be thought from the results of analysis to be present in excess, when the

SCHEME OF ANALYTICAL WORK

SAMPLING - FIXATION - CHLOROPHYL SEPARATION - EXTRACTION - FILTRATION - CONSERVATION



* p and g subindices correspond to proteids and glucids fractions respectively.

• Only they are evaluated when they are presented in appreciable quantity. Normally they are only as traces.

CHART. I

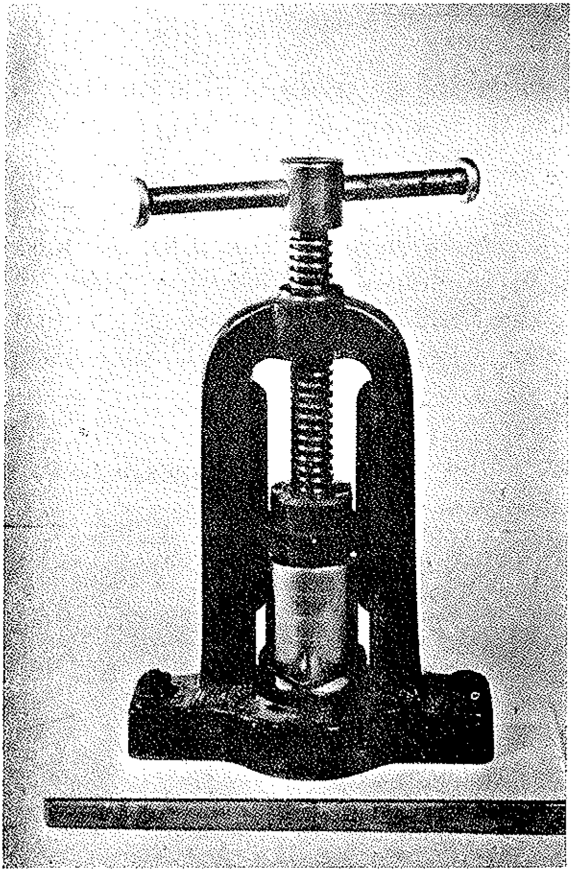


FIG. 1

real meaning of the finding is that a deficiency of another element is limiting the use of the first one.

Applications on tomato plants.

We have studied the results of field experiments with tomato plants, the most significant of which were these:

A dose of fertilizer as small as 50 Kg/Ha causes a very large increase in the content of the elements in sap, which makes it possible to detect with precision the need of even much smaller quantities. The following Table I shows the results obtained with calcium nitrate, 18% superphosphate, and potassium chloride in the doses indicated:

Table 1 — *Results of sap analysis in tomato plants. Time of fruit production. Concentrations in mg/1.*

Samples	N (NO_3^-)	P ($PO_4H_2^-$)	K^+
Normal	475	65	4,670
Deficient without treatment	222	44	3,740
Deficient with treatment	406	66	4,530

As Table 1 shows, the differences are quite significant, which proves the accuracy of the method.

Furthermore, in a subsequent study we clearly showed that this technique can be used to follow the variation in the content of a given element in the sap of the tomato plant, as a function of fertilizers furnished. The changes that occur in the various stages of development are so large that they make it possible to define the plant's nutritional state with full accuracy.

The extreme values obtained for the sap are shown in Table 2. The intervals in this table guarantee that sap analysis is a very sensitive method to evaluate the needs of fertilization.

TABLE 2 — *Extreme concentrations found in tomato plant sap, expressed in p.p.m. (mg/1).*

Elements	Maximum and minimum values
N (NO^-_3)	40.- 3000
N (NH^+_4)	tr- 600
P ($H_2PO^-_4$)	15.- 500
Cl^-	40.- 8000
S ($SO^=_4$)	4.- 100
Na^+	10.- 2900
K^+	1000.-12000
Ca^+	40.- 2500
Mg^{++}	80 415

Another purpose to which this method has been put with very satisfactory results is the study of the effect of salinity on irrigation water.

It is a well-known fact that saline irrigation water (due primarily to NaCl) results in diminishing yields, and this is a problem that has affected tomatoes grown in the Spanish Levant.

However, this plant resists the effects of salinity up to a certain point, and a low sodium chloride level is even beneficial to it for a number of practical reasons.

Control of salinity and determination of the maximum level tolerable by tomato plants are problems that can be solved with this analysis method, on account of its high sensitivity, as can be seen from Tables 3, 4, and 5.

Table 3 reveals the influence of NaCl on yields, when N treatment (normal N level) is combined with different doses of NaCl varying from 0 to 90 meq. of NaCl per liter of nutritive solution.

TABLE 3

Effects of NaCl on yields.
Tomatoes. - Margoble variety. - Grown under controlled conditions.

Development indices	Treatments (*)				
	NCl_0	NCl_1	NCl_2	NCl_4	NCl_6
Fruit yields, g/4 plants	1380	1240	814	72	35
Flower buds on 4 plants (initial stage of fructification)	64	60	56	27	21

(*) Cl' levels are 0, 15, 30, 60 and 90 meq/l. The 15 meq/l level is the highest without toxicity effect.

Sap analysis (Table 4) picks up the difference perfectly well, with Cl concentrations varying from 40 to 7000 mgm/l., and Na concentration from 28 to 2900 mgm/l, data which resolve all doubts about the sensitivity of the method.

From the data on yields, it seems that the toxic level is reached at 4200 mgm/l of Cl and 1300 mgm/l of Na in sap. At these levels, accumulation and the consequent toxic effect on the plant begin. These concentrations may be used as reference indices.

We are currently doing a study on the differences in the absorption of NaCl as a function of the interaction of the following elements: Ca/Na, No_3/Cl, and K/Na. Data from these experiments are contained in Tables 4 and 5. The latter

TABLE 4 — *Influence of NaCl on tomato plant nutrition (N fixed and NaCl variable).*

Sap analysis. - Variety: Margoble.
Stage of development: Start of flowering.
Organ analyzed: Entire plant.
Concentration of elements in sap.

Elements mg/l	Treatments				
	NCl_0	NCl_1	NCl_2	NCl_4	NCl_6
N (NO_3^-)	1520	936	1020	930	824
Cl^-	40	4200	5800	6200	7100
K	4380	3415	3650	3400	3400
Ca	58	79	130	150	195
Na	28	1320	2000	2560	2920

TABLE 5 — *Experiment: Influence of NaCl on tomato plant nutrition (NaCl fixed and N variable).*

Sap analysis. - Variety: Margoble.
Stage of development: Start of flowering.
Organ analyzed: Entire plant.
Concentration of elements in sap.

Elements mg/l.	Treatments (*)		
	N_0Cl_1	NCl_1 (**)	N_ECl_1
N (NO_3^-)	344	936	2944
P (PO_4H_2)	112	40	15
Cl^-	4430	4200	1100
K	3700	(Nutritive solution different from N_0Cl_1 and N_ECl_1 in K and Ca)	6700
Ca	35	»	410
Na	950	1320	190

(*) The nutritive solution is the Arnon-Hoagland solution for tomato plants, with nitrogen levels $N_0 = 7$ meq/l; N = 15 meq/l (regular dose); and N = 77 meq/l.

(**) Corresponds to the NCl_1 treatment in the first experiments. In this case the nutritive solution differs in K and Ca from the solution used in the second experiment, for which reason the values of said cations are not presented.

refers to a test conducted on the interaction of No_3/Cl, keeping the Cl^- concentration in the nutritive solution constant and raising the nitrogen from a low dose (N_0) to a high one (N_E).

It can be seen from Table 6 that the effect of Cl^- in the form of Cl_2Ca is the same as the effect of Cl^- in the form ClNa, although somewhat weaker.

TABLE 6 — *Experiment with N fixed and Cl variable (in the form of Cl_2Ca).*

Sap analysis. - Variety: Margoble.
Stage of development: Start of flowering.
Organ analyzed: Entire plant.
Concentration of elements in sap.

Elements mg/l.	Treatments		
	NCl_0	NCl_2	NCl_4
N (NO^-_3)	1650	1100	1040
P ($PO_4H^-_2$)	59	35	35
Cl^-	1350	3550	5100
K	6625	6625	6500
Mg	275	415	500
Ca	150	375	613
Na	175	55	55
N (NO^-_3)/Cl^-	1,2	0,3	0,2
Na/Ca	1,1	0,15	0,1
K/Ca	44,2	17,7	10,6

Table 7 shows that the $N(No^-_3)/Cl$ antagonism does not appear when the concentration of Cl^- corresponds to the Cl_4 treatment. It does appear, but in amounts too small to eliminate toxicity, when the Cl_2 treatment is applied.

TABLE 7 — *Experiment with N and Cl in two different dosis (Cl in the form of Cl_2Ca).*

Stage of development: Start of flowering.

Elements mg/l.	Treatments			
	N_0Cl_2	N_0Cl_4	N_ECl_2	N_ECl_4
N (NO^-_3)	580	420	1290	960
P ($PO_4H^-_2$)	74	102	59	139
Cl^-	6850	7850	5250	7350
K	4875	4375	6500	6875
Mg	307	330	225	365
Ca	56	56	313	357
Na	2100	2625	1450	2000
N (NO^-_3)/Cl^-	0,1	0,1	0,2	0,1
Na/Ca	37,5	46,9	4,6	5,6
K/Ca	87,1	78,1	20,8	19,3

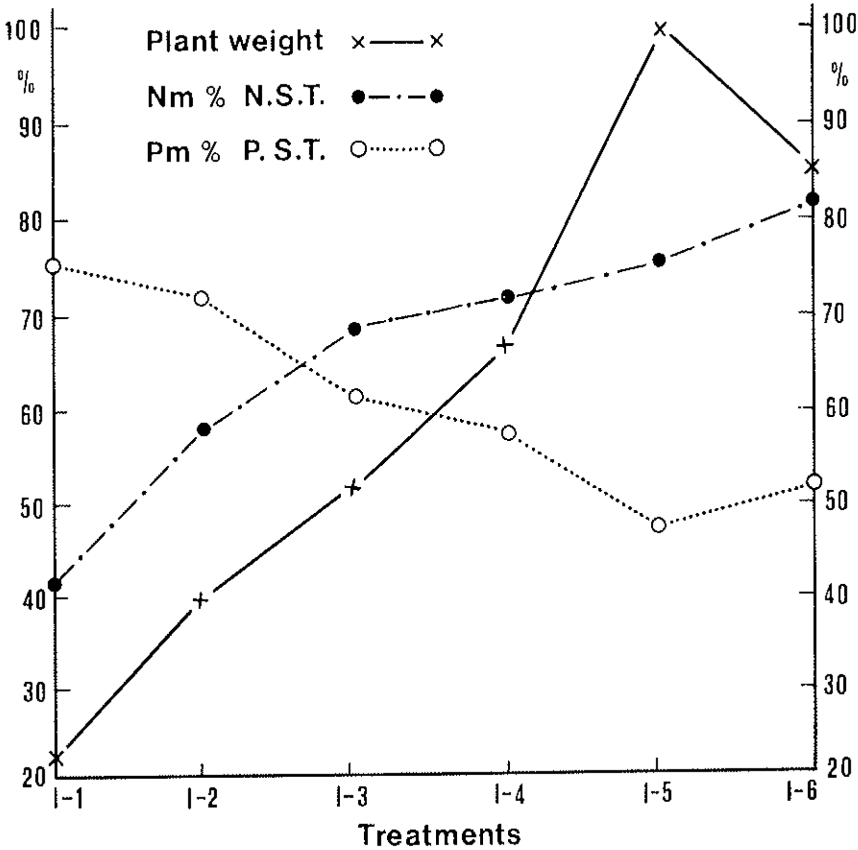
Study of the N/P ratio.

This method has also been employed in the study of the N/P ratio in the tomato plant.

This experiment consisted in applying a total of six treatments to the plants — nutritive solutions added under controlled conditions. The solution corresponding to the first treatment (I-1) contained a sufficient amount of all the elements, except ones: the nitrogen, level was very low.

The concentration of the solution corresponding to the second treatment (I-2) was double that of the first solution, and so on, so that (I-6) was six times more concentrated than (I-1). Also, in the sixth treatment, the solution contained nitrogen in greater than normal amounts; the normal level of nitrogen for this solution was that contained in (I-5). Consequently, the N/P ratio was maintained at a constant level in all of the treatments.

Graph 1 shows the comparative ratios between the nitrogen and phosphorus minerals in the sap, and the total amounts



GRAPH 1 — Variation of N and P minerals in % of N and P total. Plant weight in % of optimal yield. Fruit period.

of soluble nitrogen and phosphorus (mineral plus organic), in terms of the yield obtained.

A close correlation exists between the percentage values of mineral nitrogen with respect to the total (Nm/%N.S.T.) and the yields.

While nitrogen is the factor which determines development, phosphorus evolves in the opposite direction. The same phenomenon occurs for the ratio of phosphorus and nitrogen minerals.

The N_m/%N.S.T. and P_m/%P.S.T. values corresponding to the best solution (I-5) are considered metabolic or development indices.

The fundamental conclusion drawn from this experiment it that the amount of nitrogen absorbed by the plant seems to affect the metabolism of phosphorus, so that when the absorption of nitrogen is increased, the percentage of transformation into organic phosphorus is increased (decrease of P_m/%P.S.T.). (Graph. 1)

This type of investigation has also been used to study nutrition in other types of plants, especially corn, lettuce, and wheat, although less intensively.

Below we present some of the more interesting results.

Research on corn.

Variations in the mineral composition of the sap have been analyzed when this was subjected to two different types of nitrogenized nutritive solution; one of the solutions contained nitrate, and the other ammonia only as nitrogen.

In order to study the problems of ammonia poisoning which frequently appear in the corn crops of Southwestern France, an experiment was done in sand, under controlled conditions. The method of control used was sap analysis. The composition of the two nutritive solutions used is indicated in Table 9. The first contained nitrate, and the second ammonia.

TABLE 8

Nutritive solutions. Concentrations expressed in meq/l (macroelements), and g/l (minor elements). pH: 6.2 (adjusted with NaoH).

Anions / Cations	Nitrogen solution					Ammonia solution				
	NO^-_3	$PO_4H^-_2$	$SO_4^{=}$	Cl^-	Total cations	NO^-_3	$PO_4H^-_2$	$SO_4^{=}$	Cl^-	Total cations
K^+		4		0,5	4,5		4		0,5	4,5
Na^+		1			1		1			1
Mg^{++}			3,75		3,75			3,75		3,75
NH_4^+					0			10		10
Ca^{++}	10				10			10		10
Total anions	10	5	3,75	0,5	19,25	0	5	23,75	0,5	29,25

Minor elements common to both solutions:

Bo_3H_3	0,003 g/l.
So_4Mn	0,003 "/".
So_4Zn	0,001 "/".
So_4Cu	0,0005"/".
So_4Fe	0,001 "/".

Results: The weight in grams of the aerial part of the plants in different stages of the growth cycle is shown in Table 9, and the sap analysis in Table 10.

TABLE 9 — *Weight in grams of the aerial part of the plant.*

	21/3	3/4	15/4	19/4
Ammonia plants	0,76	1,57	3,91	4,62
Nitrate plants	1,79	8,70	18,45	27,30

21/3 = 17 days after transplanting.
3/4 = 4th leaf.
15/4 = 7th leaf.

The evolution of the amounts of nitrates in the sap of the plants fertilized with nitrates indicates that from the 4-leaf stage on (3/4), the nitrogen organization exceeds the rate of absorption; therefore, keeping in mind that the amount of sunlight was kept at a normal level, the amount of nitrate employed in the nutritive solution of 10 meq/l was not enough.

The amount of ammonia in the nitrate plants, in all stages of growth, is practically nil, but this is not true of the first

TABLE 10 — *Level of mineral elements in the sap. Concentrations expressed in mgr/l.*

	Elements	Nitrate plants 21/3	3/4	15/4	19/4	Ammonia plants 21/3	3/4	15/4	19/4
N	NO^-_3	1160	200	traces	traces	90	230	175	375
N	NH^+_4	0	40	0	0	265	265	10	5
	P	185	305	150	140	225	740	315	310
	K	3325	2600	2300	2150	6475	3650	2800	2750
	Mg	335	410	360	420	350	340	150	225
	Ca	120	105	155	380	50	70	50	50
	Cl	1150	450	550	—	1300	400	550	1150

two stages of the ammonia plants. At this time symptoms of ammonia poisoning appear — peripheral burns around the edges of the leaves, and transparent dead sections scattered in an irregular pattern along the leaf blades.

The comparison of the phosphorus levels in the saps of the nitrate and ammonia plants shows the ratio of the nitrogen and phosphorus metabolisms, since the mineral phosphorus accumulates when the absorption of nitrogen is at a low level.

The migration of potassium towards the young leaves is more intense in nitrate plants, which undergo a rapid development, while this element accumulates in the nerves of the ammonia plants, due to the retarded development of the leaves.

RESEARCH ON LETTUCE.

Using the isotope ^{32}P, the N/P ratio in the sap has been studied.

The problem was studied in terms of the amounts of radio-active phosphorus measured in the sap, taken from the stems and nerves.

An experiment consisting of applying different doses of nitrogen and fixed amounts of phosphorus to the plants during the respective treatments was carried out; the potassium level was also kept constant in all the trials.

The measuring of radioactivity was done on a comparative basis only. The yields and measures of activity appear in Table II.

TABLE II

Yields expressed in g/pot of green material.
Average values, from four trials.
Measures of activity.

Treatments	Yields	Activity
T	5,7	—
N_1	8,1	60
N_2	8,4	42
N_3	3,8	10
N_4	0,8	6

It can be clearly seen that when the nitrogen dose is increased, the amount of ^{32}P in the sap decreases; this result confirms the findings of the experiment on corn.

Other experiments done with different kinds of soils, using sap analysis to find the fertilization index for each soil, showed that the N/P ratio was proportional to the yields. It further showed that the maximum yield was obtained when the N/P ratio was between 2 and 2.5, 80 days after transplanting. This value is very close to that found for tomato plants, at the stage when fruit begins to appear.

RESEARCH ON WHEAT.

Sap analysis was used to control the potential nutritive value of the soil, by relating the soil, plant, and sap analyses.

The study was done with non-irrigated soils, and three different profiles with the same climatological, ecological, and fertilization characteristics were chosen; therefore, any differences must be due to the differing depths of the soils.

The results from which the effect of the greater soil potential on the yields, and on the amount of nitrogen, phosphorus, and potassium in the sap can be seen, are found in Table 12.

The rest of the elements analyzed did not show a significant difference. The yields produced are in direct relation to the levels of the three elements found by sap analysis, which also reflects the nutritive potential of the soil. Said potential

TABLE 12

Navalcarnero 1967. - Sap and yield analyses.
Concentrations expressed in mg/l and yields in Kg/Ha.
Average of five determinations.
Variety: Pané 247. Samples taken from the same plot.
Stalked (Stal.)*; *Eared* (Ear.).

Samples	N (NO_3^-)		P ($PO_4H_2^-$)		K^+		Yields	
	Stal.	Ear.	Stal.	Ear.	Stal.	Ear.	Grain & Straw	Grain
Profile 3	33	7	130	335	1810	1110	9500	3450
Profile 5	23	6	90	225	1510	1030	7820	2620
Profile 4	8	4	105	245	1370	955	2420	1000

(*) Shooting time.

can be even more clearly appreciated if we take into account not only the concentrations of the elements, but the plant's total exports in terms of its weight in each stage of the growth cycle as well.

Considering that the moisture was practically the same for all the samples studied, and that the final yields in grain and straw are proportional to the weights of the plants in the different stages of the vegetative cycle, we can obtain an index of the total amounts of the elements in each plant. This is done by multiplying the concentration levels of the elements in the sap by the yield in grain and straw; the results thus obtained for wheat the stalked and eared stages are presented in Table 13.

TABLE 13

Index of total amounts of N, P and K in the sap.
Amounts proportional to mg. of the element in the sap/m².
Stalked (Stal.)*; Eared (Ear.).

Samples	N (NO_3^-)		P ($PO_4H_2^-$)		K^+	
	Stal.	Ear.	Stal.	Ear.	Stal.	Ear.
Profile 3	31,4	6,7	123,5	318,2	1720	1055
Profile 5	18,0	4,7	70,4	175,9	1180	805
Profile 4	1,9	1,0	25,4	59,3	330	230

(*) Shooting time.

The concentration levels of the elements in the plants, obtained by the classical method of analysis, are shown in Table 14. It seems that the concentrations of the elements in the sap are in closer correlation with the yields.

TABLE 14

Navalcarnero 1967. - Plant analysis. - Concentrations expressed in meq % gr. of the sample.
Variety: Pané 247. Samples taken from the same plot.
Stalked (Stal.)*; Eared (Ear.).

Samples	N		P		K	
	Stal.	Ear.	Stal.	Ear.	Stal.	Ear.
Profile 3	145,7	67,9	38,0	22,0	65,0	32,5
Profile 5	145,7	70,0	25,6	10,8	50,0	20,0
Profile 4	130,0	59,3	46,5	14,8	50,0	25,0

(*) Shooting time.

Behaviour of the same variety of wheat in two slightly different soils in a typical irrigated area.

In this experiment, two soils from an irrigated area with alluvial sediments modified by irrigation, specifically, the Tajo Lowlands, on the skirts of Añover de Tajo (Toledo), were used. The experiment consisted in studying the behaviour of the Ariana variety of wheat, common in said area, in the two soils, which differed from one another in the texture of their subsoils, and in the amounts of N, organic material, and phosphorus contained in each.

The results obtained are shown in Tables 15 and 16. The first shows the soil fertility analyses, of the different layers of each profile. The second shows the sap analyses of the plants and yields for the two soils studied.

The most interesting conclusion that can be drawn from Tables 15 and 16 is that the sap analysis gives us an exact idea of the soils nutritive potential; that is, not simply the amounts of each mineral that a laboratory analysis offers for

TABLE 15

Añover de Tajo - 1967 - Profiles studied - Soil analysis.

Type of soil: Alluvial, modified by irrigation.

Sample	Depth cm.	Texture	pH H_2O	pH ClK	% CO_3Ca	% M.Or.	% N	C/N	mgr/100 gr. Ca	Mg	P_2O_5	K_2O
1	0-20	Clay loam	7,75	6,95	1	1,66	0,092	10,4	580	71	22,5	54,5
	20-40	Clay	7,70	6,85	1	1,15	0,074	9,0	565	68	13	37,5
	40-60	Clay	7,60	6,80	6,01	0,91	0,063	8,4	590	69	8,5	27
	60-80	Clay	7,85	7,00	19,2	0,64	0,038	9,7	575	59	7,5	21
4	0-20	Clay loam	7,85	6,95	4,59	1,36	0,084	9,4	533	42	45	54
	20-40	Sandy clay loam	7,80	6,95	5,27	0,84	0,052	9,4	515	26	24	39
	40-60	Sandy clay loam	7,85	7,00	11,3	0,60	0,043	8,1	500	32	22,5	20
	60-80	Sandy clay loam	7,85	7,00	12,12	0,38	0,023	9,5	500	34	29	14

TABLE 16

Añover de Tajo - Sap analysis and yields.
Concentrations expressed in mg/l and yields in Kg/Ha.
Variety: Ariana.
Stalked (Stal.)*; Eared (Ear.).

Samples		1		4	
Yields	Grain & Straw	9300		12.300	
	Grain	3200		4.400	
Elements		Stal.	Ear.	Stal.	Ear.
Nitrogen NO_3^-		47	24	130	94
aminoacids		344	335	254	294
protein		192	162	88	124
total soluble		583	521	472	512
Phosphorus $PO_4H_2^-$		80	190	280	390
organic		458	839	683	1103
total soluble		538	1029	963	1493
Cl^-		1500	2350	2500	2750
K		2270	3230	4340	4160
Ca		158	285	205	295
Na		88	63	25	30
N mineral % N.S.T.		12	7	35	26
P mineral % P.S.T.		15	18	29	26

(*) Shooting time.

a particular soil, but rather all the factors that affect the nutritive potential of said soil, acting together.

Therefore, Table 16 shows the sum of all the factors contributing to the nutritive potential of the soils studied, such as: ability to fix the elements (these are very heavy soils), ecological conditions, texture, etc.

The nitrogen, potassium, and phosphorus minerals in the sap are in direct proportion to the yields, the highest of which was obtained for sample 4.

Nevertheless, as occurs in non-irrigated soils, the organic fractions of nitrogen accumulate in the sample with the lowest yield. The metabolic index $N_m/\%N.S.T.$ confirms this.

Also, there is a lower level of $P_m/\%P.S.T.$ in the sample with the lowest yield, a phenomenon already observed in the experiment with non-irrigated soils.

There are perceptible differences in the amount of potassium contained in the saps of the two plants, the sample with the largest yield containing more, despite the fact that the potassium content of the two soils is very similar. In this case, the plant's up-take of the K is different, due possibly to the fact that the phosphate level in sample 1 is lower. This means that there is a difference in its ability to up-take K, also related with the humus-clay complex in the soil.

Despite the fact that the level of No^{-}_3 found in the wheat is low, the No^{-}_3/Cl^{-} antagonism common in other plants is not produced.

The wheat samples studied show us that sap analysis can be used as a method to control the nutritive state of the plant. Also, said analytic method seems to closely reflect the soil potential and yields, and especially the latter.

That is, we have a very useful procedure for interpreting the problems of nutrition for the crop in question which, at least in this experiment, gives a truer indication of what the yields will be than the data obtained from a chemical analysis of the soil.

Comparison of levels of concentration of elements in non-irrigated and irrigated soils.

Table 17 shows the average concentration of elements for the twenty samples analyzed, which were taken from both irrigated and non-irrigated fields found in Añover de Tajo area.

The most significant and systematic differences are found for mineral phosphorus, potassium, and chlorides, and for mineral nitrogen in the wheat in the stalked * eared stages.

Nevertheless, these results are even clearer in the irrigated soil when we consider the total export of elements in the non-irrigated and irrigated areas.

Table 18 shows the differences between the two soils studied, with regard to the total amount of elements contained in the sap per m^2 of surface. The differences are shown for three stages in the growth cycle.

Substantial differences are observed between non-irrigated and irrigated soils, and become even more evident in the eared condition. These differences can be very useful in prescribing the dosage of fertilizers appropriate for the two cases studied.

Seasonal variations in the mineral and organic content of wheat plants (Ariana variety).

In order to know when the plant's absorption of nutritive elements is at a peak, and the levels of said elements at certain characteristic phases of the plant's growth, a study was made of the variations in the concentrations of elements in the sap. The sap was taken from the wheat plants' conducting tissues during its growth cycle.

On the one hand, concentrations of both mineral and organic elements were determined, in order to study the seasonal variations and use them as a reference, at least for the area —

(*) Shooting time.

TABLE 17

Sap analysis - Wheat - Comparison non-irrigated and irrigated (S-R).
Organ analyzed: Entire plant.
Concentration of elements in the sap expressed in mg/l.
Stages: Tillered, stalked * and eared.

Elements (mg/l)	Samples and stages					
	Tillered		Stalked		Eared	
	S	R	S	R	S	R
Nitrogen:						
NO_3^-	80	80	10	60	130	150
aminoacids	470	880	320	340	700	790
protein	320	430	190	50	370	220
total soluble	870	1380	520	450	1200	1160
Phosphorus:						
$PO_4H_2^-$	80	100	110	160	150	240
organic	350	420	240	120	300	340
total soluble	430	520	350	280	450	580
SO_4^{--}	130	120	170	190	270	290
Cl^-	900	2100	600	2850	950	2940
K	7100	8200	3450	7200	5800	8200
Na	100	110	50	110	40	130
Ca	250	200	260	200	660	260
Mg	195	230	160	150	400	250

(*) Shooting time.

TABLE 18

Exports - Wheat - Comparison non-irrigated and irrigated (S-R).
Total amount of elements in the sap from the stem per m².
Stages: Tillered, stalked and eared.
Amounts expressed in mg of elements/m².

Stages	Tillered		Stalked (*)			
Area	S	R	S	R	S	R
g.sap/m2	43	133	119	518	166	1318
Nitrogen:						
NO_3^-	3,4	10,6	1,2	31,1	21,6	197,7
aminoacids	20,2	117,0	38,1	176,1	116,2	1041,2
protein	13,8	57,2	22,6	25,9	61,4	290,0
total soluble	37,4	184,8	61,9	233,1	199,2	1528,9
Phosphorus:						
$PO_4H_2^-$	3,4	13,3	13,1	82,9	24,9	316,3
organic	15,1	55,9	28,6	62,2	49,8	448,1
total soluble	18,5	69,2	41,7	145,1	74,7	764,4
SO_4^{--}	5,6	16,0	20,2	98,4	44,8	382,2
Cl^-	38,7	279,3	71,4	1476,3	157,7	3874,9
K	305,3	1090,6	410,6	3729,6	962,8	10807,6
Na	4,3	14,6	6,0	57,0	6,6	171,3
Ca	10,7	26,6	30,9	103,6	109,6	342,6
Mg	8,4	30,6	19,0	77,7	66,4	329,5

(*) Shooting time.

the Lowlands outside the Añover de Tajo (Toledo) region — the type of soil — "alluvial, modified by irrigation" — studied. On the other hand, the exports per square meter of surface of all the elements contained in the sap of the irrigated plants was found. This was done to be able to determine when the plants' absorption was at a maximum level, and thus select the ideal stage in which the soil should be applied with fertilizer. At first, samples of wheat in the tillered, stalked, eared and "milk grain" stages were taken.

In order to determine the total amount of elements contained in the sap per square meter of cultivated area, the amount of sap contained in 20 plants was found. The number of plants per square meter being known, the amount of sap corresponding to said area could be found. By multiplying the concentration level of each element analyzed by the total amount of sap, we obtained the amount of elements contained in the sap, which we will conventionally call « exports ».

Five samples were studied from the area chosen; the analysis of the soils involved is shown in Table 19.

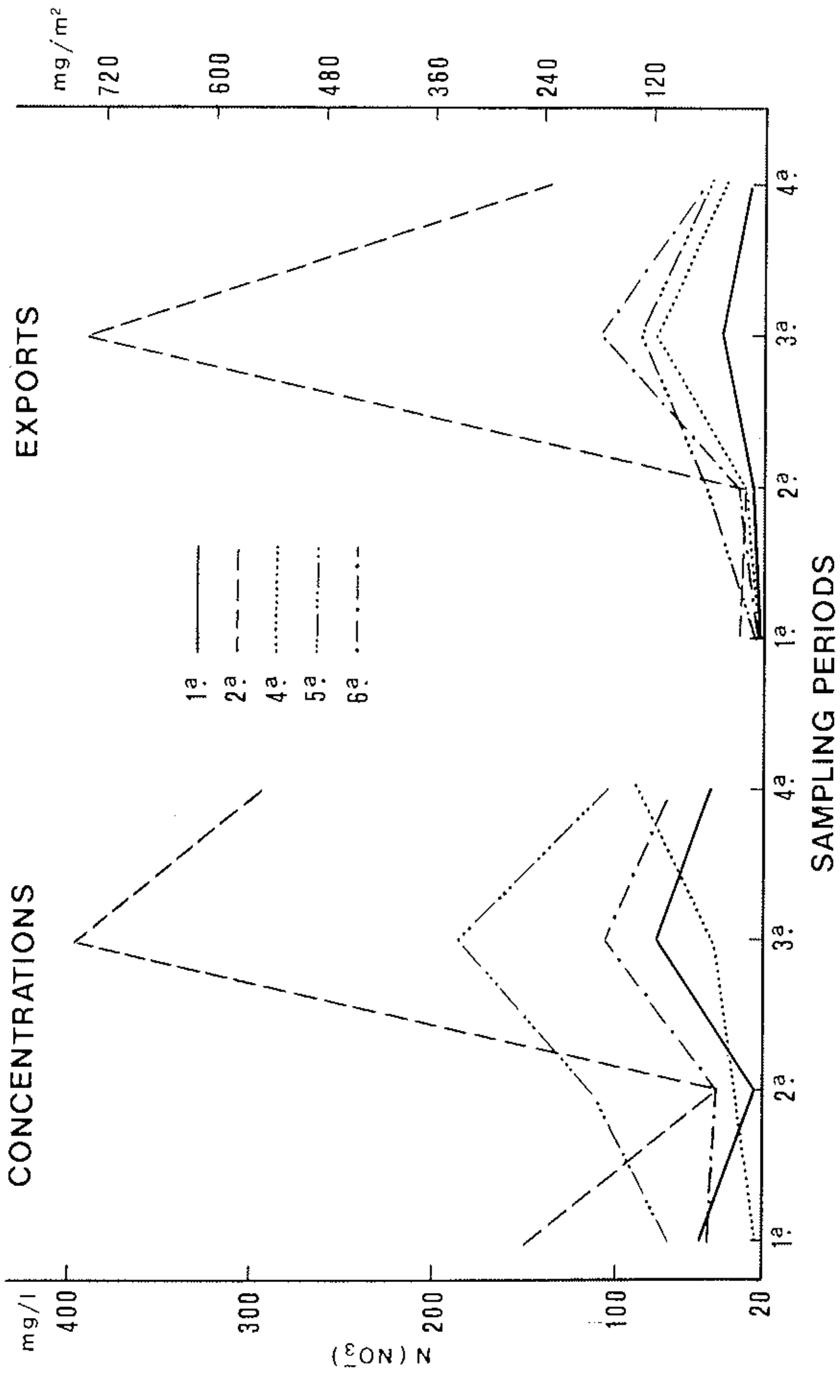
The fundamental differences between the five soils studied consist in the different N, P and K contents, and in the texture of the 2nd sample in comparison with the rest. We will see below how this textural difference has the greatest effect on the results of the sap analyses, considering that the five soils were fertilized in the same way, and irrigated properly.

Also, in Table 19 the yields indicated can be compared with the differences in the N, P and K levels, directly and clearly.

Graph. 2 till 6 show the seasonal differences found for the four phases studied, with regard to both the concentration of the elements in the sap (taken from the conducting tissues of the entire plant), and the total amount of sap contained in the plants, per square meter. The four phases indicated in said figures are: 1st, 2nd, 3rd, and 4th, and correspond to the tillered, stalked, eared and « milk grain », respectively.

TABLE 19 — *Analysis of soils and yields (g. of grain/m²). - Añover de Tajo - Irrigated* - 1970.

Samples	Texture	pH		%								grain
		H_2O	ClK	CO_3Co	Org. Mat.	N	C/N	Ca	Mg	P_2O_5	K_2O	gr/m²
1°	Clay loam	7,30	6,70	10,5	1,14	0,086	7,6	580	56	20,7	31	240
2°	Sandy silt	7,60	7,00	10,9	1,27	0,085	8,7	450	26	19,2	38	330
4°	Clay loam	7,60	7,00	15,9	1,67	0,120	8,0	650	60	40	72	540
5°	Clay loam	7,70	7,10	14,1	1,77	0,118	8,7	660	66	32	67	305
6°	Clay loam	7,60	7,00	4,6	1,36	0,098	8,0	550	60	52	90	460


CONCENTRATIONS
EXPORTS
mg/m²
720
600
480
360
240
120
mg/l
400
300
200
100
20
N (NO₃⁻)
SAMPLING PERIODS
1ª.
2ª.
3ª.
4ª.
1ª.
2ª.
4ª.
5ª.
6ª.

GRAPH. 2

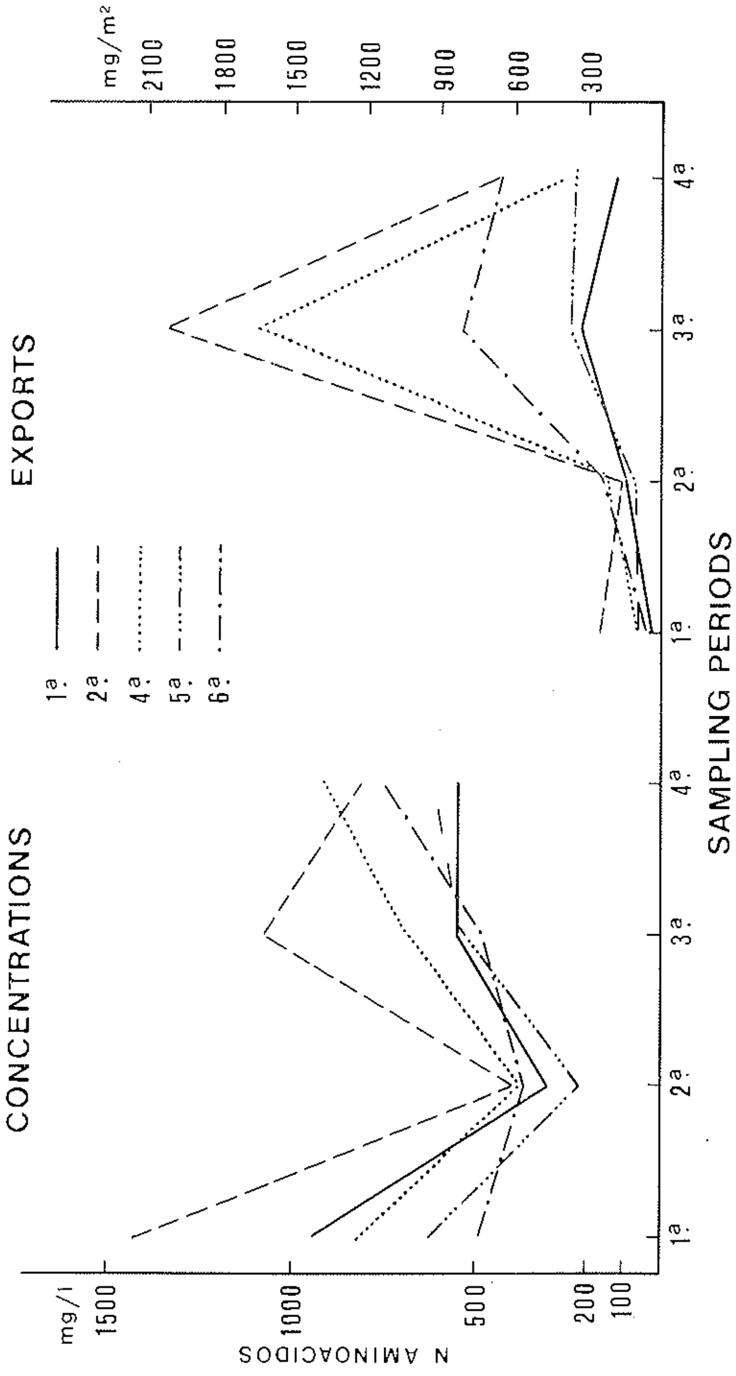
The $N(No^{-}_3)$ (Graph. 2) shows a considerable increase between the stalked and eared stages, and a decrease (with one exception), as the plant reaches maturity. Both concentrations and exports follow similar tendencies, although the exports seem to be more systematic, since there are no exceptions in any one of the five samples studied. From these results it can be seen that the wheat plant shows the greatest need for nitrogen between the stalked and eared stages. Sample 2 stands out, because it had a better appearance than the rest of the samples during the entire growth cycle. Nevertheless, this difference was not so evident in the yields. This fact emphasizes the need for more research on the relation between the concentration of elements in the sap and the quantity and quality of the fruit obtained.

Aminoacids and protein nitrogen (graph. 3 and 4) show, in general, variations similar to those obtained for $N(No^{-}_3)$, with regard to the total export of elements per square meter. Nevertheless, the concentration levels of these elements behave opposite those of $N(No^{-}_3)$ when the plant nears maturity, that is, during the formation of the grain.

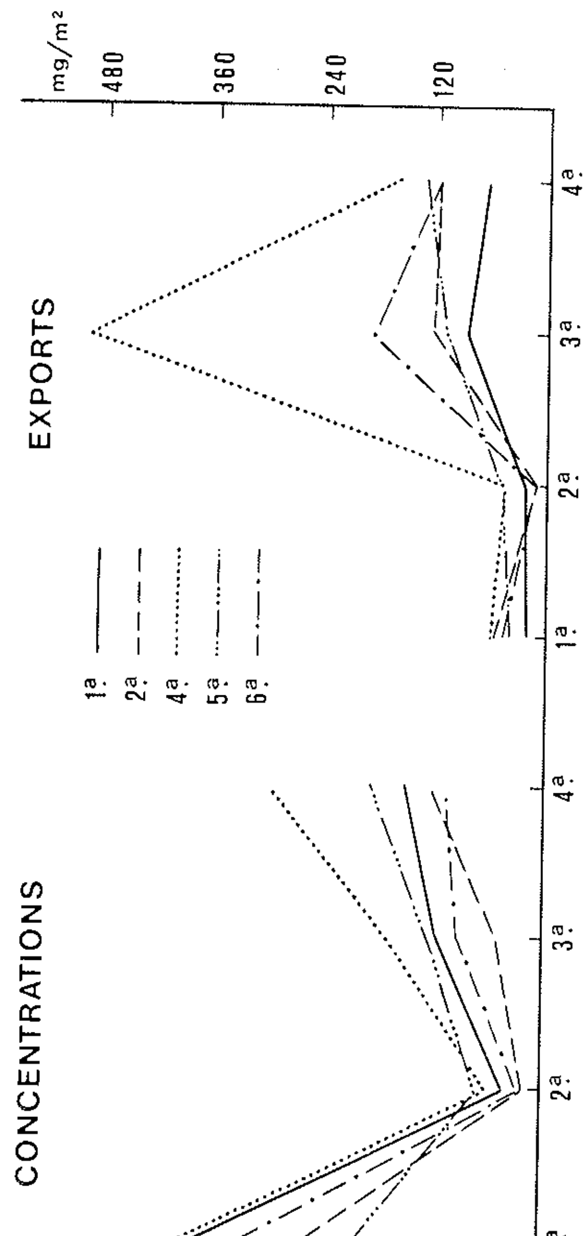
As far as phosphorus exports are concerned, conclusions similar to those found for nitrogen are obtained. The concentration levels of mineral and organic phosphorus, especially the latter (Graph. 5 and 6), show us that the plant absorbs little phosphorus between the tillered and stalked phases.

The anions Cl^- and $So^{=}_4$ accumulate during the plant's development, but the constant rate of increase in the concentration of Cl^- is slightly reduced between the stalked and eared phases, and even decreases in some cases. In general, the concentration levels of Cl^- and No^{-}_3 vary in opposite directions in the four phases studied, a fact that has already been observed in experiments on other plants.

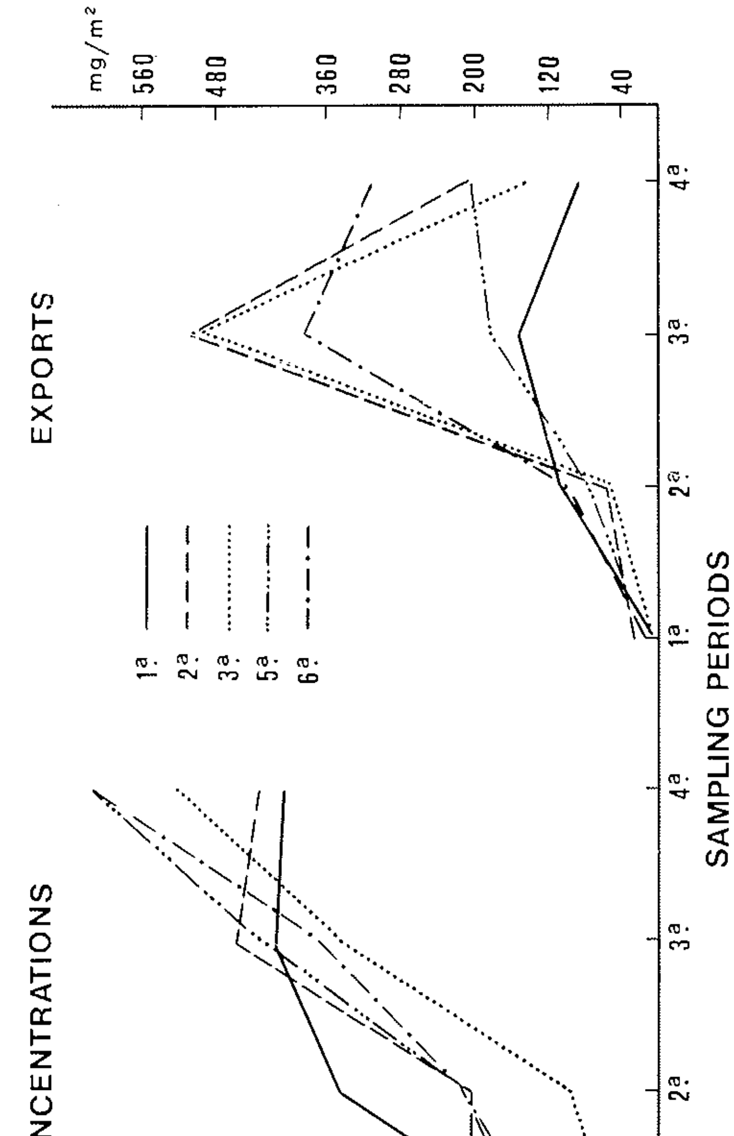
The export shows tendencies similar to those of the rest of the anions, although between the tillered and stalked phases there is a definite increase, greater than that experienced by nitrogen and phosphorus.


CONCENTRATIONS
EXPORTS
mg/l
1500
1000
500
200
100
N AMINOACIDOS
mg/m²
2100
1800
1500
1200
900
600
300
1ª.
2ª.
4ª.
5ª.
6ª.
1ª.
2ª.
3ª.
4ª.
SAMPLING PERIODS

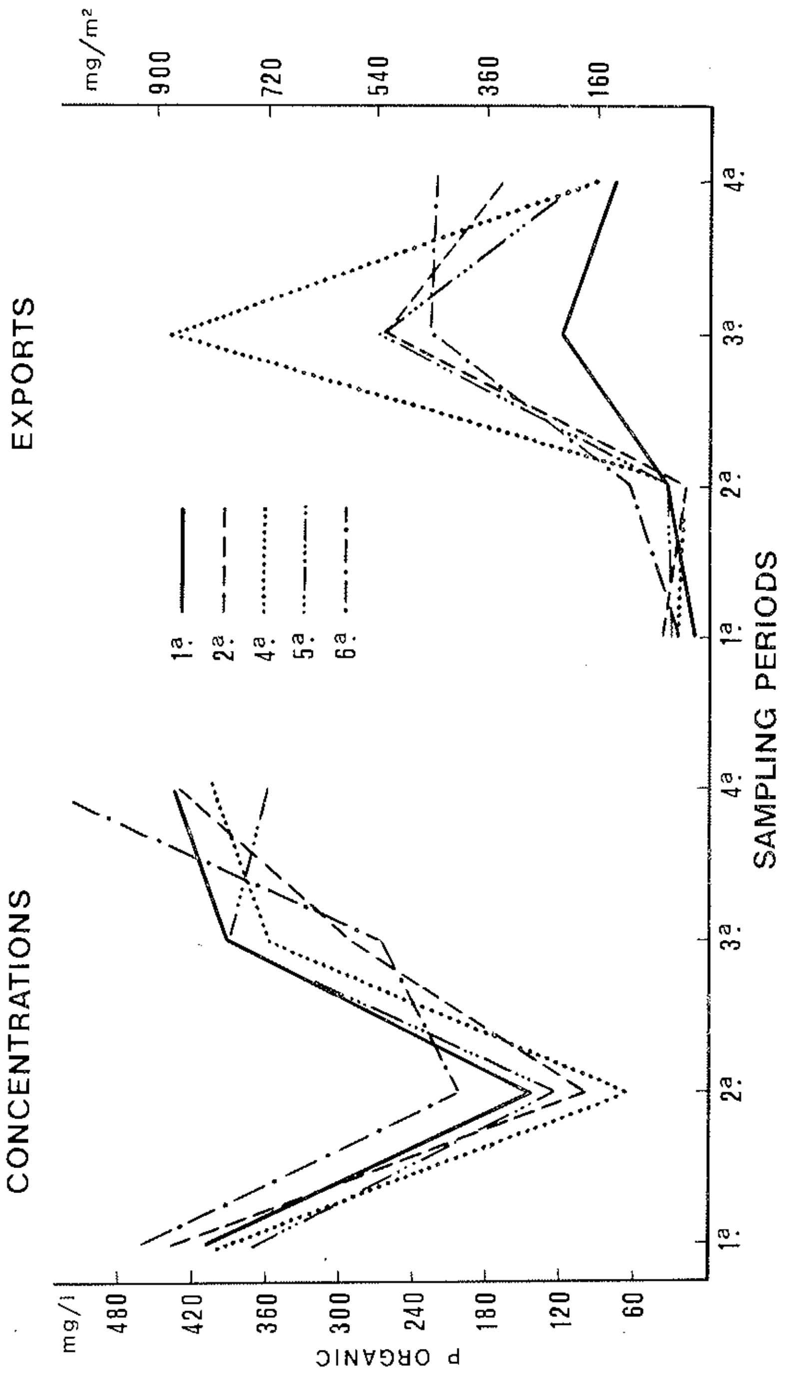
GRAPH. 3


CONCENTRATIONS
EXPORTS
SAMPLING PERIODS
N PROTEINS
mg/l
600
500
400
300
200
100
mg/m²
480
360
240
120
1ª
2ª
3ª
4ª
1ª
2ª
4ª
5ª
6ª

GRAPH. 4


CONCENTRATIONS
EXPORTS
mg/l
300
200
100
60
40
P(PO4 H2-)
mg/m²
560
480
360
280
200
120
40
1a.
2a.
3a.
5a.
6a.
1a.
2a.
3a.
4a.
SAMPLING PERIODS

GRAPH. 5


CONCENTRATIONS
EXPORTS
mg/l
480
420
360
300
240
180
120
60
P ORGANIC
mg/m²
900
720
540
360
160
1ª.
2ª.
4ª.
5ª.
6ª.
1ª.
2ª.
3ª.
4ª.
SAMPLING PERIODS

GRAPH. 6

The potassium and calcium concentrations do not show any clear variations between the first and third phases, but there is an almost general increase between the eared and "milk grain" phases (phase 4).

Sap analysis as an indicator of the boron mechanism in plant nutrition.

The utility of sap analysis as an indicator of trace element (specifically, boron) mechanism has also been tested.

Macroelements, microelements, and some organic fractions were analyzed with this end in view.

Fig. 2 shows the typical symptoms of toxicity and boron deficiency in tomato plants (the crop used as indicator).

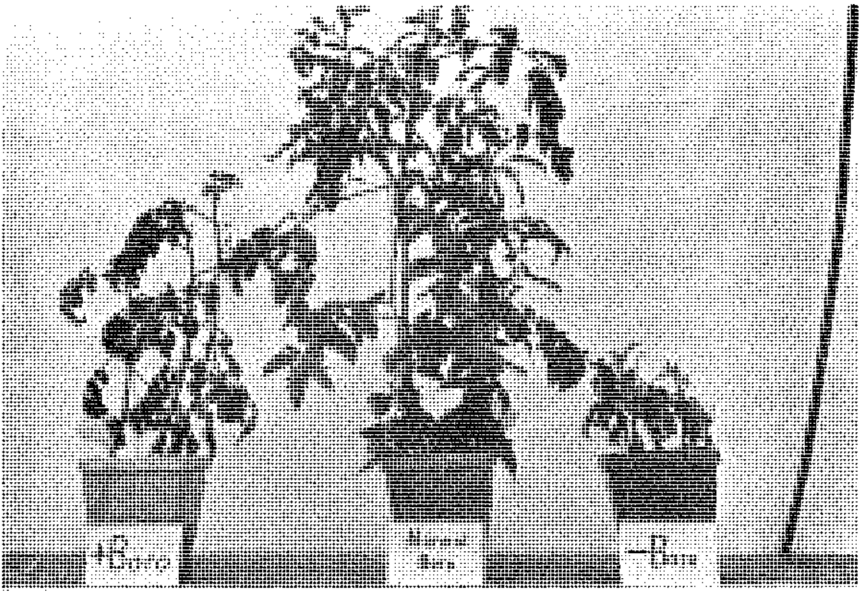


Fig. 2

Table 20 shows the analysis values for sap and leaf boron, under conditions of deficiency and toxicity, and the nutritional solutions used.

TABLE 20

Boron content in nutritional solution, sap, and leaf.
Values expressed in p.p.m.
Period: Flowering.

Treatments	Nutritional solution	Sap	Dry leaf (*)
Deficient	< 0,03	< 0,5	< 50
Normal	0,03 to 2	0,5 to 1,0	50 to 650
Toxic	> 2	> 1,0	> 650

(*) Values increase progressively during the growth cycle.

Table 21 shows the development indices during flowering, and the yields, for comparison. The development indices, which are very useful for the interpretation of the meaning of the analysis values, are for plant weight, leaf weight, and number of flowers.

In the case of the macroelements contained in the sap from plants receiving both deficient and toxic boron treatments, the values are higher than for plants treated normally with the latter element.

The explanation of this fact can be deduced from the development indices which suggest the presence of concentration effects, given the sharp differences in plant and leaf weights, which came out to be statistically significant, even at the 1% level.

This may serve to explain the confusion in the data to be found in the bibliography concerning the effect of boron on plant nutrition.

TABLE 21

Development indices (flowering) and yields.
Weight of fresh matter in grams.

Treatments p.p.m. of B in nutritional solution	Weight of 5 plants	Weight of leaves from 5 plants	Number of flowers from 5 plants	Yield (weight of fruit from 5 plants)
Deficient (0,005)	23	21	0	0
Normal (0.5)	474	275	40	927
Toxic (10)	160	62	10	15

The real variations in macroelements resulting from boron treatment should therefore be more clearly observable when deficiency and toxicity are not so marked, so that concentration effects will be negligible. A second experiment was therefore conducted from this viewpoint, and these assumptions were confirmed.

The trace elements Fe, B and Mn were studied, and analyses were made of sap and leaf content. In both sap and leaves, the boron level matched the type of treatment, and reference levels could be established.

Trace elements accumulate in the leaves, which yield higher values than sap. It is nevertheless worthwhile to compare the boron and iron contents in the two plant substances for a clearer interpretation of the results.

Table 22 contains a specific case of B, Fe, and Mn contents in sap and leaves with deficient, normal, and toxic boron treatments.

Table 22 shows that, when the B level rises, the Fe level falls in leaves and rises in sap. There may be a conflictive

TABLE 22

Trace elements in sap and dry leaves.
Concentrations expressed in p.p.m.

Elements	Treatments					
	Deficient		Normal		Toxic	
	Sap	Leaf	Sap	Leaf	Sap	Leaf
B	0.16	9.0	0.93	137.2	1.20	907.2
Fe	18.4	224.0	20.0	214.0	48.8	138.0
Mn	2.6	114.0	3.6	208.0	3.2	176.0

effect operating between the two elements so that Fe mobility is reduced as B content increases, causing it to accumulate in the sap while its leaf concentration falls.

Sap Glucide Contents.

Sap glucide content was studied at two periods of the growth cycle, under deficient, normal, and toxic treatment conditions.

The results are summarized by the chromatograms of figures and which show the qualitative and semi-quantitative differences between a deficient treatment (0.01 p.p.m of B in nutritional solution), a normal treatment (0.5 p.p.m.), and toxic treatment (7 p.p.m.).

The chromatograms were taken at the start of fructification, and show the presence of glucose and fructose.

The concentration of both monosaccharides is higher with the normal treatment than with the deficient and toxic ones.

The reason for this may lie, in the case of toxicity, in boron's property of acting as a glucide carrier, with the result that an excess of boron will increase glucide transport to above the normal level, causing a drop in the sap glucide content.

In the case of deficient boron treatment, it must be remembered that this trace element has an effect on the auxin action in polysaccharide hydrolysis Thus, since the boron concentration is low, this hydrolysis takes place to a lesser extent, so that the production of reducing monosacharides (i.e., glucose, and — fructose in the case of tomato plants) in sap is reduced.

It must be remarked that treatments which were only slightly deficient or toxic resulted in no marked symptoms of concentration effect in the development indices calculated from this experiment.

The quantitative data in Table 23 show the sap glucosa concentrations for the three treatments, expressed in mgs/liter.

TABLE 23

Reducing glucides: mgs of glucose/l.
Start of flowering.

Treatments	Glucose (*)
Deficient	1.440
Normal	2.320
Toxic	960

(*) Mean values of four repetitions.

The data in Table 23 provide quautitative confirmation of the results contained in the chromatograms of figures 3 and 4.

Qualitative and quantitative composition of the free amino acids in tomato plant sap.

Tomato plants were grown in the green house and fertilized with Boron as follows, in order to study the effect of this element on the biochemical composition of tomato plants:

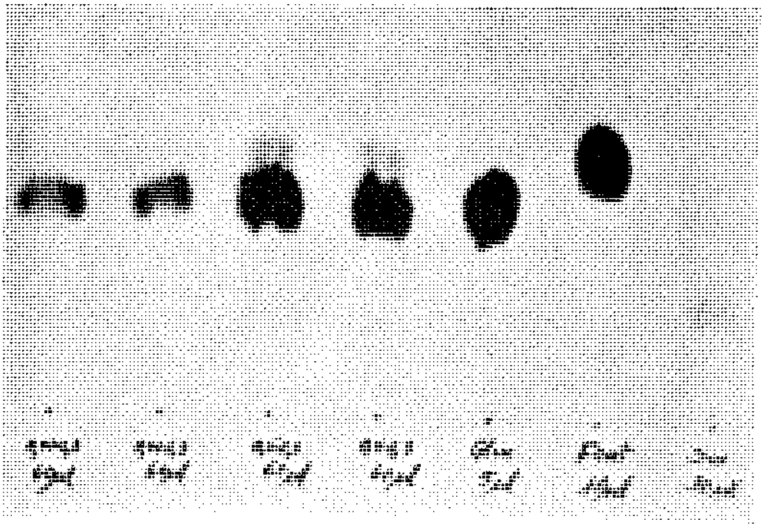


FIG. 3

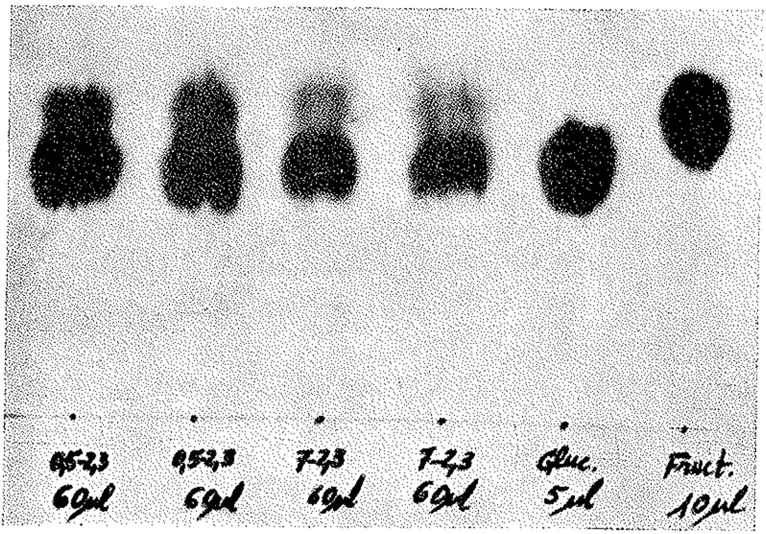


FIG. 4

First experiment: Done to extract sap at the beginning of floral budding (F.B.)

1 -	Plants fertilized	with		0.005	p.p.	million	(Deficient levels)
2 -	»	»	»	0.01	»	»	
3 -	»	»	»	0.5	»	»	(Normal level)
4 -	»	»	»	7.0	»	»	(Toxic levels)
5 -	»	»	»	10.0	»	»	

Second experiment: Done to extract sap at the beginning of flowering (Fl.)

6 -	Plant fertilized	with		0.01	p.p.	million	(Deficient level)
7 -	»	»	»	0.5	»	»	(Normal level)
8 -	»	»	»	7.0	»	»	(Toxic level)

Third experiment in which the sap was separated at the beginning of fructification (Fr.)

9 -	Plant fertilized	with		0.01	p.p.	million	(Deficient level)
10 -	»	»	»	0.5	»	»	(Normal level)
11 -	»	»	»	7.0	»	»	(Toxic level)

Obtaining the sample: As the plants are cut, the metabolism is interrupted, and they are set into recipients which contain a refrigerated mixture of carbon dioxide snow/ethylene ether, which reaches temperatures of from $-30°C$, to $-70°C$.

Techniques.

The proteins having been denaturalized in boiling ethanol, in order to prevent their degradation and possible interference with the free amino acids, the filtered problem liquid is passed through a column of Amberlite IR-120 resins, from which the amino acids are later displaced with 2.8% ammonia, and are vacuum concentrated into small volume. From here a sample is taken to do an electrophoretic development in a formic acid buffer using a current of 10 volt/cm. at 8 m. Amp. followed by another ascending chromatographic one with n-butanol/acetic/water — (4:1:1), and the spots were made visible with S-Collidine Ninhydrin.

The quantitative evaluation was done with the aid of a « Chromoscan » densitometer, interpolating the densitometric readings for the problems of the standard curve of the corresponding amino acid. Both the values for the standard curve and those for the problems represent the average value obtained for six trials, which values follow the Gaus curve for each amino acid.

Results.

The densitometric readings for the deficient and toxic levels for the experiments at the beginning of « Flowering and Fructification » (only the normal values - 0.5 p.p. million) do not appear in the results, because this part of the experiment is still being carried out, and the following is considered a preview of the final results of the experiments.

Once it is in the Laboratory, the sap is obtained from stems and petioles with a minipress. From each sample 2 to 4 mls. were used for proteinic denaturalization by heat.

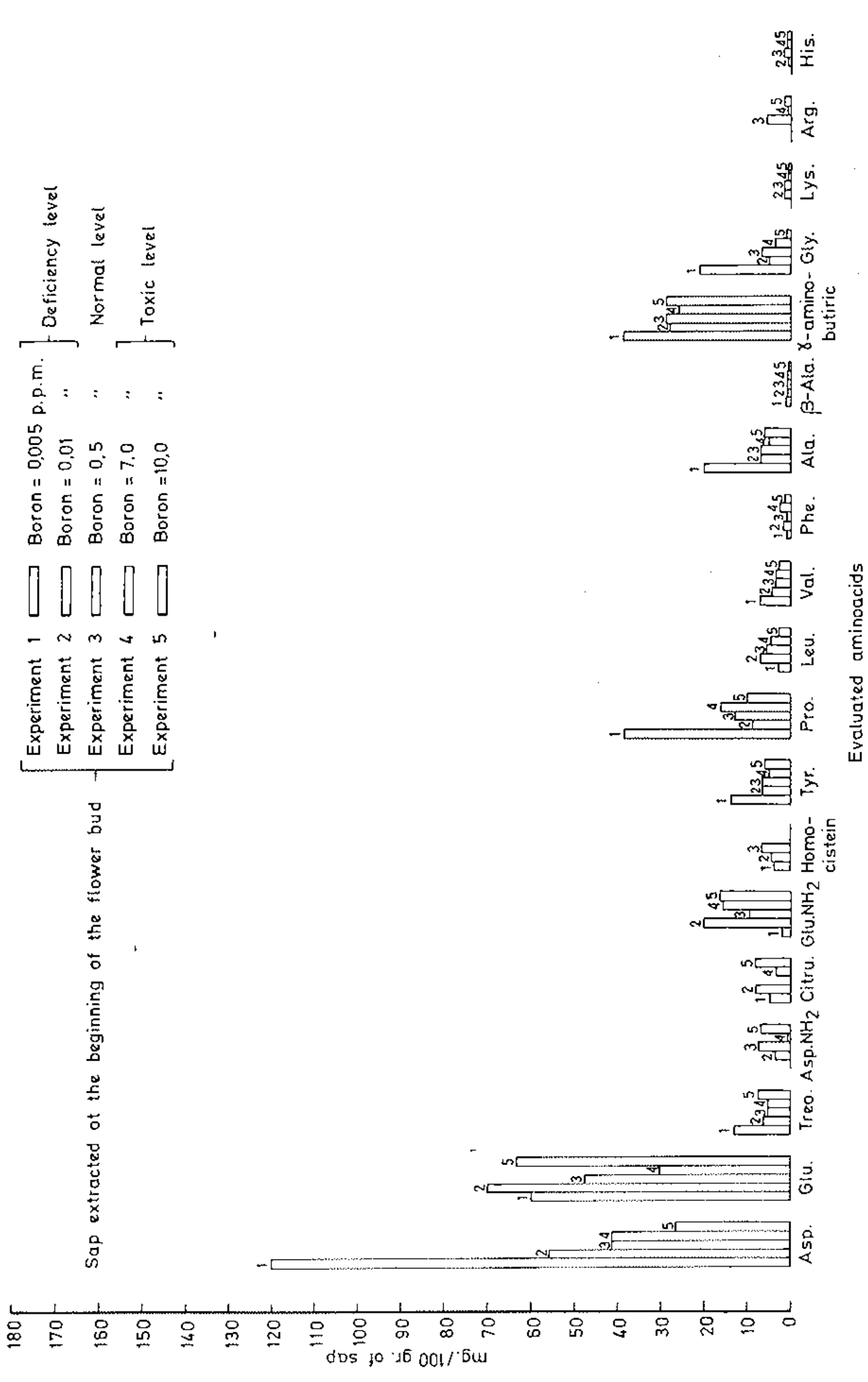
The levels of each amino acid are expressed in mg/100 g. of sap of every trial in the three experiments. A study of these has provided the following observations:

a) (Histogram I)

Comparing the five trials of the first experiment (at the beginning of budding), we note that:

— When the dose of B is 0.005 p.p.m. that is, deficient, there is a considerable increase in Asp, Pro, Ala, and a lesser

HISTOGRAM I


Sap extracted at the beginning of the flower bud
Experiment 1 Boron = 0,005 p.p.m.
Experiment 2 Boron = 0,01 "
Experiment 3 Boron = 0,5 "
Experiment 4 Boron = 7,0 "
Experiment 5 Boron = 10,0 "
Deficiency level
Normal level
Toxic level
mg./100 gr. of sap
Evaluated aminoacids
Asp.
Glu.
Treo.
Asp.NH2
Citru.
Glu.NH2
Homo-cistein
Tyr.
Pro.
Leu.
Val.
Phe.
Ala.
β-Ala.
γ-amino-butiric
Gly.
Lys.
Arg.
His.

one in Glu, Treo, Tyr, aminobutyric Val and Gly compared to those obtained with a normal dose of B (0.5 p.p.m.), the values of $AspNH_2$, Lys and Arg. were practically nil, and that for His was completely nil.

— When the dose of B is 0.01 p.p.m. (deficient), there are increases in Asp, Gly, and $GluNH_2$ over the normal values, and all points ordinarily come nearer to normal.

— When fertilization with B is normal (0.5 p.p.m.), the absence of Citruline, the relative increase of Asparagin compared both to the deficient and toxic doses, are noted. In general, the levels of amino acids in the sap occupy a discrete average position among all the problems, where fertilized with normal levels of Boron.

— Also, with regard to fertilization at toxic levels, wholly disproportionate increases of some amino acids (Glutamine and Proline at the 7 p.p.m. level and Glutamic at the 10 p.p.m. level) are found.

In our attempt to find an explanation for the absence of Citruline the treatments with a normal dose of B, and its appearance on the other hand in the other cases, we propose the following hypothesis:

If in plants as in animals, deamination occurs when ammonia is released, a poisoning process could be set off in the plant. In order to prevent this, the free ammonia is transformed into Carbamyl phosphate, with ATP energy. This carbamyl phosphate can react with the Ornithine coming from the decomposition of Arginine in Urea and Ornithine, thus producing Citruline.

This would explain the absence of Arginine in numbers 1, 2, and 4 and it is near absence in 5, in all of which Arginine may have been decomposed into Urea and Ornithine. On the other hand, in trial 3 said level of Arginine is higher since it has not been decomposed, and the resulting Ornithine blocks the excess freed-ammonia.

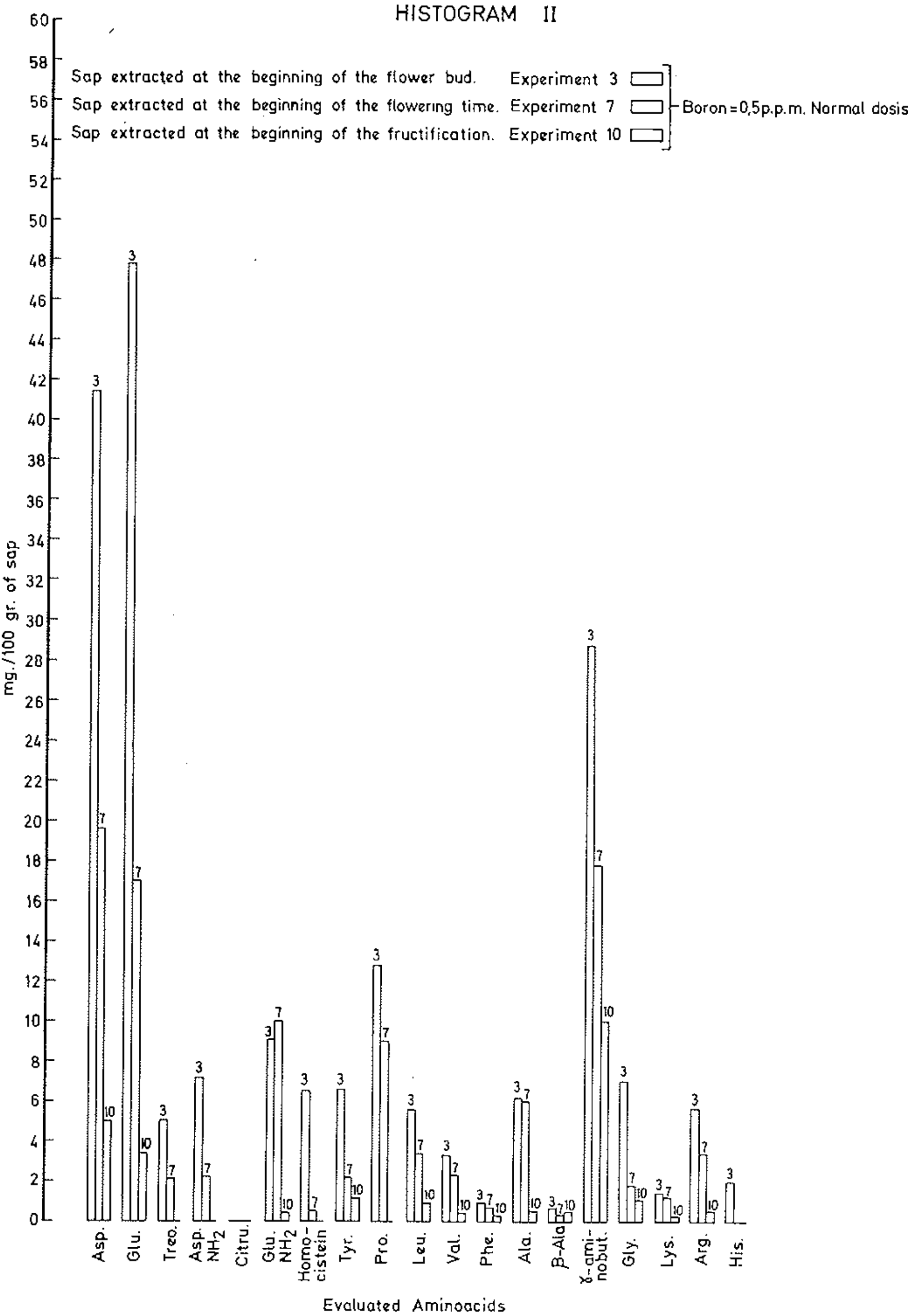
b) (Histogram II)

If the curve for trials 3, 7, and 10, treated with a normal dose of B in the three stages of the vegetative cycle (beginning of budding, flowering and fructification) are compared, a clear decrease in the free amino acids throughout the vegetative cycle can be appreciated (see enclosed table): This is a result of the progressive increase in protein synthesis, specially in the last stage, fructification, when they have practically disappeared, with the exception of — aminobutyric: The literature of this subject does not mention the fact that it becomes integrated with the polypeptides, and that although a progressive decrease can be observed, this can be interpreted as due to the decrease of its progenitor, Glutamic, as it is incorporated into the protein.

	Total amino acids in mg/100 g. of sap
Trial n° 3 (BF)	197,70
Trial n° 7 (FI)	99,21
Trial n° 10	24,24

— We must point out an anomaly in the comparison of curves 3, 7, and 10, since while the levels of the free amino acids in the flowering stage (FI) occupy an intermediate position between the B.F. amd Fr. stages, the Glutamic level on the other hand increases very slightly in the FI. stage. This shows that it is not integrated into the protein synthesis until the Fr. stage. This seems to indicate that Glutamine must be among the final links in the peptide chain.

We can say much the same thing about Proline, Alanine and Arginine, because they are polymerized almost entirely in the final stage. This behaviour of Arginine that is, integration into


HISTOGRAM II
Sap extracted at the beginning of the flower bud. Experiment 3
Sap extracted at the beginning of the flowering time. Experiment 7
Sap extracted at the beginning of the fructification. Experiment 10
Boron = 0,5 p.p.m. Normal dosis
mg./100 gr. of sap
Asp.
Glu.
Treo.
Asp. NH2
Citru.
Glu. NH2
Homo-cistein
Tyr.
Pro.
Leu.
Val.
Phe.
Ala.
β-Ala
γ-ami-nobut.
Gly.
Lys.
Arg.
His.
Evaluated Aminoacids

the protein slowly at first and more rapidly towards the end of the cycle, was already known. However, there does seem to be a contradiction in these results with regard to Alanine; its peptide integration here is quite slow at first. while it is known to be perhaps the fasted integrating amino acid.

— Alanine is the only amino acid which increased in the final vegetative stage (Fr), due to the fact that it is usually not found integrated in a protein chain, but rather in a free state.

— Finally the absence of Citruline in curves 3, 7, and 10, all fertilized with normal doses (0.5 p.p.m. of 8) is confirmed.

CONCLUSIONS.

As for amino acids, a definite drop in the content thereof can be observed for all types under conditions of a normal boron treatment with the passage from the stage of the first budding to flowering to fructification. This is quite the normal process.

In samples taken at the start of budding from plants with deficient, normal, and toxic boron treatment. sap content is progressively less in the given order for asparagin, prothrombin, glycine, valine and alanine, but citruline tends to increase and homocysteine is clearly on the rise.

The other amino acid contents, vary, but no definite tendency is discernible.

ACKNOWLEDGMENT.

I want to thank all the members of the Department, and particularly Dr. Cadahia for his cooperation in conducting a major part of the experiments reported here.

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DISCUSSION

Chairman: TH. WALSH

PRIMAVESI

After you gave your magnificent Course on Plant Nutrition at the Federal University of Santa Maria, in 1969, we worked with success with your method, because our experience taught us that chemical soil analysis only, as an indication for correct fertilization, is not enough. In most cases, the results of soil tests alone are not enough. This is the experience not only from the University Federal of Santa Maria, but from many institutions. Because of this, we are very happy, to work with your sap analysis technique, which gives a real indication of fertilizer needs at any given time.

We think your sap method is of very great importance, not only in practical agriculture, but also for the programing of increased yields, especially in tropical and sub-tropical areas.

PESEK

I did not see in your paper whether you established times of sampling during the day especially with respect to nitrate reduction.

HERNANDO

I think it was not possible to explain the whole paper. I took out the details for a matter of time. We found that for tomatoes, for example, it is convenient to get the samples in the South-East of Spain between eight and eleven o'clock in the morning. Such samples can also be taken between four and six o'clock in the afternoon. But in the middle of the day, for example, the values are very low. Therefore, of every type of plant we choose the right moment for taking samples. As you say, the daytime is very important also with relation to the land, the date of the last irrigation. Normally we suggest to the technicians to take samples fifteen days after the irrigation. In areas like the South-East, where irrigation is applied every ten or fifteen days in summer time, it is necessary to take samples a week after the irrigation. Also we must take details as to whether there is sunshine or whether there are clouds. When there are clouds we can take the samples, but we should take details about that, because normally the concentration of the mineral elements is higher, and the concentration of organic fractions lower. Therefore, it is very important instead of using only the analysis of inorganics on one side and organics on the other, to show, as it appears in the paper, a relationship between the inorganic and the organic content of one element, or the relationship between the total content (the organic plus inorganic), and the inorganic one at the moment of the analysis. The relationship is essential to know if everything is going well in the plant or not.

FITTS

I was wondering, in your analysis of sap if it is on fresh plant material?

HERNANDO

Yes.

FITTS

And then on your plant analysis, that is leaf analysis, this would be dried leaf, do you make a total analysis on it?

HERNANDO

No. We present here a test with the dried analysis on leaf but normally at the beginning we made a leaf analysis with the material extracted with the Morgan method. Or we also make the total analysis which is the treatment with acids of the material to dissolve the whole of the nitrogen, phosphate, potash, etc., normally used in other laboratories.

FITTS

In the collection of your sample you take only the leaves or plants and make one composite, and then do all analysis on the composite sample; is that the way you do it?

HERNANDO

You say, how we select the samples?

Well, the number of leaves we use, for example with tomatoes, is between fifty and one hundred. The tomato leaf is very light, and the plant is long. In other plants it is necessary to take the whole plant, as in wheat, and separate the stems for the analysis. It depends on the plant. But there are two important points: First, the time of taking the sample must be a physiological one, for example the tillering time, flowering etc. For tomatoes you use a sample at flowering time, beginning of fructification, middle of fructification and at the end of fructification. The results in relation to the time you take the sample will be different. The other important point is that of the leaves to take. We found with tomatoes that the best leave to take is the second one next to the fruit. Not the first one, but the second; normally the second leaves are completely developed In this type of plant which becomes very high, nearly more than two meters, it is very difficult to take the sample of leaf there, when the fruit is high. But it is not the same when you take samples at 40 cm above the soil than to take a sample at one meter above the soil. In this case, when the plant is high, it is necessary to show in the details of the sample that the leaf is taken from the fruit at one meter above the soil, or at one meter and a half above the soil. But the whole of the sample must be taken under the same conditions, if not, the level of the leaf elements contain something more or less than the proper sample, and we cannot properly evaluate the different elements or nutrients.

WELTE

Only one question: If you take samples from tomato plants in a very late stage, that means during the fructification period, what will be the chance to correct the nutrient status where the plant already has developed fruits? Do you then apply fertilizers to the soil, or to the leaves directly (foliar-spraying), and what is your experience?

HERNANDO

Well, this is a most important point because it was most surprising to us that when the first time we applied 50 kgs of superphosphate to the surface of the soil, we got the response of the plant in a very short time, four of five days later. The idea we had before was to recommend to the farmer not to apply phosphates late in the growing season, but always before the transplanting, because later it is of no use to the plant. But sometimes the farmer replied: We found that when we apply phosphate we get a better crop, especially at fructification. We replied, however, that the knowledge at this moment is that the application of superphosphate is of no use because it does not move down into the soil. Later, when we found the real effect, we stated that the roots are established close to the surface in the row. The plant is laid out in this row here, as here, too. Here is another plant. Well, here we apply the water, we leave that part free in order to get aeration and to go through to pick the fruit. The roots normally are like that, but this plant, growing under these conditions, may develop root in this area. In this case the nutrients don't need to move if the root is coming to the surface. Therefore, the scientific idea is true, i.e. the phosphates do not move down, but it is also true that the root goes to find the phosphate, and this comes already near to the idea of the farmer. The farmer has always his reason, I believe. We applied 50 kgs of superphosphate and five days later we made the analysis of petioles and we got a clear answer in the results. We take samples between September and the end of January. Sometimes we get frost before. We finish with frost, anyway, but since the end of the growing season for picking fruit is at the end of January, we take a sample at the beginning of January at the latest to change the conditions of plant growing. The work is difficult when the plant grows properly and the growing conditions are good. There we do not make the analysis after the middle of December. This is normal for tomatoes. For wheat, it is very different.

VAN DER PAAUW

You have taken the petiole for your analysis instead of the total leaf, the reasoning for this was that the petiole is a couducting tissue. In my opinion only a small part of the petiole is conducting tissue; the other part is parenchym. My question is whether there is much difference between the petiole and the blade of the leaf, could you not use the total leaf for the same work? Is there a real reason to prefer the petiole? And then another question: when there is no petiole, as is the case with maize or wheat, what are you using then?

HERNANDO

On tomatoes we made an evaluation of the whole leaf and we did not get a good relationship, because we made many trials during three or four years before we arrived at this method. At the beginning we did not get good results with the sap analysis too for the reason pointed out by Prof. PESEK, i.e. the problem of the sun conditions. We took samples at any time of the day and we got wrong answers. We found later that the reason for this difference was the hour of the sampling. In regard to your question, at the beginning we took the blade of the leaf though without getting good results; therefore we took the petiole later, thinking that it would be easier to find in the petiole the material going on to the photosynthesis, that is before it proceeds to the photosynthesis. As pointed out in my paper, we believe also that some materials in the petioles are of no use for the photosynthesis, and they come down to another area of the plant, f.i. to the root, but this is a theoretical point. At the real end of the question we found that in taking it as a whole it is a good method to know which is the level of the fertilizer that the root finds in the soil: this is the most important point, more important than the theoretical point. In a theoretical point you may get something like the truth, but later in the practice it is of no use. Here, however, it is the contrary. Theoretically it may be of no use, but in practice it turns out to be useful. You asked me another question?

VAN DER PAAUW

What part of the plant are you using with maize and wheat?

HERNANDO

With maize we take the interblades' area of the leave but especially when the plant is more than 40 cms high, when it is smaller we take the whole of the plant. We take the blade out and we use the rest to take the sap. And with wheat we take the whole of the plant. Also when the plant is in the stage of the tillering. In this case we have no real reason to do so. In others we take possibly petioles for similitude with the tomato plants, since it was the first type of plant we sampled.

PESEK

The fundamental reason for doing analyses is eventually to help farmers to produce their crop. In the case of tomatoes, which are high in value and with which you have demonstrated that corrective measures can be taken within a few days, what kind of a system of analysis and reporting back for corrective measures is available and how does it work?

HERNANDO

I do not think I got your question because I hear at the same time the translator, but I think you asked abont the effect on the price of the yield of the fertilization, is that right?

PESEK

No, my question was: is your system available for application for production of tomatoes which have a high value? You have demonstrated that you can correct nitrate or phosphorus shortages by applications in irrigation water; how does the system operate in reality as an advisory function to farmers to correct their production practice while the crop is still growing? Because this is a very valuable crop, it is probably valuable to correct the deficiency; how much time is involved in getting the answers back to the farmer?

HERNANDO

Well, winter tomatoes is a very valuable crop that pays to make trips up to 400 kms from Madrid to take the samples, to send to Madrid and to evaluate there. But at the end, between December and January, it is not possible to do that because the farmer needs the answers very quickly. In this case the sample is taken there directly, with other methods which do not appear here but it is a simplification of this. We used it in Santa Maria (Brazil) when I was there, for taking the sample. The equipment is the same but made of very hard plastic material, and it is possible to press the petioles very easily. First they are put in dry ice conditions which is important in order to stop the metabolism, and at the same time to get easier to the sap, as the material is already frozen. The results are obtained at the same day. With a crop not so high in price, we must normally use only one evaluation, for wheat normally at tillering or at the beginning of shooting, but no more; it is not so important to have very quick results. Because it does not pay to work as hard as for tomatoes. For a wheat yield differences of 100 kgs or 200 kgs are less than the price the farmer must pay for the sampling and the analysis. But it is always useful to do it once, especially as a complement to the soil test method. The quickest method, however, is not the method we showed which is more difficult and more expensive.

BUSSLER

May I make some remarks on the insertion of the leaf. You take one leaf very distinctly from about 40 cms above the soil.

Räuterberg in Berlin takes two leaves, an older leaf and a younger leaf. There is always a distinct ratio, potassium for instance in the younger leaf to potassium in the older leaf. And when there is a disturbance in the nutrition of potassium then this ratio will change: if there is an excess the potassium amount in the older leaf increases and if there is a deficiency the potassium in the older leaf decreases and so we have a change in the ratio, and this ratio is also an indication for the nutrition status of the plant.

HERNANDO

Well, that is true. But in the petiole this difference does not appear so clearly as in the leaf and it is also important, I show here one of the tables, on page 7, table 2, where you can see the high difference, you can determine these different elements in the petioles with the sap. Some vary very much with the growing of the plant, therefore, it is true that if you take a very young leaf from one side and a very old one from the other you get the wrong answer. Now, we take, maybe I do not explain it clearly, we take the first leaf close to the fruit, completely developed, and this is normally the second leaf after the fruit. But the technicians don't take the leaf, if it is not completely developed. Never take a leaf that is not completely developed, but the first one completely developed; it is not old but completely mature. We always take this type of leaf. You see it is the average. But I said we take the sample when the plant is 40 cm high, or we take the sample when it is one meter and a half or more, but we always know the right values with each size of the plant. The important point is, if you have the sap control well prepared, then no matter what type of leaf you take, but always take the same type of leaves and under the same conditions that your sap control was prepared. That is the thing.

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THERON

My experience with leaf analysis has been very disappointing, except for citrus trees or crops of that kind, I now learn from Dr. HERNANDO, as he puts it here, that he used a specific part of the plant, at a specific height, and time of day, and he gets good results, that is probably where we failed. We certainly did not do it as accurately or as specifically as he did. I should like to ask does he think it possible that one could develop or determine the specificity for all other types of crops, such as maize, sorghum, potatoes, etc. or would one have to experiment all over again with each crop?

HERNANDO

There is another problem. With potatoes it is similar to tomatoes, nearly the same. We try to use this technique with citrus trees, but for the moment we don't get good answers. The problem is that it is very difficult to get the sap from the citrus leaves. Now we are working with a new method but it is not yet completely developed. With this new technique for citrus trees we get quite good results for macroelements, but not for the rest. When taking buds of the trees we got good results. But the farmers, owners of the orchards, say that this is bad because we can spoil the later yield. Anyway, sometimes we took up to 200 young leaves as sample and we put them in dry-ice conditions, and later we pressed them, but we did not get enough sap to make the analyses.

For the moment we do not get good answers with trees but for the rest, especially from annual plants we get good results.

The problem in trees is to get enough sap. To find a good method to get sap easily, one should use this technique in every type of plant, but I do not know if the answer will always be good.

Anyway, it is necessary to study every crop, but the experiments with others are always helpful.

BLANCHET

En dehors de cet objectif de tester des sols, des conditions d'alimentation des plantes dans un but de test seulement, il me semble que votre méthode, Dr. HERNANDO, est aussi extrêmement fine et précise pour aborder des problèmes de recherche, à proprement parler, sur l'alimentation des plantes selon les conditions de milieu. Alors, pour les principales voies de développement de cette méthode, je voudrais vous demander si vous la voyez plutôt vers les problèmes de tests, ou vers des problèmes plutôt de recherche?

Besides this objective to test soils, nutritional conditions of the plants for the purpose of the test only, it appears to me that your method, Dr. HERNANDO, is also extremely fine and precise to tackle research problems, properly speaking, on the plant nutrition according to the environmental conditions. Then, for the main developing trends of this method, I would like to ask you if you see this method rather towards the problems of the tests or towards the problems of research?

HERNANDO

As I told you, when I presented the paper the reason to develop the method was a testing problem only, we did not think about the possibilities to use it for research. But now we find there are high possibilities in research, especially to evaluate the organic composition of the sap; at the end of my paper there are a few lines about the amino-acids content in tomatoes sap. There are very high changes in the amount of amino-acids with different levels of boron.

In the leaf analysis it is very difficult to detect more even with a soil-test, but very easy to detect in the analysis of the composition of the sap. Therefore, I think it is good to improve the knowledge of the problem of the deficiencies in plants, with contents very close to the normal or regular condition. We do not have the answer; we are asking everyone to work on this problem.

WALSH

I would like to thank Prof. HERNANDO for a very fine contribution. There is a point I would like to bring you back to now. Prof. FITTS raised a very important point, and that was the question of day length, nutrient response and nutrient deficiency symptoms. I believe that this is an important point. We must not forget how environment effects nutrient uptake. Equally there are micro-climatic variations which affect nutrient uptake. In Dr. CAPÓ's paper, he was using a basic technique i.e. Mitscherlich's, to interpret his own response effects and endeavouring to relate these to nutrient analyses for potassium, phosphorus and other elements. This is of course a very good approach. However, I want to say that there is of course in that response a normality situation. There is a point of deficiency below which there is a serious physiological disturbance in growth. Above this there is a normal area of response, where a normal response effects operate. Beyond this there is the threshold luxury level above which no increase in yield and quality takes place. There are then the threshold deficiency values and the threshold luxury values. Only in the in between region can one attach significance growth-wise to plant nutrient determinations.

In order to get an indication of what is happening in the plant you must I believe look at the organic composition of the plant as affected by mineral nutrients. Richard of the Imperial

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College in London, pointed the way here for us many years ago when he found that potassium deficiency was associated with the development of putrecine, a degradation product, in plants, i.e. a mineral nutrient affected the organic compositon of a plant. I don't know whether we have gone far enough yet in this direction. Dr. HERNANDO's basic approach here is a promising one, of course, in this respect. In using for instance enzyme systems as indicators of nutrient effects, a rational approach is developing. After all it is not potassium or phosphorus or copper or zinc *per se* that matters; it is the effect of these nutrients on the whole physiological process in the plant which matters. The work which has been going on in Israel and in my own country, using enzyme systems in a practical way to determine nutrient deficiencies, particularly in high value crops is promising. In my early days it was certainly very difficult to embark on monitoring organic constituents, but to-day with developments in analyses — automated organic analyses of various types — the position is entirely changed. So I think it is time we sent back some of these problems to the basic plant physiologist for another look. Prof. THERON raised the point as to whether we needed to research the whole field again? I think we do. I think we have been moving maybe in the wrong direction. I was one of the earlier enthusiasts about plant analysis for potassium and other mineral nutrients as giving us some advance on old methods. I say however to-day that we must look more and more at the organic composition of plants, getting away from some of the old concepts, to give us a new basis, not alone for better yields, of high value, high quality crops, but also for crops of relatively low value, grown by people in some areas where the economic returns are more important in actual fact, than they are in the more sophisticated countries. I will leave you with another thought before we finish this session, Supposing you or any of us were in Santiago to-day at the UNCTAD Conference. What would a group of soil fertility specialists say to them at this point of time. We must end up our meeting here with positive advice

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and be able to indicate what must be done in order to realise the potential of soils, to get more food more economically. Our less fortunate brethern in underdeveloped countries should be the main focus for our attention and our consideration at the present time.

II

EMPLOI DES FERTILISANTS DANS LES REGION DU MONDE A CONDITIONS CLIMATIQUES DIFFERENTES

CORRECT USE OF FERTILIZERS IN THE HUMID TROPICS AND SUBTROPICS AND ITS EFFECT ON: I. PLANT RESISTANCE TO DISEASES - II. CROP PRODUCTIVITY

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1. INTRODUCTION.

1.1. WHAT ARE HUMID TROPICS AND SUBTROPICS.

I would like to speak about the humid tropics and subtropics and their problems relative to plant production. First I must say what I consider humid tropics and subtropics. Everyone knows that in tropic and subtropic countries there is always an alternation of humid and dry periods, this alternation being responsible for the formation of lateritic soils, typical of these regions. The dry regions of northeastern Brazil have still 800 mm of precipitation anually; this precipitation is the same as in some regions of the humid tropics of southern central Brazil. There are dry regions in southern Africa which have about 1.200 mm of precipitation per year. In northern Brazil drought is one of the most serious problems even with an annual rainfall of 1.400 mm.

I want to make the following point: I cannot consider a dry region a zone which suffers by drought in consequence of its deteriorated soil structure and destroyed landscape. Humid regions are those which have lateritic or podsolic soils, even if they suffer from pronounced dry seasons; and dry regions are these which have alkaline or saline soils.

In Asia and partially in Africa the number of habitants is controlled by drought. In South America, population density is transport conditioned.

In the Tropics and Subtropics the soil sciences are still little developed, although 24 years ago the American and European patterns began to be adopted. Only in the last 10 years the use of fertilizers has developed on a larger scale. But fertilization, as they call the commercial dressing with NPK, and soil amelioration, as they call liming, was done in an empirical way, and even soil analyses, executed by chemical soil laboratories or agronomical institutes or universities, still follow the North American or European examples, using the experience of temperate climates.

However, while the plant and livestock production in the temperate climates improved to highly satisfactory levels, that of the tropical and subtropical countries — in spite of all efforts, — remains low; fertilization and soil correction have only little effect and after some years they decrease yields instead of increasing them. These facts are corroborated by statistics of several Secretaries of Agriculture. Techniques of soil treatment developed for temperate climates have destroyed enormous areas of tropical soils.

Something must be wrong! It is generally admitted that the technicians of the tropical countries are less experienced, but it has seldom been considered whether the techniques developed for the specific conditions of temperate climates and soils, are those best fitted for tropical and subtropical climates and soils.

There are not a few people who say: « Imported agricultural technics have destroyed our tropical and subtropical soils!

Unfortunately, it is true and Uruguay is the last example of this truth. What is the difference between temperate and tropical soils?

1 - The climate (temperature, precipitation and air humidity, insolation rate and rain violence).

2 - Soils (oxisoils, soil texture, clay type — kaolinitic instead of illitic or montmorillonitic — small exchange capacity, small micronutrient reserves, high phosphorus fixing capacity, low nitrogen use capacity, little calcium reserve and generally good potash supply. Low pH — 3,8 to 5,1 — and high exchangeable acidity — Al, Mn.

3 - Soil life: extremely active microlife; generally Gram negative organisms; extremely prolific edaphic and hemi-edaphic fauna ad as a consequence little organic matter (0,9 - 2,0%) in crop soils and in virgin forest soils (3,5%), except in mountainous regions; very high frequence of pests and diseases in old crop soils (3 or more years cultivated) and easy compactness and erosion.

We may summarize that soil biodynamics are completely different. This may be understood when we consider that there does not exist any isolated factor in nature: climate, soil, microlife, nutrient balance, plant cover, water economy, etc. and they mutually influence each other. Changing one factor all the others change automatically, to establish a new equilibrium. It is erroneous to suppose that if one factor — such as temperature — changes, all the others will remain unaffected. With the change of temperature there change: mineral decomposition of soils, clay formation, microlife, acid formation, evaporation, plant growth and these modify in their turn nutrient forms and availability, organic matter type and content, soil structure, chemical reactions, soil fauna, and so on. It surpasses the limits of this meeting to consider all the problems which arise. Very little is yet known, but we know what this means for the practice of tropical agriculture: we have to go our own ways, if we want to increase our crops and banish hunger from our zones. Let me mention some examples.

In temperate climates the main problem is to mobilize the inactive soil. This, you do with deep tillage, high nitrogen dressing, green manuring and liming.

Our main problem is an extremly active soil life and we have to restrain it. Thus we have to avoid everything which would mobilize it to an explosive activity.

Illite fixes potassium and the problem of temperate soils is the low potassium availability, sesquioxides fix phosphorus and our soils have a grave phosphorus problem.

Soils of temperate climates suffer much more from lack of nitrogen than tropical ones and there is a saying that "if we have rain we have nitrogen". Where it comes from is not well known but a photo-chemical fixation is suggested by Dhar.

It must be said that the interrelations among the different soil factors cannot be understood by a scientist who only knows the conditions of temperate zones. Nobody may imagine that the luxuriant forests of the Amazon River regions survive on the poorest sandy soil; that organic matter accumulation in these forests, where sunlight never enters, is nearly nil; that a 95% sandy soil may be as hard as stone when dry, and flow like water when moist. Nobody may imagine how in a soil with 0,9% of organic matter, without fertilizer dressing, corn may grow 4 m high and yield about 4,5 tons per hectare. There are few who can imagine that potash application depresses yield, even when it is lacking; that deep plowing is the best way to create infertile, barren land, and so on. Tropical agriculture is much more difficult than that of temperate climates, because tropical and subtropical soils have a high activity all the year round, always producing crops. They never have the benefit of winter rest which recuperates harmfully treated soils, improves soil strncture, balances soil life, and diminishes pests. In tropical climates, everything has to be done by man, and every error is exposed in a short time. Nature does not forgive anything!

1.2. Introduction to the works presented

Topics which have absorbed most of the attention of the author and his team were the low crop production and the high incidence of pests and diseases.

These would seem quite different problems belonging to phytogenetics and phytopathology. What has it to do with soil? Everything! Where are plants growing? On soils! Where do they feed? On soils! Well fed plants produce well, and are more resistant to plant diseases. We must distinguish between over feeding plants with NPK and biologically fed plants with a balanced nutrient spectrum of all elements plants need.

Plant nutrition depends thus on:

a) availability of nutrients,

b) the possibility to develop sufficient rootlets to absorb these nutrients, and

c) sufficient moisture in soil to permit exchange and maintain sufficient nutrients in solution.

Certainly there still exist only a few varieties of crop plants in the tropics, but they give high yields in soils after long fallows and give low yields in cultivated ones, even with high fertilizer dressings.

Our experience is: in healthy soils grow healthy plants.

What is a healthy soil? In the Tropics and Subtropics a soil with a good crumb structure always offers a complete scale of balanced macro and micronutrients, lets roots grow in a satisfactory way and has a reasonable water economy. For that: If a well structured soil deteriorates, something is wrong. It may only be that the ploughing was too deep, that organic matter is lacking, or that some micro or macroelements are deficient or exist in excess. Thus, a nice water resistant crumb structure (tropical soils easily crumble, by iron, calcium, a.s.o., but these crumbs are not water resistant) is the expression of a productive soil. A crop grown in such a soil is healthy, the growth is satisfactory and is not attacked by plagues and pests.

The reports we selected from more than 180 works executed by our team show that even in extreme climates, as the tropical one, there may be obtained high yields on an economical basis.

Our latest experiences with Gneiss as a complete fertilizer for tropical crops on sandy soils, seem very promising, avoiding the problem of nutrient unbalance.

The conservation of an adequate organic matter level has been studied and points to minimum tillage. The problem of weeds is also being solved by crop friendly and weed hostile plants, avoiding the danger of herbicides which pass to the ground water (which generally is at little depth), poisoning drinking water for man.

1.2.1. Experiments lasting 9 years made in extremely poor soils in the State of São Paulo, exhausted by monocultures and periodical burning, were definitely improved in an economic way, giving high and healthy crops of good quality, while the test plots and neighbouring fields gave miserable, pested crops, and of a poor quality unacceptable to the market. The above experiments confirm that with resistance to plant diseases and increasing yield the quality of the product also improves.

1.2.2. In a 5 year experiment in the State of Rio Grande do Sul, the addition of copper sulphate to paddy rice yielded 81% more, with one particular variety. There was no brusone attack present whilst the rice without copper fertilization was annihilated by *Piricularia oryzae*. The full copper effect appears only when the rice seed was enriched with this micronutrient. These experiments confirm that the well fed plants produce well and are resistant to plant disease.

1.2.3. The results of a 5 year experiment in Eastern Brasil show that low sugar cane yields on Terra Roxa Estruturada Soils, cultivated for a long time, are due to deterioration of soil structure and poor root development, even though the soil texture, fertilizer practices and extractable nutrients are the same as on a newly cultivated soil.

The uptake of mineral nutrients depends essentialy on the opportunity for root development.

1.2.4. Another work shows that different varieties of a crop respond in different manners to a given fertilization, on the same soil and under the same climatic conditions in tropical and subtropical zones. Therefore, the recommendation of fertilizer should not be made for a certain crop, but for a specific variety. Uneconomic fertilizer application could be avoided in this way. Specially less demanding varieties, suitable for poor soils, do not resond to a higher fertilization and sometimes, even respond negatively.

1.2.5. The other paper shows that fertilizer response depends on the soil biostructure, and this biostructure depends essentially on organic matter and on the mineral equilibrium in the soil. This experiment shows tbat plant diseases can be avoided with better and more balanced plant nutrition.

2. Works.

2.1. Interrelation between plant nutrition and plant diseases.

2.1.1. *Abstract.*

Correct fertilizer application isn't only important to increase the crop production, but also to fight plant diseases.

In contrast to crops on old arable soils which suffer, apart from mineral deficiencies, regularly from diseases, crops grown on virgin soils are never attacked. This leads to the assumption that occurence of disease is connected with nutrient deficiencies.

Experiments with wheat on a large scale and two smaller ones with bananas and cabbage, showed the correctness of this assumption. These results, and others made previously in other places, may be summarized as follows: A plant disease has to be preceded by a definite related mineral deficiency.

2.1.2. *Introduction.*

Why do plant diseases, in Brazil, increase in such an alarming way and why do fungicides and insecticides loose their efficiency after some time of use?

Large zones of Brazil, which in earlier times produced sugar cane, wheat, cotton and coffee, cannot produce these crops any more due to the excessive increase of plant diseases and pests. The soils have deteriorated, partially destroyed by erosion.

Based on visual leaf analysis (confirmed by sap analysis) it was found, that abnormal growth and leaf colorations of plants, which occurred in these zones, are due to lack of minerals. This couldn't be confirmed exactly by chemical leaf and soil analysis, as both methods work with various sources of error.

There may be cited only one example here: with boron deficiency the shoots of coffee trees show deformed leaves; already lignified shoots die and disorderly growth of side shoots begins around the dead tissues (witch-broom). These appearances are favored by drought periods and disappear in humid seasons. After a good rain, when the plant has supplied itself with sufficient boron, chemical leaf analysis shows an entirely normal boron level, though the crop yield decreased considerably due to this lack. The chemical soil analysis too, showed no lack of boron in consequence of normalised exchange processes in the moist soil.

According to Baver the climate reacts through the soil and plant. Soil with a good permeability, a high field capacity and good aeration rate, buffers the extreme climatic factors. On deteriorated soils, in which infiltration as well as moisture retention capacity and aeration are very deficient, the crop depends very much on the climate. Structureless soils quickly suffer from droughts or excessive moisture and therefore from lack of minerals brought about by climate, since the nutrients are not available in a sufficient amount.

In Brazil a great part of the tillable land has deteriorated. The existence of pronunced rain and drought seasons, makes the crop suffer permanently from climate-induced lack of nutrients: by droughts B, Zn, Mn; by rain K, Ca, Mg, N deficencies. Seldom does nutrient deficiency really exist. On the deteriorated soils, crops will therefore show signs of hunger and pests, while the soils still are, relatively, well supplied with nutrients.

Crops on virgin land do not show signs of hunger and are not attacked by pests. A fact which every Brasilian farmer knows.

Therefore it is obvious, that plant diseases are correlated with deteriorated soils and often with disturbed nutrient uptake.

2.1.3. *Methods and Experimental Materials.*

For an experiment on a large scale there was selected by experts of the Ministry of Agriculture, waste land in a humid zone with drought periods; there appeared red — black — and gray rust on wheat.

Characteristics of the land: 720 hectares of red-yellow podsolic soil. Vegetation: a scattered cover of *Aristida pallens*. Agriculturally abandoned for 87 years, every year burned down by neighbouring farmers. Aspect: petrified, resistant

Analysis of the Red-yellow Podsolic Soil

Sample no.	horizon symbol	horizon depth cm	air dry sample % stones > 20 mm	air dry sample % gravel 20-2 mm	air dry sample % fine earth < 2 mm	bulk density apparent	bulk density real	pH water	pH KCl
30.459	A_1	0-30	0	0	100,0	1,46	2,57	4,5	3,6
460	B_1	30-50	0	0	100,0	1,23	2,63	4,5	3,6
461	B_{22}	50-85	0	0	100,0	1,24	2,65	4,7	3,7
462	B_{23}	85-130	0	0	100,0	1,26	2,68	4,9	3,6
463	C	130-200	0	0	100,0	1,26	2,58	4,8	3,5

Granulometric composition (%) (dispersion with NaOH)

C %	N %	C/N	Coarse sand	fine sand	silt	clay	natural clay	degree of floculation	moisture equivalent
2,18	0,21	10,4	2,2	18,4	17,4	62,0	26,0	57	35,0
1,64	0,14	11,7	1,1	11,9	11,5	75,5	32,5	57	38,4
1,12	0,12	9,3	0,8	10,4	10,5	78,3	31,1	60	40,8
0,50	0,07	7,1	0,7	10,0	16,8	72,5	8,7	88	43,5
0,20	0,04	5,0	3,8	14,6	33,4	48,2	22,4	54	44,4

Textural relation: 1,2 = (middle of the clay % of the subhorizon of B) (exclusively B_3) / (middle of the clay % of the subhorizon of A)

Attack by H_2SO_4 s.g. = 1,47

SiO_2 %	Al_2O_3 %	Fe_2O_3 %	TiO_2 %	P_2O_5 %	Ki	Kr	$\frac{Al_2O_3}{Fe_2O_3}$	P_2O_5 (Truog) mg/100 g	$\frac{P_2O_5 \text{ total}}{P_2O_5 \text{ Truog}}$
21,49	16,48	6,77	0,58	0,14	2,22	1,76	4,14	$< 1,0$	> 140
27,18	21,36	10,00	0,68	0,14	2,16	1,67	3,63	$< 1,0$	> 140
28,03	23,56	9,51	0,67	0,12	2,02	1,61	4,43	$< 1,0$	> 120
30,62	23,30	9,29	0,68	0,17	2,23	1,78	4,14	$< 1,0$	> 170
26,23	19,81	7,19	0,48	0,10	2,25	1,83	4,83	$< 1,0$	> 100

Sorptive complex (me/100 g)

Ca^{++}	Mg^{++}	K^+	Na^+	S	$H^+ + Al^{+++}$	Exchange Capacity	Percent Base Saturation
3,91	2,46	0,47	0,06	6,90	12,17	19,07	36,2
1,05	0,54	0,25	0,06	1,90	13,25	15,15	12,5
0,95	0,70	0,31	0,05	2,01	12,78	14,79	13,6
0,56	1,66	0,40	0,05	2,67	13,05	15,72	17,0
0,93	3,66	0,43	0,12	5,14	13,30	18,44	27,9

Serviço Nacional de Pesquisas Agronômicas, Boletim n. 12, page 112 (1960).

to penetration of spade and ploughshare. Tillage only was possible 3-24 hours after rainfall. Plough: 6-share disk with additional weights. First tillage depth 2-6 cm. The wheat on test plots reached 16 cm in height, was attacked by leaf and stalk rust and produced 2, seldom 3, cumin-like grains.

First tillage in 1953, following dressing with lime; as green manure was used the legumes *Canavalia ensiformes DC* and *Stizolobium Deeringianum Steph. Bort.*, which, when flourishing (January) were incorporated at 5-7 cm depth. In March and April the wheat was sown. During the two first years wheat only was sown on the control plots, while the experimental plots received green manure plants. The ploughing depth was regulated after the biophysical soil analysis and reached a maximum of 18 cm, as the underlying soil crumbs were not water resistant.

2.1.4. *Results.*

In 1958, there were only 15 mm of precipitation during the vegetative cycle of wheat (120 days), and the total wheat crop of the State of São Paulo was annihilated by rust. On the experimental plots an average of 1.800 kg/ha of wheat was harvested, a crop 93% higher than the annual average in the State, with a hl-weight of 84, which is rare in Brazil.

The wheat of the control plots withered in this year before shooting. The green manure which preceded the wheat, received the mineral fertilizers destined for the wheat; the wheat itself was not fertilized, as in dry seasons the mineral fertilizer uptake is not warranted.

The protein in a great part was present as gluten. The prize instituted by the government for the "best wheat" was obtained. Even traces of rust couldn't be detected, nor in any of the following years was there detected rust on the wheat of the experimental plots.

TABLE 1 — *Wheat Crop in Relation to Increasing Mellowness of Tilth* (var. Frontana, hard, red summer wheat).

Year	cultivated area/ha	number green manuring	rain mm	quant. seed kg/ha	height of plants cm	crop kg/ha	protein content %	Hl weight
1953	0,5 (*)	0	65	110 (*)	16 (*)	36 (*)	0,8 (*)	—
1954	3,0 (*)	2	48	110 (*)	30 (*)	39 (*)	1,2 (*)	—
1955	60,0	1	62	110	82	351	3,5	66
1956	240,0	1	51	110	102	753	10,5	72
1957	300,0	1	63	110	123	1302	12,6	76
1958	420,0	1	15	90	99	1806	15,3	84 (***)
1959	360,0	(**)	56	90	126	2103	13,2	78
1960	390,0	1	63	90	129	1710	12,6	76
1961	390,0	(**)	39	90	117	1902	14,1	79

(*) Planting on the test plots only. The other numbers are refering to the experimental plots (first crop of the wheat experiments in 1955). The rain amount refers to the vegetative cycle (dry period) of wheat.

(**) Instead of green manuring, rotation with *Glycine max.* (*L*) *Merrill*.

(***) Record hl-weight in Brazil.

Further experiments were made in a 3 hectare banana field, of the variety "banana maçã" where the oldest stems were annihilated by the "Panama disease" (*Fusarium oxysporum* var. *cubense*). The visual leaf analysis suggested Zn deficiency, which in this case was confirmed by the chemical leaf analysis. In the Tropics, as a rule, zinc deficiency is induced by the strong irradiation of the sun, due to the lack of soil moisture. The soil of the bushes therefore was covered on the north side (midday sun).

Within 2 weeks no bushes were newly infected, and after 40 days slightly diseased plants recovered.

TABLE 2 — *Fusarium Attack in Relation to Zinc Absorption by Bananas* (in ppm).

soil	bush 1	bush 2	bush 3	bush 4	Fusarium attack
sunshine	0,04	0,03	0,04	0,02	very high
2 weeks covered soil	0,09	0,12	0,08	0,15	unaltered
40 days covered soil	0,18	0,21	0,17	0,24	none

Another experiment was made in a 3 hectare leaf cabbage field totally attacked by mites. Potassium deficiency was detected, though this wasn't clearly deducible from the soil analysis, but only from the sap analysis. Four rows of cabbage plants, through the middle of the field, were fertilized with 8 g/m² of potassium cloride and the soil was covered with a 12 cm thick rice husk layer, in order to assure sufficient uptake of potassium. After 6 weeks the fertilized cabbage was rid of mites, while the plants which were not treated remained infested.

TABLE 3 — *Potassium Dressing against Mites.*

K_2O in cabbage leaves %	potassium in soil me/100 g	Depth of crumb layer cm	mites attack
0,30	0,020	5	heavy
0,28	0,021	5	heavy
0,22	0,023	4	heavy
0,27	0,030	4	heavy
0,82	0,025	10	none
0,93	0,040	9	none
0,69	0,170	12	none
0,69	0,050	10	none
0,72	0,120	8	none
0,80	0,040	10	none

NOTE: A greater potassium uptake runs parallel to a lower mite infestation. Besides fertilizing an increasing mellowness is important.

2.1.5. *Discussion.*

It may be supposed that no crop is attacked by diseases and plagues, as long as its continuous and normal growth is supported by an uninterrupted and balanced nutrient uptake. Plague and disease attack occurs probably only when there is a lack of nutrients, or when drought, excessive moisture or fog make nutrient uptake difficult and the plant fights for its survival. Climatic oscillations are able to be buffered by good mellow tilth, so that even a 12 week long dry period or a 3 week long dry period or a 3 week long rain period have no decisive influence on the normal nutrient absorption and do not therefore interfere with the development of plants.

It seems that all bacteria, fungi, protozoa and viruses need suitable life conditions, that is, a necessary weakness "offered" by the plant.

Unbalance of potassium may promote animal parasitas while zinc, copper or magnesium deficiency favour fungal attack, though a general nutrient unbalance may be required as in the case of infection by *Pseudomonas citri* (citrus cancer) where boron, manganese, zinc and magnesium were deficient. Whenever this plant weakness, which is necessary to the microorganisms, is not present, they suspend their life. These phenomena can be summarized as follows: "Plant disease depends on a preceding, exactly defined, specific, mineral deficiency".

The question originally propounded could be answered with the supposition that plant diseases probably increase parallel with the soil deterioration and have their origin in the deficient or unbalanced plant nutrition.

2.2. INFLUENCE OF PLANT NUTRITION ON *Piricularia oryzae* *Cav.* IN RICE.

2.2.1. *Abstract.*

In soils of the State of Rio Grande do Sul, Brazil, the addition of copper sulphate to paddy rice yielded 65 to 81%

more — depending on the variety. The copper effect cannot be attributed to its fungicide action, but must be credited to its nutritional qualities. The copper fertilized rice was of a clearer green and shorter than that without Cu fertilization. It did not show any *Piricularia oryzae Cav.* attack whilst the rice without added copper was annihilated by this fungus.

The full copper effect appears only when the rice seed was enriched with this micronutrient.

2.2.2. *Introduction.*

In earlier years the rice crops failed with increasing frequency in the State of Rio Grande do Sul. Initially, rice develops extraordinarily well, has a green-blue color and promises record crops. However, instead of flowering its heads become white and sterile.

Sandy and gleyed soils, especially, with deficient drainage showed these symptoms. The rice was partially attacked by *Pericularia oryzae Cav.*, but in some areas there were only physiological disturbances. In the literature there are no references about this.

The exceptionally luxuriant growth suggests an excess of nitrogen. The nitrogen, however, is closely related and very sensitive to the supply of copper. VETTER and VLAMIS (1961) and PRIMAVESI (1953, 1958, 1965) report dry heads of wheat and rice due to the shortage of copper. VETTER and THEICHMANN (1968) describe the influence of copper on wheat as an inhibiting factor of vegetative growth, but it also shows a beneficial effect in crops. The only experiment about copper fertilization to rice is reported from Borneo, where from organic, acid soils additional crops were obtained (Institut d'Azote: Le Rice). In Rio Grande do Sul, so far, all experiments of the IRGA (Institute Riograndense do Arroz) with micro-elements showed negative results.

Our first experiments with micro-elements in rice, in 1965 showed an increase of production of at least 80%, and even more than 100% in crops from seed enriched with copper. The results were so astonishing that the possibility of some mistake in the irrigation of the test plots was suspected.

In 1966 and 1967 these results were repeated, but only with rice whose seed had been treated with copper sulphate. Systematic experiments were made in this area.

2.2.3. *Methods and Experimental Materials.*

I - Plots of 4 × 5 m area were sown in 10 different treatments (4 repetitions): 5 well irrigated and 5 with deficient irrigation.

1 - Received only the basic fertilization 20:60:50 kg/ha of $N:P_2O_5:K_2O$ respectively which all the other plots also received.

2 - The seed was submerged during 4 hours in a 0.005% solution of $CuSO_4$.

3 - The seed was submerged during 30 minutes in a solution of $CuSO_4$.

4 - The seed was sprayed with a solution of 1g $CuSO_4$ in 30 ml of water/l kg seed.

5 - Copper was applied as overall fertilization, 3 kg/ha.

The same treatments of fertilization were repeated with rice in constant inundation and with rice irrigated only every 2 weeks.

The average values of the results, with small statistical variations, were the following:

	Rice continuously irrigated	Rice irrigated every 2 weeks
NPK	14,05 kg/20 m²	3,40 kg/20 m²
$CuSO_4$ 50 mg/l	16,80	5,20
$CuSO_4$ 1,5 g/l	7,80	5,70
$CuSO_4$ 1 g/kg	16,80	14,70
$CuSO_4$ 3 kg/ha	11,40	3,40

2.2.4. *Results.*

The results show that:

1 - Copper is able to increase the crop.

2 - The best way to apply copper was spraying the seed.

In 1968 the experiments continued, with varied quantities of nitrogen.

II - 2 varieties of rice were used:

a) The superceded, very demanding, but still popular variety "Agulha", a late yielding variety with long grains, very productive in good soils, with the highest quotation on the market;

b) and the new variety E.E.A. "404", a rice with medium to long grains, of a medium growth period, nutritionally tolerant which in poor soils still produces good crops.

The plots were of 200 m². The experiments were made with 4 replications. Eighty five kg/ha seed was planted, although the customary quantity in this zone is 140 kg/ha. From experience we know that Cu-enriched seed would have better tillering and therefore it could be sown with larger distance between the rows. Similarly if the seed of oats has been previously enriched with Mn and B, it is possible to plant in our soils 35 kg/ha for forage, instead of 180/kg which is normally used.

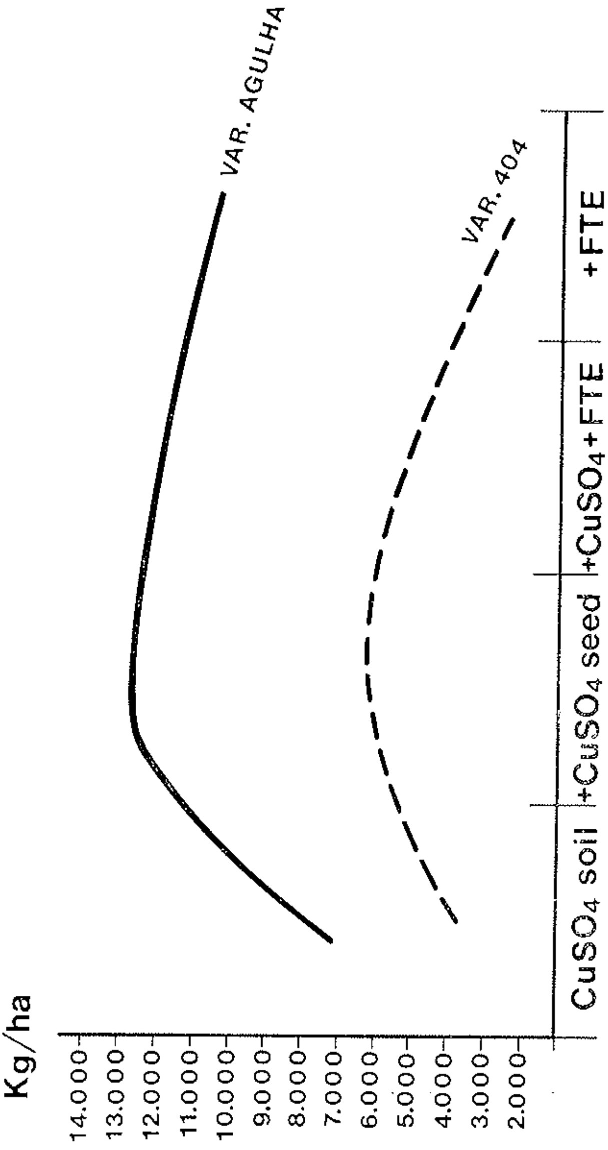
The fertilization was the same for all the plots; 60 kg/ha P_2O_5 in the form of bone meal on the seed bed and a top dressing of 30 kg/ha N.

The experimental treatments were the following:

1 - Control: no copper. All following treatments received a top dressing of 3 kg/ha of copper sulphate.

2 - Top dressing fertilization of Cu only.

3 - The seed was sprayed with 1g of $CuSO_4$ per kg plus top dressing.



Kg/ha
14.000
13.000
12.000
11.000
10.000
9.000
8.000
7.000
6.000
5.000
4.000
3.000
2.000
VAR. AGULHA
VAR. 404
$CuSO_4$ soil
$+CuSO_4$ seed
$+CuSO_4$+FTE
+FTE

GRAPHIC I

4 - The seed was sprayed with 1g of $CuSO_4$ per kg plus top dressing and dressed with 10 g of FTE/kg.

5 - The seed was dressed with 10 g of FTE/kg plus top dressing of copper.

The FTE applied had the following composition: 7% $FeCl_3$, 16% MnO_2, 1,2% CuO, 8,5% ZnO, 9% B_2O_3.

This year exceptional climatic conditions occurred, with a high fixation of nitrogen by microorganisms (fungi and algas); 240 ppm of NH_4 was found in the irrigation water on the field so it was not possible to apply the anticipated differential nitrogen fertilization because there was already a considerable excess of nitrogen. We continued therefore in this experiment only with a series of essays, now with 8 repetitions.

In the year of 1968/69 one third of the rice crop of Rio Grande do Sul was destroyed by *Piricularia oryzae Cav.*, and our trial plots were destroyed; the few grains which had formed were little and brittle.

Copper fertilization applied only to the soil could nevertheless save the crop, but it did not provide an essential improvement in yield.

2.2.5. *Discussion.*

The surprising effect of copper on rice cannot be attributed to its fungicide action, because the rice seed of neighboring fields had been treated with Aldrin and was sprayed against *Piricularia oryzae Cav.* with Kitasin: in spite of that, 80% of their yield was lost through *Piricularia oryzae Cav.* It must, therefore, be admitted that copper acts as a nutrient.

In experiments with corn, the action of trace elements was only considerable if the seed was previously enriched with them. This also was evident in the case of rice, where the best yield among the plots with soil fertilization and those with additional enrichment of the seed, were 65 to 81% higher in the latter.

The plants in the copper plots with blind ears were collected and examined at the Department of Phytopathology. No attack by *Piricularia oryzae Cav.* could be detected.

It is, therefore, apparent that copper is able to compensate the unfavorable effects of a high dressing of nitrogen and allows better crops to be obtained without fear of an attack by fnngus. The bigger yield in grain on the plots treated with copper was highly significant.

2.3. Factors responsible for low yields of sugar cane in old cultivated terra roxa estruturada soils in eastern Brazil.

2.3.1. *Introduction.*

Yields of Sugar Cane (*Sacharum officinarum*) are often low in eastern Brazil and show little or no response to dressings of commercial fertilizers. The object of this investigation was to determine whether poor yields were related to lack of chemical fertility or to deterioration of soil structure after years of cultivation.

2.3.2. *Methods and Experimental Materials.*

These studies were conducted on a large sugar cane plantation in southeastern Minas Gerais, State of eastern Brazil. The Terra Roxa Estruturada soils investigated have a textural B_2 horizon and form in basic volcanic materials. In some ways they are like the Low Humic Latosols, but not identical. They are also similar to the Red Loams of South Africa and nearly equivalent to the "Laterite Pardo Rojiza" of Chile. They contain 39 to 57% clay. The climate is tropical with a 10-year average precipitation of 1,237 mm. The months of May through to September are a rigorous tropical dry period and cane is cut soon after the dry period starts. Two fields of about 100 ha each with the same flat topography were selected. Field 1 of 96,3 ha was an uncropped area of virgin soil cleared during the year before planting of its native vegetation containing mostly peroba (*Aspidosperma gomezianum A.D.C.*), canela-preta (*Ocotea pulchella*), jacarandá (*Machoerium villoseum V.*), jatobá (*Hymenaea courbaril*), and ipê roxo (*Tecoma ipe Mart.*) and other trees. Field 2 containing 98,1 ha was an old cane field cropped for 23 years and fertilized during the last 9 years before replanting.

Both fields were limed with 1,500 kg of limestone per ha and both were planted at the same time with sugar cane stalks 40 cm long, of the variety CB 4513, always placed one overlapping the other 3 cm in furrows 40 cm deep and 120 cm apart as is the custom in the region.

At planting, a dressing of 200 kg of bonemeal (the customary P-fertilizer of the zone), 47,2 kg of K (90 kg KCl) and 11,5 kg of N (70 kg $NaNO_3$) per ha was applied in each furrow. Each succeeding year a top dressing was applied at the begining of the second rain month containing 26,4 kg of P (60 kg P_2O_5 as superphosphate), 23,6 kg of K (as KCl), 6,9 kg of N (as $NaNO_3$) and 1,000 kg limestone per ha in spaces between alternate rows. Beginning 18 months after planting, the crop was manually harvested each year and the straw heaped in the spaces between rows, alternating with the spaces where annual top dressings were made.

Soils were sampled at four locations per ha, before planting and fertilization, and in the fertilized space after 5 years of cropping. On a Morgan extract, K was determined with Na cobaltnitrite, Ca as the oxalate, P with the molybdenum blue method, and nitrate with diphenylamine. pH was determined electrometrically on a 1:2 soil: water extract.

Soil structure was examined in blocks 20 cm wide and 10 cm thick, taken to a depth of 30 cm with a specially constructed plane spade having a very well sharpened steel blade, from the side of a cavity 30 by 50 cm and 40 cm deep in the soil. A block was very carefully shaken with a five-fingered steel claw to make it split at all places where soil structure changed.

2.3.3. *Results and Discussion.*

Table 1 shows the large differences in cane yields between a soil that had been cropped for many years and a newly cultivated soil, in spite of equal heavy initial and annual fertilization. The soluble P was much lower on the old cultivated soil indicating a high P-fixation capacity. This level of soluble P in the old cane field is considered somewhat low, but not insufficient. The NO_3-N was also lower on the old cultivated soil indicating possibly more leaching. However, this level of NO_3-N produced very good yields on other fields. Bonemeal could be found in the soil even after 5 years of cultivation. The differences in cane yields cannot be explained by the small differences in chemical analysis of the two soils.

In the new soil of field 1 the cane root system was well developed in the loose mellow soil to a depth of 40 cm. However, in the long cropped soil of field 2, root development was confined to the upper 5 cm of soil. This layer of soil is alternately very dry (after one day of sun) and very wet after rain and so is not favorable for root development even though root development is mostly confined to it. The chemical analysis shown in Table 1 shows the lower pH, and depletion of this layer in Ca, K and soluble P compared to the whole 30 cm depth.

Various stages in the physical degradation of a cultivated soil can be recognized. At first, a hard layer begins to form below 22 cm in depth. Later, this layer extends to within 3 cm of the surface. Finally, there will be 3 cm of loose, dusty soil on the top maintained by cultivation. The 3 to 10 cm depth breaks up in big blocks when disturbed. Below 10 cm

TABLE I — *Chemical analysis of two Terra Roxa Estruturada soils before and after 5 years of sugar cane culture in Brazil.*

Soil history	Depth cm	No. of samples	pH	Ca	Ions in Morgan Extract K	P	NO_3-N	Cane yield metric tons/ha
				me/100 g				
Field 1-								
Uncropped:								
Before planting	0-30	384	6,0	3,93	1,08	0,07	0,020	165 (1st crop)
After 5 years	0-30	384	6,3	4,86	1,20	0,06	0,015	156 (4th crop)
Field 2-								
Old cane field:								
Before planting	0-30	393	6,9	6,30	1,50	0,02	0,006	12,6 (1st crop)
After 5 years	0-30	393	6,6	5,40	1,45	0,03	0,003	6,3 (4th crop)
After 5 years (well-rooted top soil)	0-5	393	5,4	1,80	0,06	0,0003	0,007	

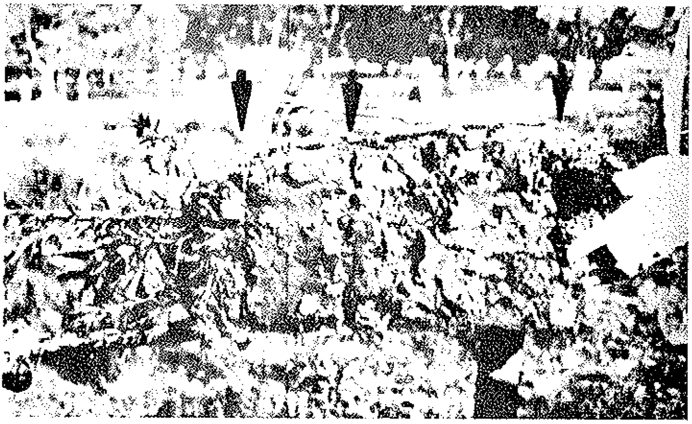


FIG. 1 — A soil block taken from a deteriorated field. Mark 1 (left) shows the limit of the well rooted layer. Mark 2 shows the last plowing depth. Mark 3 (right) indicates the transition of the compact layer to the loose subsoil.

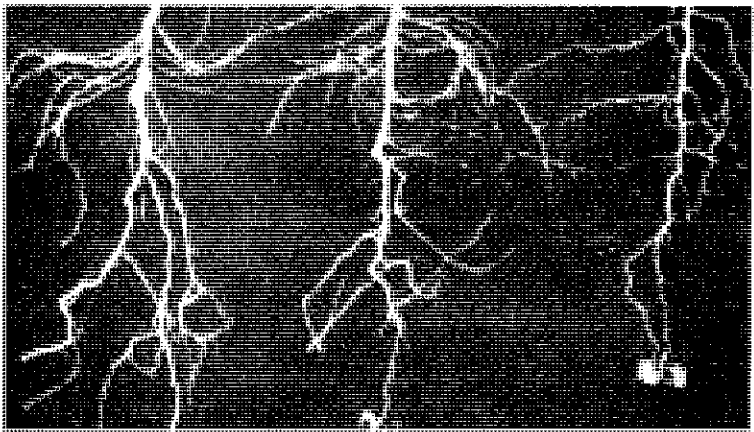


FIG. 2 — Root systems of *Sida rhombifolia* L. showing abrupt bends resulting from the tendency to grow between hard blocks of soil.

the soil breaks into fine, thin sheets. Figure 1 shows a block of soil excavated from a decadent, long-cultivated field in which different structural layers can be seen. Figure 2 shows the deformed roots of a malvaceae (*Sida rhombifolia L.*) grown in a decadent soil.

Our results show that low cane yields on a Terra Roxa Estruturada soil, cultivated for a long time, are due to deteriorated soil structure and poor root development, even though the soil texture, fertilizer practices and extractable nutrients are the same as on a newly cultivated soil. The availability of mineral nutrients depends essentially on the opportunity for root development. Classical soil analysis applied to a decadent soil can lead to erroneous interpretations unless the effects of tilth and soil structure on root development are considered. Taken together, they can be useful in predicting soil fertility.

2.4. Influence of variety on fertilizer effect in rice (*Oryza sativa L.*) and soy bean (*Glycine max.* (*L*) *Merrill*).

2.4.1. *Introduction.*

In the calibration of chemical soil analysis, recommendations of fertilizers, chemical leaf analysis and analysis of dry matter of plants, one considers only the crop itself; results are given for wheat, soybean, cotton, rice, etc, in spite of the fact that the most diverse varieties are cultivated and investigated.

On the other hand, the breeding of new varieties is well developed, thanks to the enormous possibilities of production of mutants, through irradiation with γ-rays, or by the use of mutagenic substances, or by simple hybridization. New varieties continuously appear on the market, which are more productive, more resistant to diseases and drought or simply better adapted to the soil of a given region. This plurality of varieties means that the chemical analysis of the soil seldom gives a single correct interpretation, for what is adequate to the soybean of one farmer, may be inadequate to the soybean of his neighbor.

We have examined systematicaly the reasons for this. FOY, FLEMING and BURN (1967) have demonstrated with wheat that the variety tolerant to Al had more Ca in its dry matter than the varieties more sensitive to Al. The same applies to soybean according to ARMINGER (1968).

KAMMLER (1969) noted that the success with fertilization depends on the variety.

PAULSEN and RONTINI (1968) report that high doses of P decrease the production of varieties of soybean sensitive to phosphorus, and in these varieties the correction of zinc deficiency induced by phosphorus had no effect, while the varieties tolerant to phosphorus would respond to it. In 1963 HIATT noted that the absorption of potassium by tobacco changed with the variety. Furthermore, every agrostologist knows about calcium, as reported by LEHMANN and GARZ (1964): by fertilization the level of minerals in the plant cannot be elevated above the level caracteristic to the plant.

BASTOS LAGOS (1968) noted that non-demanding varieties of wheat gave good production in poor soils, but they do not give higher production in rich soils or through fertilization. In experiments with 3000 varieties of wheat in the state of Rio Grande do Sul (1968) he noted a specific response of each variety to fertilization and to limestone. An identical observation was made by PRIMAVESI (1969) with potatoes.

2.4.2. *Materials and Methods.*

The crops cultivated were soybean and rice.

I - Soybean (*Glycine max.* (*L*) *Merrill*).

The varieties used were L-326, L356, Hood and Majós.

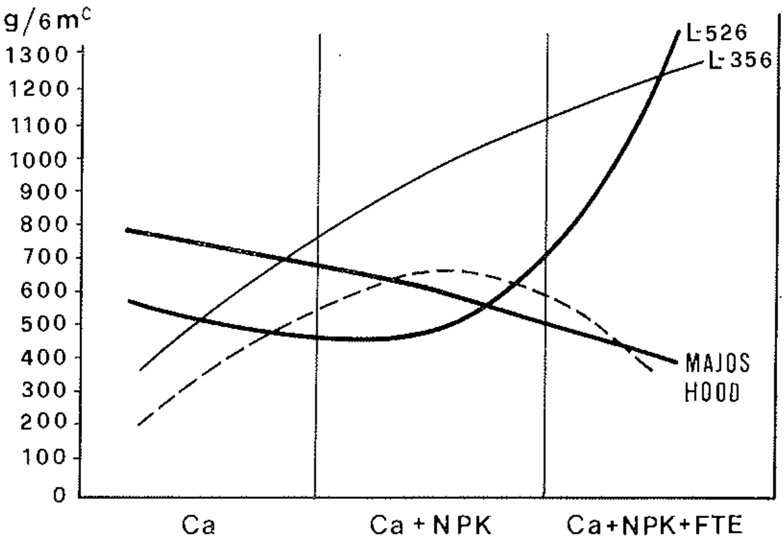
The different fertilizer treatments were:

1 - limestone (1500 kg/ha, dolomitic form);

2 - lime and NPK = 6:60:75 kg/ha;

3 - lime, NPK and FTE 50 kg/ha (the composition of Fritted Trace Elements was: 7% $FeCl_3$, 16% MnO_2, 1,2% CuO, 8,5% ZnO, 9% B_2O_3, 0,2% MnO_3). Each plot measured 2 × 3 m, with 4 replicates.

Soil used was of the mapping unit: transition "São Pedro-Santa Maria". The average soybean production, statistical values was as follows:



GRAPHIC 2

It may be deduced that the Majós variety gives relatively good production in poor soils, when lime is applied.

However, it does not increase the yield when fertilized. On the contrary, it suffers a decrease in production.

The Hood variety which yields poor crops on poor soils increases its yields through NPK fertilization, but decreases considerably when trace elements are added.

L-326 variety responds poorly to NPK fertilization, which probably indicates a trace element deficiency. It increases abruptly in yield when it receives trace elements.

L-356 variety can be considered a classical variety which, as expected, shows an increased production for each fertilizer added.

II - Rice (*Oryza sativa L*).

For this experiment we used 2 varieties of rice. Agulha, a demanding and productive variety which is not being propagated any more due to uncertain yields production under less favorable conditions, and a new variety with reliable production, the EEA-404.

The rice was planted, with 8 replicates, on plots of 10 × 20 m.

All plots received the same basic fertilization: lime (dolomitic limestone) 900 kg/ha and phosphorus 60 kg/ha P_2O_5 as bonemeal. Nitrogen 50 kg/ha, of which 40 kg/ha was applied as a top dressing. The level of soil potassium was normal with 80 ppm.

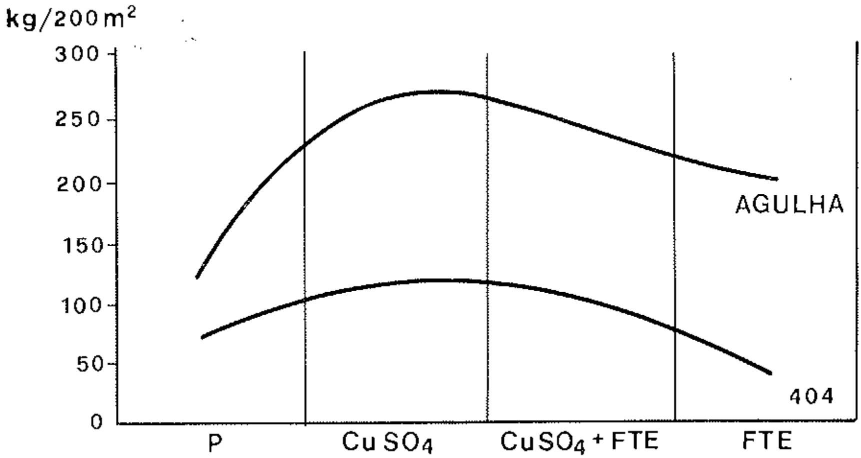
4 treatments were used:

1 - control;

2 - copper sulphate on the seed (1g/kg) and in the soil (3 kg/ha);

3 - besides the copper sulphate to the seed and soil, trace elements (FTE) to the seed (20 g/ha);

4 - trace elements on the seed and copper sulphate to the soil (the fritted trace elements composition was: 7% $FeCl_3$, 16% MnO_2, 1,2% CuO, 8,5% ZnO, 9% B_2O_3, 0,2% MoO_3).



GRAPHIC 3

From the average rice yields which were significantly different, we could deduce that the variety EEA-404 responded less to the copper fertilization than the variety "Agulha". The yields, despite running parallel, show that the EEA-404 variety (with low requirement) does not present a striking increase of productivity, while the more demanding variety shows a highly satisfactory increase in relation to the copper fertilization.

2.4.3. *Discussion.*

From the results, 2 factors were evident:

1 - that each variety responded in a completely different way to fertilization and therefore it is empirical to make a general recommendation of fertilization for soybean or rice.

2 - that in spite of the fact that the so called "varieties of safe production" give crops relatively safe in poor or compact soils, they don't have the capacity to take advantage of a higher supply of nutrients.

Varieties that are very low yielding on poor soils show, however, a great production capacity and can, after an adequate fertilization and soil treatment, produce very satisfactory yields.

It seems that:

a) the production capacity is inherent to the variety;

b) the fertilization of varieties of safe production on poor soils, are uneconomic;

c) nutrient requirements, which were found in one variety, can not be generalized to the species.

The commercial fertilization, based on soil analysis will be much safer when given according to the variety and not empirically, to a crop.

2.4.4. *Summary*.

Fertilizer experiments with different varieties of soybean and rice showed completely different responses which were specific for the variety. Consequently it is not possible to establish the mineral requirement for a crop, but only for a variety.

Varieties with dependable yields in poor soils do not respond economically to a fertilization and even may yield less. It must be supposed that these varieties have a limited yield potential.

Varieties with unreliable yields in poor soils have generally a high yield capacity and respond very satisfactorily to fertilization and soils improvement.

It may be concluded that a dependable and economic fertilizer response, based on chemical soil analysis is only certain when the recommendation is made for the variety and not empirically for the crop.

2.5. Influence of soil structure and of micronutrients on the corn crop (*Zea mays*).

2.5.1. *Abstract.*

The experiments were carried out to look for an explanation for the small influence of commercial fertilization, usually with NPK, on corn crops (*Zea mays*).

Maize production can be influenced by improvement of soil structure. In this case, the better soil structure allows the plant better nutrient absorption.

On the other hand, if besides soil fertilization with NPK and Ca, we also apply zinc and boron on soil or seed, maize will give a favorable response.

But, on compact soils, even with customary fertilization and micro nutrients, there is no production increase of maize. This is explicable by improper soil structure hindering good root development of plants.

2.5.2. *Introduction.*

According to the report of the "Southeast Region Technical Commission » 1966, corn responds less and less to the usual NPK commercial fertilization, although there has been considerable progress in the field of genetics.

Research in the areas of Santa Maria, Julio de Castilhos, São Sepé, and São Gabriel in the State of Rio Grande do Sul, have confirmed as principal causes:

1 - A stagnation in growth, with typical symptoms of zinc deficiency in hybrid, corn, from the 2 nd. week after germination, which is only overcome 18-22 days later. In this period the plant is attacked by *Elasmopalpus lignosellus* which provokes the decay and death of many of the young plants. Seed treatment with "Aldrin" prevents the attack but not the stagnation in growth, which always leads to a lowering in production.

We know through WIDDOWSON (1966), that the lack of zinc in the soil increases with cultivation and fertilization with NPK. CHIBA (1962) notes that maximum production is not reached through maximum fertilization of NPK, but through harmonious balance of all nutrients.

According to ARAGON and BRESSIAN (1965) the deficiency of microelements, mainly of zinc and boron, causes a decrease of the amino acids and hence of the biological value of the plant which consequently becomes more receptive (PRIMAVESI 1964, 1966) to pests and diseases.

FUEHRING (1966) also noted a great lowering of production in cases of zinc and boron deficiency.

2 - The poor utilization of fertilizers.

PRIMAVESI (1964) demonstrated at the 8th International Congress of Soil Science, with work carried out during 9 years, that through the improvement of the biostructure of the soil the utilization of fertilizers, and hence production, increases.

SCHMID (1966) showed that soil loses its productivity if only saturation with bases is achieved even if balanced fertilizers are used, including trace elements. Normal NPK fertilization is insufficient.

GORODNIJ (1961) noted that humus decomposition is faster with mineral fertilization, and FEDOROVA (1966) demonstrated that owing to continuous fertilization with commercial fertilizers (NPK) soil not only acidifies and increases in exchangeable Al, and therefore decreases the saturation of bases.

The deterioration of bio-structure of the soil and the deficiency of zinc are the main factors responsible for the lowering of corn production in the surveyed area.

2.5.3. *Materials and Methods.*

A) The soil treatment consisted of the following:

a) An old pasture was ploughed 5 months before sowing to prevent antagonistic influences of the gramineous flora;

b) a green manuring (40 to/ha) was incorporated for the crop which preceded corn;

c) a green manuring (40 to/ha, each) was incorporated for both the crop preceding corn and for the corn crop.

B) To remedy the evident deficiency of zinc in the seed, the seeds were put into a solution of zinc sulphate of 0,005% (50 mg/1000 ml) and borax 0,005% for four hours (the control seed was put in distilled water), dried for one hour in the shade and sowed with a sowing machine in rows 80 cm apart at intervals of 30 cm. The size of the experimental plots was of 50 m^2.

TABLE 1 — *Chemical and physical soil analysis - Extraction of Ca, Mg, K, P in Morgan-solution and Al in KCl lN.*

Series of experiments	pH (Water)	Ca <	Mg ppm	K	P >	Al me %	Volume of pores %	Illuvial horizon; depth. cm	Aggregate stability
a	4,4	40	10	10	0,5	1,2	15	5	extremely bad
b	4,4	30	10	10	1,2	0,6	21	9	weak
c	4,9	60	20	10	1,0	0,3	27	12	medium

Two months before sowing, the plots were limed with 800 kg/ha of dolomitic limestone (36% CaO and 12% MgO).

All the plots were poor in nutrients. All received equal fertilization which was applied at sowing time, 2 cm beside the row, and constituted NPK = 20-30-60 kg/ha (in the form of ammonium sulphate, triple superphosphate and potassium chloride plus 5 kg/ha of borax and 3 kg/ha of zinc sulphate for each plot of the experiment.

In half of the plots of each series of experiments zinc and boron were applied, since the lack of boron in this area is notorious.

2.5.4. *Experimental Results.*

In all 3 series of experiments, the zinc-boron treatment promoted continuous, uniform, young growth; after 6 weeks the plants with zinc-boron were bigger than those in plots with simple NPK fertilization. Furthermore, 33% of the plants without zinc-boron treatment had died due to the attack of *Elasmopalpus lignosellus*. The production of several series of experiments was significantly different.

TABLE 2 — *Results of the crop.*

Series of experiments	Without Zn-B		With Zn-B (soil)		With Zn-B (soil + seed)	
	mean kg/ha	hl weight	mean kg/ha	weight hl	mean kg/ha	weight hl
a	930	74	930	74	1.056	81
b	1.110	78	1.200	79	1.494	84
c	2.970	86	3.027	86	3.465	90

2.5.5. *Discussion.*

Considerable differences could be observed between the plots with different structures of soil, and also between the plots with or without zinc-boron treatment.

Hard soil gave only about 1/3 of the production of a mellow soil, in spite of the same fertilization. It is apparent that there is considerable difficulty in the absorption of nutrients. Consequently, corn production can be increased when:

1) the structure of the soil permits a good absorption of nutrients;

2) the seed deficiency is removed by soaking in a nu-

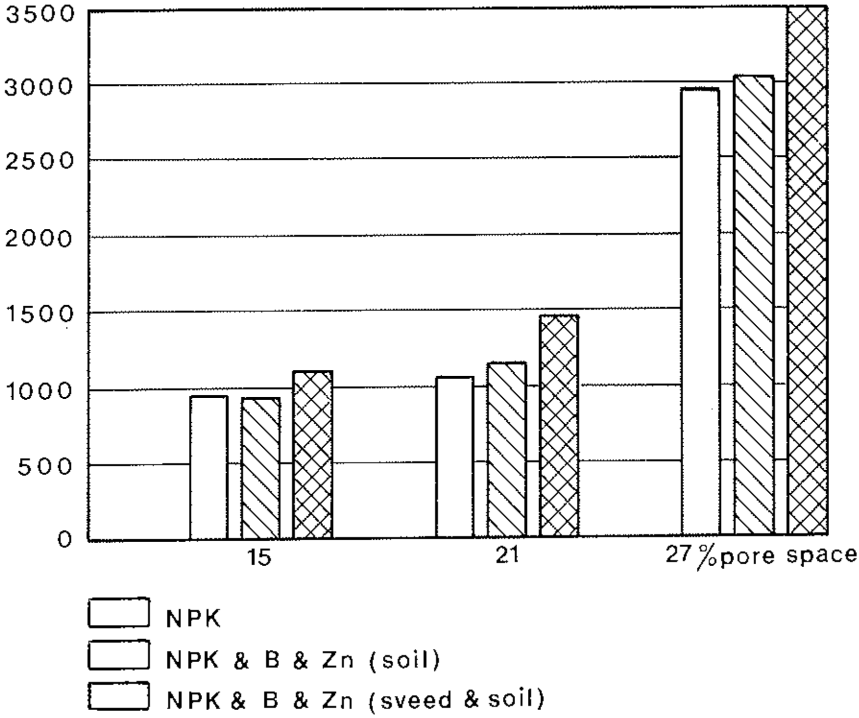


FIG. 3 — Influence of air pores and seed treatment on yield.

tritive solution (according to SOKORINA (1966) it is enough to spread the nutritive solution over the seed);

3) soil deficiency is removed through adequate fertilization.

The zinc-boron fertilization in itself is not able to increase production in hard soils since the improper structure of the soil acts against the development of the plant. However, with a slightly improved structure, it becomes active.

3. Final considerations.

The application of fertilizers is doubtlessly an urgent necessity in the tropical and subtropical zones. However the question is not only to put the NPK into the soil, but owing to the unfavourable characteristics of the kaolinitic clays which predominate in these zones, the importance of organic matter, the structure of the cultivated soil, the mineral equilibrium, the timing of fertilizer application, the peculiarities of varieties and the micro-nutrients must all be investigated in much greater detail.

The greater biological activity of the tropical and subtropical soils makes the factors limiting production appear much earlier than in temperate climates. The soils lack rest during winter and therefore they also lack an automatic recuperation. The multiplication of pests and diseases is much more rapid owing to the nature of the climate.

But in soils with a good active structure the plagues and pests are reduced, fertilization has a better result, and the crops are abundant and healthy. The philosophy of fertilization must be changed. We must not fertilize in order to get a good crop, but to maintain the soil in conditions of mineral equilibrium and of excellent productivity. No fertilizer must be applied in such a way as to damage the structure, that is by inciting a quicker breakdown of organic matter, unbalancing other elements or damaging the micro and meso life.

We know that tropical soils have little ability to retain calcium and may quickly become acid, they have a high capacity of phosphorus fixation, and easily show deficiency of micro-nutrients.

Irrigated crops need special treatment and cannot be treated as crops on dry soils. Here we only wish to remember the sad experience made in the valley of the São Francisco, where, by badly planned irrigation, there was salinization of the soils. Our experiences with rice show that fertilizers with residual acidic power increase the susceptibility of rice to fungus diseases, such as the Bruzone (*Piricularia oryzae*).

Other experiments have shown that water-logged soils require a certain level of calcium and magnesium to be able to produce and also to respond to commercial fertilizers. They need a continuous conservation of the organic matter, which accumulates in very acid soils and on high places, in form of "moder" and sometimes even turf.

On the other hand, tropical and subtropical soils with adequate levels of P and Ca are able to fix the nitrogen of the air, a power which temperate soils do not have. They develop many more nematodes, but in circumstances favorable for the plants, they do not have any harmful action; this is shown by our latest research which is still being carried out.

From our long experience we are convinced that management of tropical soils is inadequate, when it is oriented by the methods developed in temperate climates; there is not one factor only which changes with the modification of climate, but, as we all know, the entire complex system of interrelations changes automatically with the modification of one variable.

Tillage is also being more and more discussed in tropical countries; and in the sandy soil of Amazônia the rule is: "He who wishes to make a desert must plow his soil".

Many problems still remain for research, because now people of the tropics are becoming aware of the fact that the agriculture methods imported from temperate countries served to show that there are other systems for cultivating soil than simply burning and planting.

The methods may also be responsible sometimes for the low productivity of these soils and their rapid destruction.

If the tropical and sub-tropical zones develop appropriate methods, as they have been developed for temperate climates, they will produce at least equal if not greater crops.

There is no need for hunger in tropical countries if they know how to treat their soils and to obtain a mineral equilibrium by appropriate fertilization.

4. Summary.

The differences between the agricultural conditions of temperate and tropical countries are summarized. The fact that tropical Agriculture up to now has been managed according to experiences of temperate climates, and not according to experiences in tropical climates, has led tropical agriculture to low productivity and deterioration of their soils.

The biggest mistake, perhaps, is the supposition that all methods are the same for temperate and tropical soils, and that only the temperature is higher and the distribution of rainfall less favorable. Few consider that in nature everything functions like a train of gears and the least change of one factor modifies all the others.

Therefore the problems of tropical soils require appropriate studies, methods and solutions. It is not possible to use techniques developed for soils with other problems, under other conditions, and in other climates.

The papers reviewed were chosen from more than 180 investigations performed by our team, and show that in poor soils, and extreme climates, we also may obtain high yields on an economical basis.

The first paper shows experiments over 9 years made in extremely poor soils, exhausted by monoculture and periodical burning. They were economically restored, giving high and healthy crops of good quality, while the test plots and neighboring fields gave miserable, diseased crops of poor quality, unacceptable in the market. These experiments confirm that, with the resistance to plant diseases and increasing yield, the quality of the product also improves.

The second work brings the results of a 5 year experiment in Southern Brazil. It shows that the addition of the micronutrient copper to paddy rice yielded 81% more. It did not show any *Piricularia oryzae* attack whilst the rice without copper fertilization was annihilated by this fungus. These experiments confirm that well fed plants produce well and are resistant to plant disease.

The third paper brings the results of 5 year experiments in Eastern Brazil. It shows that low sugar cane yields on Terra Roxa Estruturada soils, cultivated for a long time, are due to deterioration of soil structure and poor root development, even though the soil texture, fertilizer practices and extractable nutrients are the same as on a newly cultivated soil. The availability of mineral nutrients depends essentially on the soil space occupied by the root.

The next paper shows that different varieties of a crop respond in different ways to a given fertilization on the same soil and under the same climatic conditions. Therefore, fertilizer recommendations should not be made for a given crop, but for a definite variety. An uneconomic fertilizer application could be avoided in this way. Less demanding varieties, especially suitable for poor soils, do not respond to a higher fertilization and, sometimes, even respond negatively.

The last paper shows that fertilizer response depends on the soil biostructure, and this biostructure depends essentially on organic matter and on the mineral equilibrium in the soil. This experience shows that plant diseases can be avoided with better and more balanced plant nutrition.

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DISCUSSION

Chairman: F. van der Paauw

Oberländer

I think we all should be very grateful to Prof. Primavesi that he has shown us in such a nice example what happens to soils where the organic matter is not quite « in order », and besides discussing all the problems in connection with nutrient supply and with adequate fertilization. We should also find some time, maybe now, or at any other occasion during this meeting to discuss what measures can be taken to restore declining organic matter levels in the soil, particularly in support of mineral fertilization. We know what we have to do in temperate zones in such cases, but I am not sure if we always know the right remedy that has to be applied particularly under these serious conditions as described by Prof. Primavesi.

Primavesi

I think our first step is to study the physical, chemical and microbial situation of the soil, after this study, we can indicate the treatments. Our experience taught us that it is necessary to have a good organic matter level not an acid one when we will obtain a good response of fertilizer application. Generally, in tropical and in sub-tropical crop soils the organic matter level is bad. Only two or three years after cultivation of virgin soils the organic matter level will be maintained. The rain bursts are very strong and the sunshine and high temperatures provoke a very active microlife, and organic substances are used for the transformation. We have many cases where fertilizer application has not given a good economic response because of the low organic matter level, or of an acid organic matter.

RUSSELL

I would like to comment on the effect of high temperatures on the rate of decomposition of organic matter. I do not think decomposition proceeds actively in dry soils but only when the soil is moist. But when the soil is moist, plant growth will also proceed actively and puts back a certain amount of organic matter into the soil. Thus the conditions needed for rapid decomposition are the same as those needed for rapid plant growth.

PRIMAVESI

In our case, we have dry seasons, but we do not have a dry climate because we have good precipitations but they are very badly distributed. We have during three months, perhaps, precipitations of more than 1.000 mm out of a total of 1,400 mm of the year. When there is not a good soil structure, like I showed to you, all this water is lost. When we have a good one the water will infiltrate and microfile has optimal conditions: heat and water. Because of this, I suggest to create a research station, not only for study and investigation of soil chemistry factors, but also the soil's physical and microbial factors. For our situation, I think, the soil's physical factors are very important and the biological ones also.

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HERNANDO

I think there are so many questions to ask on your paper. I only make some comments so as to leave time for other people. I think the tropic, as you say, is completely different from the temperate countries, but I think there are no real differences. In different countries in Europe we have the same problems but they go slow on. In the tropics you get them very quickly, what we get in 100 years, you get in five years. For that I think tropical countries are a very good place to learn and to find when we do the things properly or not. The new people to work on our problems must learn a little on the problem of the tropical conditions, because if they do something wrong, in two or three years they spoil the soil. The same happens in our countries, but in 100 years, or much more than that, they die before finding the answers. Because of that I think this point is very important to raise. I have another question, but I prefer to leave other people to follow.

PRIMAVESI

I completely agree with you Prof. HERNANDO, but the situation is the following: in Brazil, for example in Paraná, we have virgin soils, very good virgin soils, and after two years the soil deteriorated. It does not have any more soil structure. This state is unknown in Europe — in 200 years, 300 years perhaps. For this, I make the difference between the temperate climate and the tropical climate. But in principle, I think Dr. HERNANDO is perfectly correct.

ARATEN

Prof. PRIMAVESI mentioned soils where the water is running off and not infiltrating. We have such soils and by drip irrigation the drops infiltrated. This method is also used in the south of Israel near the Red Sea, where the water has a very high content of chlorine and sulphate. You have always the growth of the plant at the maximum because you have day and night the maximum amount of water and fertilizer which a plant needs which with normal irrigation you don't get because you get it only during irrigation time and then you wait, say, three days before irrigating again, the yield goes down. Another factor is that by drip irrigation all the fruits obtained are equal in size and colour because each plant gets exactly the same amount of water and fertilizer. The percentage of export grade of tomatoes, melons, strawberries etc. is much bigger than with ordinary irrigation. This method is not intended for very large areas but for small areas it is very important. We developed in Israel this method of drip irrigation by dripping water and fertilizer on the plant only. The whole surroundings remain dry and is pratically free of weeds, and we were able really to convert part of the desert in the Red Sea area into the most beautiful gardens which are exporting melons and everything at very high prices and it is beautiful to see the result The system is laying plastic pipes on the soil and through those plastic pipes is flowing water plus liquid fertilizer, and if, say, each meter a plant there, or each half meter, near the plant in the plastic pipe is a gadget which will supply to the plant a certain amount of water and liquid fertilizer per hour. This is a very simple gadget and works very precisely. This goes on during the whole time of vegetation, day and night, drop, drop, drop.

PRIMAVESI

I admire your work in Israel but I remember that we in Brazil cannot do this because Brazil is a continent. We can only work with very cheap methods. Firstly, we must think on economical possibilities. You are a small land, you have very much intelligence and money accumulated. Our situation is different;

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we do not have the money accumulated as you in Israel. Your system can be an ideal one.

BUSSLER

I want for this last question only to direct your attention to the last picture from Dr. PRIMAVESI because I think the last picture is the most important one. The last picture has shown that there is a connection between the soil deficient in some minerals and the animals grazing on it which have not the health we want, and also the man who eats these nutrients produced by the soil. So any mistake in the soil composition would be given further to the man, to us, and this is a point which is never mentioned concerning the economy of fertilization.

BRAMAO

I would like to congratulate Prof. PRIMAVESI, and I would like to say that I would support very much his idea of establishing pilot farms throughout the State of Sao Paulo, which is a highly organized State already from the agricultural angle. Experiments at the pilot farms, taking advantage of the existing network of experiment stations in the State could really contribute much for the improvement of food production in Brazil, which is a continent by itself, but also in the whole of South America. Thank you.

PROBLEMS OF FERTILIZER USE IN LATIN AMERICA

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The rapid growth of population and the demand for a higher level of living in the rural areas make it imperative to increase rapidly the production of farmers in Latin America. The situation in Latin America is particularly critical as the average agricultural productivity for the region is only 35% of the average non agricultural productivity as reported by the Economic Commission for Latin America of the UN [20].

Recent development in some of the important crops of the area, as for example, maize and wheat, are putting the much improved and adapted plant varieties at the disposal of the farmers.

Evidently, the nutritional requirements of these more efficient plants are higher, adding to the necessity of an increased fertilizer use. In line with this necessity it was reported by FAO [23] that in Latin America during the period from 1963/1969 the nitrogen consumption increased by over 50%, that of P_2O_5 by 78% and that of K_2O by 70%. These figures are quite similar to that of the world at increases of 56% in average.

The total share of the region in world NPK consumption is however very low with slightly under 2% of the total N and K_2O use and under 3% of the P_2O_5 consumed [23]. If one considers the per area consumption, the situation is even less promising. The world average use of total N-P_2O_5 - K_2O per hectar is 39.95 kg. The Latin American average is less than the third of this with 11.30 kg/ha, less than one tenth of Europes' at 138.62 kg/ha.

The main reasons for this limited use are economic. High fertilizer prices which are illustrated in Table No. 1, are one of the reasons.

TABLE No. 1 — *Comparison of fertilizer prices in US $ per 100 kg of plant nutrient paid by farmers* [23].

Fertilizer	European prices (Austria, Belgium, France, Greece average)	South American prices (Argentina, Ecuador, Perú, Venezuela average)	Difference %
Ammonium nitrate	24.8	42.9	73
Superphosphate (over 25% P_2O_5)	17.6	26.8	52
K_2O	8.7	16.6	91

This large price differences make the use of fertilizers less attractive in Latin America than in more developed countries.

As a consequence, high yield increases are needed to pay for the fertilizers. These increases can be obtained if adequate conditions exist. One of the most thorough studies of these conditions was undertaken by the University of Minnesota in cooperation with the Ministry of Agriculture in Chile. The study [48] indicated that some of the most important factors for a rapid and appreciable increase are the following:

1. It must be known that the projected increases in production are technically possible; existing research and

production data from progressive farmers can indicate this possibility.

2. There must be an economic incentive to promote the new technology. This needs a particularly careful analysis as high fertilizer prices (see Table No. 1) and often low product values make it under some conditions unattractive to increase production.

3. The political situation should encourage better production practices, as this requires additional effort and inversion.

4. For an increased production achieved by a production education system as proposed by the Minnesota-Chile group, the existence and reasonably steady inflow of the essential means of production as high quality seeds, fertilizers, machine parts, etc., is required.

5. An adequate market must exist for the increased production.

6. It is also necessary to have an efficient research system capable of resolving the problems deriving from higher production.

Only if these multiple conditions exist, production can in many instances increase and the adequate use of fertilizers be assured. Even then progress will sometimes be rather slow.

Even with all these complicating factors existing, fertilizers can be used economically in many instances and in these situations represent appreciable increases in productivity and in farmers earnings [14, 35].

To allow a better appreciation of each main nutrient, further discussion will appear in separate subchapters.

Nitrogen use

Responses to nitrogen containing fertilizers are common on most soils and explain that the largest sum inverted for any individual nutrient goes to nitrogen. Due to the high transportation cost high analysis N fertilizers are the most used.

Under rather different conditions, no difference was found between various N sources [28, 42] in Perú. On the contrary, with the volcanic soils of the coffee area of Colombia, nitrate is recommended as it is reported to cause less cation movement [36]. These volcanic soils are often very high in organic matter, but due to the reduced mineralization of N by many volcanic soils, as reported by Bornemisza and Pineda [10] there are fertilizer responses to N up to 8% of organic matters present, and in some instances, even above this amount.

The wide usefullness of nitrogenous fertilizers is well illustrated in the case of Guatemala where, dividing the country in 14 ecological zones, and testing the areas for fertilizer responses, nitrogen needs was indicated in ten of these zones of the country [50].

For Chile, Letelier and Wright consider N a critical element, together with P. This is reflected by this country's higher than average per area consumption which being over 4.39 kg/ha is about 10% above the Latin American average [23]. Colombia has an even higher per hectar use, of over 9 kg/ha, mostly due to intensive agriculture in some quite highly developed agricultural areas, as the Cauca Valley and the coffee producing Andean area. In the mentioned valley as reported by Flor *et al* [27] a positive response to N was obtained for corn in about one third of the cases using up to 100 kg/ha of N.

However, even Costa Rica's 25 kg/ha use of N, one of the highest in Latin America, represents about one fourth of what is estimated would be used, if current recommendations be followed for all crops and pastures in the country. This might give an idea of the tremendous potential of fertilizer use in the area for N [54].

The use of nitrogen is evidently enhanced by an adequate water supply as is reported for example for Central Chile [34] and Mexico [49]. Experiments in this last country showed that the amount of N to be applied depends on the water availability for cotton, and can be economic up to 175 kg/ha.

Another very important factor in N fertilization is the ability of the variety used to take up and use this element. A good example of it is given by CORDERO, who has shown that by only considering the rice variety fertilized, can adequate recommendations be made for nitrogen use [15]. He indicated, that varietal differences affect the recommendations in nitrogen more than that of P and K which depend mainly on soil characteristics.

A few studies also exist on the effect of N application on the quality of agricultural products. BRESSANI studied the effect of fertilizers on the protein content and nutritional value of beans [11] and found no significant differences in the protein content, or in nutritional value. However, due to the appreciable total yield increase (56%) the total amount of protein produced per area increased.

A significant improvement in pasture quality was reported as result of N application in Puerto Rico [63] and in Costa Rica [3]. In the first area, up to 800 kg/ha of N were used as fertilizer to grasses for cutting. The Costa Rican experiments have shown that adequate use of N can help to maintain a better protein level in grasses, even during the prolonged dry seasons of the Pacific Coast of Central America [3].

Generally, nitrogen fertilization had a favorable effect and is practiced with certain frequency in the area. However, it has to be remembered, that heavy N use in wet areas can result in appreciable downward movement of soil cations as shown by PEARSON *et al* [51] which requires its correction by liming, so to reduce the resulting partial aluminium saturation of the soil exchange complex.

It is believed, that the use of this fertilizer should be encouraged as its effect contributes rapidily to better and larger crops.

Fertilization with Phosphates

The fertilizer used in largest amount in Latin American is P_2O_5 and this amounts to almost 3% of the world consumption according to the latest figures reported by FAO [23]. The average consumption for South America is 4.5 kg/ha, slightly more than one third of the world average and slightly less than one tenth of the European average according to the same source.

Many tropical soils are low in P [56] which also holds true for Latin America. As an example of the tremendous room for expansions of phosphate use, the study of PRICHETT and BLUE [54] could be cited; who calculated, that in Costa Rica, if the present recommendations for phosphate used would be followed by all farmers, a sixteenfold increase in the use of this nutrient would result.

The volume of fertilizer research on phosphate in Latin America is large. In the following, no exhaustive literature review is given, but only some investigations are cited which are estimated to illustrate the problems adequately.

The estimation of plant available P is difficult as the factors affecting it vary and as it is not easy to obtain correct information on the conditions estimated necessary by NYE [47].

In case of same soil groups, there is a rather general information indicating the need of phosphates. So many of the "latosols" and related oxisols respond to phosphates, if adequately used [38, 25, 45].

Phosphate problems were intensively investigated in Brazil [14, 19, 41, 43, 17, 24, 25] where this element is deficient in the cacao area [25], variable in the State of Sao Paulo [17, 14], and very low in the "campo cerrado" area [43, 41, 19]. As a consequence responses to phosphatic fertilizers are very positive and economically sound in many areas [14, 25, 41].

For some typical latosols from Amazon basin, FASSBENDER reported only a moderate fixation [24] explaining in this way the good responses to moderate amounts of phosphate as reported for similar soils [25]. For the "campo cerrado" area, phosphate application has to be part of a massive administration of major and minor nutrients accompanied by liming [41]. However, based on the good climatic and soil physical conditions, even this appears to be economic, especially now that the area is beginning to be used more intensively in some sites.

Letelier and Wright [34] estimate that for Chile, phosphorus is the most critical nutrient for most soils. They mention, that the volcanic soils called locally "trumaos" have the particular property to respond quite well to moderate P application in spite of being strong fixers of the anion.

For Perú the necessity of P is indicated for most of the soils of the high Andean area [20, 42]. Experiments with potatoes indicated that the use of up to 160 kg/ha of superphosphate is economically sound. Testing different P sources, superphosphate was found superior to basic slag and this better than rock phosphate.

The problems of phosphate use have received intensive attention in Colombia [36, 27, 6, 33, 63, 60]. For the volcanic soils on which most of the coffee of the country is grown, phosphate fixation is intensive and as a consequence, moderately soluble fertilizers, as basic slag, can be used advantageously [36]. Many soils of the cool highland respond well to P application, particularly if the fertilizer is applied in bands to reduce fixation [63, 6]. Adequate P application can double the production of crops as barley for example, while, for wheat and potato, about 40% yield increases were found [6]. One of the main agricultural areas of the country is the Cauca Valley, the soils of which were rather intensively studied. For corn only 11% of the locations gave positive response to P [27] in a recent study. In former work it was noticed that control of plant population and additional irrigation were of more importance than fertilizers. For sugarcane positive responses were obtained [6].

On the Atlantic lowlands of the country, the Sinú Valley, most of the P present is reported in the organic form, which might supply it in adequate amount to crops for a short period [60].

From the "sabana" soils of East Venezuela, it is reported that for peanut production P is the main limiting element. About 80 kg P_2O_5/Ha appears to be the optimun application [2].

There is also good information on the P problem in Central America. ORTIZ reports on positive responses of many crops to P in most of Guatemala [50]. LIZÁRRAGA'S experiments on beans confirm this report and show that better use is made of P as part of a complete fertilizer which permits over US $ 100 net profit per hectar [35].

DAHNKE *et al* [18] have found that in El Salvador, regosols and alluvial soils gave little or no response to P whereas the red latosols responded consistently, if corn yield was considered.

This agrees with MARTINI [38] who also found high responses to P for the latosols type soils tested in Costa Rica.

In Honduras, AWAN [4] found that for best P uptake liming is essential. The bean experiments for Honduras showed only slight increases for P, alone or with N [35]. For Panamá most soils are reported to be deficient in P [12] with problems of fixation for the volcanic soils.

With beans, positive results for P were reported [35] for El Salvador, especially as part of complete fertilizers.

In Costa Rica the bean experiments indicated a good response to P and an even better to NPK, again allowing over US $ 100 net profit per hectare [35].

As the coffee area of Costa Rica received a reasonable dosis of phosphate fertilizers, their residual effects are beginning to show up and the aluminium and iron phosphate content of the fertilized soils is increasing [13].

A response to residual P by grasses was reported by

VICENTE-CHANDLER [64], who has resumed the role of fertilizers in hot humid tropical pastures.

In the Caribbean area, on food crops CUNNINGHAM only reported P response to about one third of the 134 experiments evaluated [16].

Generally, together with nitrogen, P is needed for many tropical soils. Its availability is difficult to assess as under some conditions Fe and Al phosphates appear to contribute to plant nutrition as well.

Fertilization with potassium

The potassium status of the soils of the region is very variable, the same as is indicated for tropical soils in general by RICHARDSON [56]. As a consequence of the variable need, the consumption of K_2O in South America is smaller than that of the other essential nutrients. However, a rapid increase in this consumption is reported by FAO [23]. According to the same source, this increase noted during the last few years, is the most rapid in any area on which information exists. The average South American consumption per ha of usable land is only 2.66 kg., about one fourth of the world average of 10.55 kg/ha and one sixteenth of the European average of 42.01 kg/ha. An idea of the potential need can be obtained from a report for Costa Rica [54] where it is indicated, that if actual, well based recommendations would be followed in all the country for agricultural crops and pastures, the present use of K_2O would increase eight fold.

Large responses to K are indicated from many areas as Brazil [41, 14], Honduras [5]; in Colombia [36] in the coffee zone, but not many in other parts of the country [23, 24]; some regions of Chile [34]; the wet and coffee producing areas of Guatemala [50], some of the potato producing areas of Perú [42] and some West Indian soils [44] for example.

For Costa Rica the main K deficient areas are the ones occupied by latosols where this deficiency is next to that of N and P and severely limiting crop production [38].

The importance of K for intensive pasture production in Puerto Rico was shown by VICENTE-CHANDLER [64] who has shown economic responses up to 400 kg/ha/year from K_2O as part of an intensive fertilizer scheme.

In the Caribbean area about half of the experiments with food crops gave positive results to K application, while responses on sugarcane were less common [16]. In some area K fixation is low [44].

Unluckily, Latin America is almost completely dependent on K_2O import as the only small local sources are potassium nitrate from Chile and guano from Perú and both together amount only to about 5% of the actual consumption [23]. Probably, this heavy dependence on importation causes the large price difference shown on Table No. 1 between some typical European and South American potash prices.

Luckily, it is rather easy to determine the K necessity of crops by soil analysis or greenhouse test [38] which are quite capable of determining the need.

Lime Application

Probably one of the most discussed agricultural practice in the tropics is liming. Its application, prior to its understanding in tropical condition has often had negative results and contributed to discredit it. Undoubtedly many tropical crops prefer or tolerate moderate or rather large soil acidity quite well [55]. It is generally believed, that liming is particularly effective in combination with nutrient application [37, 55]. If intensive agriculture is practiced on highly leached soils, like many of Puerto Rico, the requirement will be the use of considerable amounts of fertilizers between which the nitrogeneous ones will be of major importance. Their leaching often will acidify the soils, requiring liming for its correction [1].

It is noticed, that the reduction of high soil Al and Mn levels is one of the most significant contribution of liming in that country. This is in agreement with the modern view on liming, considering exchangeable Al as the main criterion to determine lime need of leached mineral soils as oxisols and ultisols [32]. As a consequence, rather low amounts of lime are used, avoiding lime induced minor elements deficiencies which often developed as a result of heavy liming [55, 36, 61].

Positive responses to liming have been reported from many regions of Latin America, from Southern Chile [34] to Puerto Rico [1, 51] and many places in between [41, 4, 62, 61]. In many instances it is indicated that liming should be considered in addition to fertilizer application, as most of the soils requiring lime are the ones which have lost their nutrients, being a result of intensive and prolonged washing [61, 37, 41].

It was reported also that in quite acid soils from Honduras (pH_{H_2O}: 5.5) liming promoted organic phosphate mineralization and crop yield increases for corn, sorghum and beans [4]. The reduction of the effect of P by liming found in Sao Paulo State, Brazil [41] might be explained by the same mineralization enhancement also, considering the large contribution of organic P in tropical soils, which in some instances is underestimated due to the use of inadequate methodology [8].

In some areas the lime deposits are distant and the transport costs make liming an economically prohibitive practice. For these regions SPAIN [58] has proposed four alternatives which could contribute to resolve the problem. He proposed that liming might be carried out in accordance to the recent point of view of KAMPRATH [32] neutralizing completely or partially the exchangeable Al present, which can be done using moderate amounts of lime. A second alternative is the use of acid tolerant crops. In this group, there are quite a number of economically important species of tropical crops, horticultural varieties and fruits. As a third alternative, they proposed liming in bands, a practice which applied to soybeans appears to be adequate for the Llanos region of Colombia.

As fourth, long range solutions, SPAIN suggested to intensify research in plant breeding with the purpose to develop more acid resistant varieties.

Generally, as indicated by MARTINI [38], there is by far too little information on the topic, and investigation is badly needed.

Minor Elements

One of the minor elements most studied in South America is sulfur. In a review paper FITTS indicates, that the deficiency of this element is widespread in the region [26].

The largest S deficient region is Central Brazil [43, 39, 31, 40] where greenhouse and field studies confirmed the existence of large areas where in addition to liming and N and P, which are also decisive factors, S application is needed. The area is estimated to include almost 200 million hectares which is the Central Plateau of Brasil [43]. In this area nitrogen application enhances S deficiency [31]. For cotton about 30 kg/ha of S was found to satisfy optimum yield requirements. S deficiency in coffee in Brazil was also reported [31].

Sulfur deficiency in coffee was reported for Central America by MÜLLER [46]. This area has soils with rather different S status, a fact which probably can be explained by the variable retention of this element. This is rather high by latosols, smaller by allophanic volcanic soils and even less by highly siliceous materials, as reported by BORNEMISZA and LLANOS [9]. The large retention explains the rather high amounts of S reported for many of the soils from the Central Plateau of Costa Rica [7]. Very intensive washing can deplete however even retentive soils, as can be seen by the S responses obtained by many latosol soils from Costa Rica [37].

It is probable that other areas with S deficiency exist, which will be noticed when agriculture is intensified in those regions.

The deficiency of Zn is also important in the area and was reviewed by IGUE and BORNEMISZA [29]. Between the most affected areas, Brazil can be mentioned, in its Central Plateau [43, 41] and in the State of Sao Paulo [30]. It was indicated that the use of fertilizers enhanced Zn deficiency [30] and that for many "campo cerrado" soils this micronutrient was required in addition to major nutrients, lime and other micronutrients [43]. In Mexico the deficiency was reported for the Bajio region where it affects horticultural products [58]. In this area, soils are very low in Zn and soil application of $ZnSO_4$ or spraying with Zn chelate (EDTA) has corrected the foliar deficiencies and assured adequate production. Generally, this deficiency is widespread and easily corrected. For Venezuela Zn deficiency was reported for the leached red soils of Northern Venezuela [49].

The first Soil Fertility and Fertilizer Meeting for Latin America of FAO reported on Zn deficiency in coffee in Costa Rica, Guatemala and Perú [22].

Copper deficiency was also noticed in the area. It was observed in citrus in Sao Paulo State in Brazil [57] and in Perú. In this last country the deficiencies exist on irrigated alluvial and loes soils [22].

In Venezuela this deficiency was noted in the "Llanos" region of the Orinoco drainage basin and the region South Coast of the Venezuelan Andes [53].

For Chile Cu deficiency was observed in some of the volcanic soils called "trumaos" locally [34].

Generally this deficiency is not very common in the area.

The deficiency of Mn was noted mostly in coffee, as reported by the FAO meeting, for Costa Rica, Colombia and Perú [22].

Molybdenum deficiency was reported from the "campo cerrado" of Brazil [41, 43].

The deficiency of Mg was reported for coffee in Colombia [36], Costa Rica and Guatemala [22] and it is important, to note, that many fertilizers sold in the coffee area of Central America contain usually Mg. The response to the element on similar soils, as the coffee zone of Central America, the volcanic areas of Chile [34] was reported also.

One of the most important deficiencies of the area is that of Boron. The problem is widespread as deficiency is indicated from Chile [34], Brazil [43, 41], Venezuela [53], Colombia [36], Perú [22], Guatemala [22], and Costa Rica [22, 52]. Research initiated almost 20 years ago in Costa Rica [52] makes possible a complete control of the deficiency, a fact which has had a very positive influence on the per hectar coffee output in the area, affecting the most important cash crop for about a fourth of the countries on the region.

It was also observed that B deficiency affects coffee quality adversely, similarly as an excessive use of nitrogenous fertilizers.

Iron deficiency was also reported [22] on rather variable soils in Puerto Rico, in Haiti and Costa Rica. Its correction continues to present problems for different crops as for example coffee.

Generally, minor elements deficiencies are important in Latin America. Their correction is usually cheap if the method is known. It is believed that much confusing information from NPK experiments is due to the lack of information of the minor element status at the sites of the experiments. Intensified research on minor elements is urgent and can contribute to appreciable increases in production with small additional investments.

Some unusual approaches to maintain soil fertility were investigated recently in Puerto Rico and are worth considering. So VICENTE-CHANDLER and coworkers [66] examined the possibility of growing a series of crops in soils of the humid mountain areas of the island without tillage. The results indicate that a good many crops as tobacco, sugarcane, plantain, yams, corn, beans and sweet-potatoes can be grown without tillage, but generally with good agricultural practices in highly weathered oxisols reducing greatly the erosion problems which are serious there and at many similar areas.

Another interesting experiment of the Puerto Rico group [65] consisted in growing several crops under shade of abandoned coffee plantations. It was observed that at about 50% shade several crops as tabacco and bananas could be grown successfully. Other crops such as corn had their yield reduced. This also allows the use of soils under a true cover and contributes to conservation.

Similar unorthodox approaches should be invented and examined, requiring original, ample and well designed research in the area to provide the information on which progressive agriculture can be expanded.

It is the responsability of the experts in the developing countries to do the most useful work and it is hoped that this will meet with the help of countries which derived part of their wealth from the cheap raw materials coming from the developing areas of the world.

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DISCUSSION

Chairman: F. VAN DER PAAUW

BUSSLER

I want to ask Mr. BORNEMISZA: does he know that there is not much molybdenum deficiency in his country? Have you systematic soil surveys? Do you know the symptoms of deficiency always, because I cannot say we have it in Germany; in Germany we have only some districts where we have a systematic analysis of the soils and we do not know all the symptoms which may appear and so I would not trust so much the advice from an expert who said that here or there is no deficiency in trace elements.

BORNEMISZA

Excuse me, I said we don't know about deficiencies, I did not say we don't have them. That is quite different.

HERNANDO

I followed your paper because I had no time to read it before. and I have one point I would like to say here. You talk about the use of aluminium phosphate by the plant. I say that from our experience that if the aluminium retains the phosphate and the compound is not for long formed in the soil, it is more useful for the plants than another compound of acid soils.

The second thing I would like to say is, you speak about the use of pesticides joint with fertilizer prepared in factories or recommended by them. This is a method well-known in Europe and in other developed countries, but as I said this morning, it was not possible for me to prepare the paper I intended to bring here. In a study we developed during four years in the East of Spain, in the area of Valencia and Castellon, we found that where farmers applied pesticides and where they did not, there was no difference in the aspect of the orchards.

The healthy thousand orchards we selected were not related to pesticides but more to the level of potash in the soil. Soil with a high level of potash normally offers very good growth conditions to the plants, and many times no pesticides are used. I think this is a very important point. It is the same as when one eats properly one gets everything one needs, and there is less chance of illness. With the plant it is the same. Maybe we stress too much the use of pesticides for treating the plants before knowing if the plants are receiving what they need. I said this morning, but maybe I did not explain myself clearly, that when Liebig said, last century, that the plant takes some elements from the soil, and we need to replace them in the soil, we thought only of three elements until a very short time ago. At the time of Liebig, maybe this was right, but I think now that not only in the tropics but also in temperate countries the problem is greater, it is a problem of more elements and first we must know if we are supplying to the plant all it needs before using pesticides.

ARATEN

Prof. BORNEMISZA spoke about the contribution of aluminium phosphate to nutrition in the long run. There is no doubt that this is often the case but I would like to tell what a Brazilian farmer told me when we discussed fixation of phosphates, he said « I have to pay 10% per month interest on the money I require for fertilizers and paying 120% interest per year I cannot invest in long range recoveries of phosphates ».

BORNEMISZA

I think this has improved quite a bit in Brazil but generally the cost of inversion is high. There are also a number of countries where fertilizer loans are at about 4% to 5% per year, so one can invest a little bit more generously, but I did not think in a year in this long range use. Most of my information comes from greenhouse testing which we have done on Central American soils and even crops growing in cycles of 3 to 4 months we have proven to have taken up considerable amounts of P from the aluminium phosphate fraction. It was thought that it was necessary that extracting solutions which give reasonable correlations in the area have at least a degree of solubility for these phosphate category.

WALSH

Just a remark in relation to iron aluminium phosphates. Our work has very clearly shown that some iron and aluminium phosphates, are to a very considerable extent available to plant growth in acid soils and not only in the long run, but also in the short-run. I think that the text-books have misled many people in this respect. On the other point that you raised here about liming some of the "campo cerrado" soils. It is our experience that some of these are not only quite acid and indeed, very acid. It seems strange that some technique of liming these soils has not been developed or that there is some doubt about the value of liming them. Have you tried any gypsum on these soils to provide both a source of calcium and sulphur? Finally about molybdenum. It would seem, theoretically anyway, that for these "campo cerrado'' soils with only a low capacity for trace elements, in actual fact molybdenum deficiency might be expected and from some analyses on these soils, molybdenum deficiency has in fact been found.

BORNEMISZA

One of the two references I have on molybdenum deficiency is from the ''campo cerrado », so it is in the literature already that they are deficient on molybdenum. Now with regard to care with liming, this does not refer to the ''campo cerrado'' soils. Actually there are not any minor elements there one could precipitate so nothing could go wrong. The only reason for using a lower amount of lime is transportation costs, but there are a good many soils which are much younger. ''Campo cerrado'' soils belong to the oldest in South America, and the Brazilian Plateau is a tremendously old area, geologically speaking. While most people live on the borders of South America in the Andean area, which are, of course, geologically kids, now in this younger area leaching was by far not so intensive in this couple of million years of difference so minor elements still exist and by intensive liming can get precipitated. Also those soils quite often have allophonic clays which require a fabulous amount of lime for pH changes. I have seen soils which needed 20 tons of lime to change may be one pH unit or something. This is evidently not economic and those are not the soils from the old areas, but this is a common thing in the Andes.

THE ROLE OF FERTILISERS IN AFRICAN AGRICULTURE

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The primary purpose of introducing fertilisers into African agriculture is to help the local farmers increase the yields of the crops they are growing; but experience has shown very clearly that for the introduction of fertilisers to be profitable it is usually necessary to raise the whole level of farming that is being practiced; for only rarely does the introduction of fertilisers into a traditional system of agriculture give increases of yield that are financially profitable to the farmer. It is easy to see the truth of this observation since, in spite of several decades of good experimental work in which it has been shown very clearly that fertilisers are essential for high crop yields, and that under good management the use of fertilisers will sustain high crop yields, the actual amounts of fertiliser used in tropical Africa on general farm crops is still very small. I believe the comparative failure of the research and agricultural extension workers in persuading the local farmers to increase their crop yields and their use of fertilisers very largely lies in the lack of appreciation of the conditions that allow their profitable use on the farm.

In developing countries, fertilisers tend to be more expensive to the farmer than in developed countries, and the price received by the farmer for his produce lower. This means that the farmer in these poorer countries must obtain an appreciably higher yield response per unit of fertiliser than his European counterpart, so that one of the essential tasks of the research agronomist in Africa is to learn how to maximise fertiliser response. We now have adequate experience to give an answer in general terms to the question of what agronomic conditions must be fulfilled if crop responses to fertilisers are to be maximised. They are that the variety of the crop used must be capable of responding to a high level of fertility, the seedbed must be favourable for good even germination, the crop must be managed to ensure that its growth is as little affected by unseasonal rain, drought, heat or cold as possible, and pests, diseases and weeds must be controlled. There are many examples in Africa of the use of fertilisers being uneconomic if any one of these conditions is not fulfilled, but of being very profitable if they all are.

Fertilisers are therefore one, but only one, of the many aids farmers have for increasing the production and the profitability of their holdings. In the past, many research agronomists have ignored these limitations on fertiliser use, so that much of the earlier research work has simply shown that unless adequate precautions are taken to ensure the crop can respond to fertilisers, it is very likely they will not give a worth-while response. But this can raise very difficult problems of agricultural policy, both for the local governments and the extension services; for whilst it is, comparatively speaking, easy to adopt a policy of trying to introduce the use of fertilisers into an existing system of agriculture, without making any other change in the system, it may only be financially worth while on a small fraction of the land; whereas financially worthwhile responses could be obtained over a much larger proportion of the region if the more difficult policy of trying to raise the whole level of farming was adopted.

Let me illustrate this by a simple example. In many parts of Africa, average levels of maize yields are probably of the order of 1-2 tons per hectare, yet yields of 5-7 tons per hectare are obtainable using present-day varieties and management techniques. It is often found that, at the lower levels of yield, there is little response to fertilisers, whereas the higher yields can only be obtained using a high level of fertiliser. Thus SCAIFE (1968) showed that in western Tanzania the local maize only gave a response of 1700 kg/ha grain to 180 kg/ha N, whilst a Kenya hybrid gave a response of 2540 kg/ha. The practical question of whether the farmer should be advised to use fertiliser or not depends entirely on what level of yield the farmer is aiming for.

But the possible introduction of fertilisers into African agriculture raises a whole host of problems that must be solved before this becomes a practical possibility on a large scale. Let me start with three problems. Assuming the extension staff have demonstrated the likely profitability of a given level of fertiliser use, the farmer must be able to obtain the fertiliser in a suitable size pack at the time he wants it; he must normally be able to obtain credit to pay for it; and he must have the assurance that if he gets a higher yield due to its use, this extra production will not reduce the price he gets when he comes to sell the crop. If, as is likely, he needs an improved variety of the crop to get a high fertiliser response, he must also be able to buy the required seed, guaranteed true-to-type, at the time he needs it; and if he must protect his crop against pests and diseases, he must be able to obtain the correct pesticide or fungicide in a suitable pack for use at the correct time. These conditions require an economic and marketing infra-structure that is almost entirely lacking in many African rural areas; but until it has been built up, no amount of demonstrations on experimental fields of the magnitude of yield response that fertilisers will giwe, will enable the farmer to put into practice the teachings of the extension staff.

It is not the function of this paper to discuss the social and economic problems that must be solved before the use of fertilisers can become widespread in Africa, but I am emphasing the existence of these problems at the outset because all too frequently in the past, the research and extension agronomists have been inclined to place the blame for their failure to get what they considered to be improved fertiliser practices adopted on the incompetence or ignorance or laziness of the farmer rather than on the absence of the necessary infra-structure. This denigration, often unconscious, of the small farmer by the research and extension service has had the unfortunate result that the systems of farming being developed on the research and experiment farms have become completely divorced from the whole basis of the traditional system, without any attempt being made to see how far the improved methods could be grafted on to the local system, to make them more acceptable. This has the consequence, that has already been noted, that whilst the crop yields on the experiment stations are often rising fairly rapidly, those on the local farms on their perimeter are only rising slowly, if at all. One of the most urgent problems in agronomic research is to understand the full reasons for the traditional systems, and find out how to modify it in a way acceptable to the local farmer, to allow him to obtain the increased productivity and profitability that the research worker has shown to be possible.

Let me give some examples to illustrate this. First nearly every fertiliser experiment on a research or experiment station has been made on a field planted to a single crop, whereas the local farmer probably practices mixed cropping, growing a number of different crops simultaneously on the same piece of land, though the individual crops may be planted and harvested at different times. Quite clearly there is no reason to expect that the response of, say, maize to a fertiliser will be the same if it is the sole crop or if it is interplanted with a number of other crops. Table 1 taken from some work of AGBOOLA and FAYEMI (1971) at Ibadan, Nigeria, is an exem-

TABLE 1 — *Effect of a Complete Fertiliser on the Yield of a Maize-Grain Legume Intercrop.*

Ibadan, W. Nigeria. Fertiliser: 56 kg/ha N, 10 kg/ha P, 56 kg/ha K
Mean yield of two second season crops in kg/ha.

	Maize alone	Cowpeas alone	Maize plus Cowpeas	Green Gram alone	Maize plus Green Gram
No Fertiliser	1000	950	1410+505	900	1255+800
With Fertiliser	2150	1370	1780+820	1210	1780+455

Cowpea: *Vigna sinensis* Green gram: *Phaseolus aureus*

ple of one of the very few published experiments on the effect of fertilisers on mixed cropping that have been published from Africa, and shows that mixed cropping with the maize-cowpea combination is a more productive use of land whether fertilisers are used or not. It may later on be found that if high production is to be the policy goal, cropping with a single variety will be essential, but very little work has been done to prove if this is correct. It is obviously essential that much more work be done on the possibility of an appreciable upgrading of yields under modified systems of mixed cropping, to demonstrate to the local farming population that the policies of the research stations are really being geared to their needs.

There is also a further point that should be made here. In general the farm director at the experimental farm has been carefully selected as an exceptionally good farmer, to ensure that the standard of farming on the station is as good as possible. Yet the results obtained on this station are often assumed to apply to the local conditions in which, by definition, half the farmers will be poorer than average, and the average is likely to be a good deal poorer than the farm manager. Thus it is essential that the improved methods accepted by the extension workers should be such that at least a reasonable proportion of the local farmers have the necessary skill to use them sensibly and profitably. This has, naturally, been realised at some places at some times, but this recognition has unfortunately been the exception rather than the rule.

As a second example let me take work on the value of farmyard manure and short-term grass or grass-legume crops for the maintenance of soil condition or soil fertility. There are very good reasons why research stations in Africa should discover exactly what benefit these practices confer on tropical soils under various farming systems, for they are widely used in various regions in high-production temperate farming. But even if it can be shown that farmyard manure and the grass ley (a temporary pasture) increases crop yields, it may have little relevance locally. Thus farmyard manure can only be used if the animals are kept in yards, either at night or during certain parts of the year, and also that there are methods locally available for transporting it from the yard to the field. If the sole local form of transport is baskets carried on women's heads, it is unlikely to be used, although it may be well worth using if ox carts are available. Again grass or grass-legume leys lasting 2-3 years will have very different values to the farmer if they are being grown simply to improve the soil than if they are being converted into meat by local cattle, or if into milk by high yielding exotic cows. This means that research into the effect of organic matter on soil fertility should be very closely linked to the types of animal production that are open to the farmer under existing conditions, or under conditions that can easily be provided. Unfortunately this was largely ignored by agronomists in the past, so that little attention has been paid to some quite impressive experimental results on the benefits to be obtained from these practices.

Traditional African farming is based on shifting cultivation, in which a piece of land is cleared, cultivated for a few years until the crop yields fall too low for their cultivation to be worth while, or the land gets too weedy; it is then abandoned for a number of years, but the local livestock are likely to graze it, before it is cleared and cultivated. The amount of livestock production from the land, assuming conditions are suitable for much livestock, is very low as the amount of fodder grown on this impoverished land is low. Typically the natural vegetation brings up nutrients, including calcium and magnesium, from the subsoil, which makes good the impoverishment of the surface soil due to the previous cycle of arable cropping.

It is surprising that there have been few good experiments showing the minimum conditions that must be satisfied if acceptable yields under continuous cropping are to be obtained from the land. Only recently has it been explicitly realised that continuous cropping of these soils of low exchange capacity lowers the soil pH, due to the removal of potassium, calcium and magnesium from the land in the harvested crop. In Uganda for example, JONES (1968) showed it can be equal to a fall of about 0.07 pH units per year. This means that it is important to maintain a supply of these cations to the soil. It can be done by regular applications of farmyard manure, or by the use of fertilisers containing suitable amounts of these cations. It is not actually necessary to apply farmyard manure, applying the ashes of the manure after it has been burnt is just as efficient. Further the higher the yield of the crop, the greater the removal of these cations from the soil, and the more important it is to ensure that the pH of the soil does not fall too low.

It can easily be demonstrated that continuous cropping is possible on most African soils, as most experimental farms have at least a few fields that have been in continuous cultivation for many years; but this does not necessarily mean that this practice is agriculturally profitable. There have been few successful long-term experiments, because yields can only be maintained if adequate levels of fertiliser are used; and in probably all these experiments ammonium sulphate was used as the nitrogen fertiliser, and no attention was paid to the effect of the soil acidity it produced on the crops. In most experiments, after a few years, the soils became too acid to give high crop yields, but it is not possible to tell in any particular experiment at what stage acidity began to affect the yield. I am not aware, in fact, of a single experiment that has been carried out, and the results worked out and published, in which a serious attempt has been made to test how far it is possible to maintain high crop yields based on a scientifically based fertiliser policy and a sensible crop rotation.

General Fertiliser Requirements of African Soils

African soils, like soils in all other parts of the world, have a wide range of natural fertilities, from soils that are almost pure quartz gravel, and so of no agricultural value, to soils of high natural fertility. But over considerable regions of Africa, soils developed on old land surfaces which have not been subjected to serious erosion can be divided into two groups — the savanna and the forest soils. The savanna soils are those which have carried a savanua-type vegetation for a long time and are subjected to a fire running through the vegetation most dry seasons; and forest soils are under closed forest in a climate sufficiently moist for the vegetation to be too succulent to burn. The characteristic of many savanna soils is that the vegetation brings up calcium, magnesium and potassium from the subsoil during the early dry season, most of which is returned to the soil surface as ash after the burn. All the nitrogen in the vegetation is naturally lost in the burn. Typically also the phosphate content in the deeper subsoil appears to be low, so little can be brought up by the roots. These soils are thus liable to be low in orgauic matter, available nitrogen and available phosphate, but to have some reserve of potassium, calcium and magnesium in the surface.

Forest soils bring up less nutrients from depth, because they typically occur in areas not subjected to a prolonged dry season, their litter falls on to the soil surface and, in so far as it is not eaten by termites, it becomes incorporated in the surface soil. Thus the nitrogen it contains tends to remain either as organic nitrogen or, if converted to ammonium or nitrate, will be taken up by the trees in this form. Forest soils are thus usually better supplied with organic matter than are savanna soils, and so have higher reserves of organic nitrogen and phosphate in the surface soil and these mineralise slowly on cultivation, as shown by NYE and BERTHEUX (1957). They are however typically more poorly supplied with potassium, perhaps because grasses keep more potassium in cycle than forest trees; and the crops grown on these soils typically respond to potassium manuring, though this is partly due to a much larger proportion of the crops grown in these areas being root crops, such as yams (*Dioscorea* spp.), sweet potatoes (*Ipomoea batatas*) and cassava (*Manihot esculenta*), which have a much higher potassium demand than the cereals or grain legumes. These general statements however become increasingly less valid as land is cropped continuously and intensively.

There are very few soils that can maintain high yields of cereals without the use of nitrogen fertilisers. Very little work has been done on the fate of the fertiliser nitrogen added to the soil. The fertiliser that has been used most extensively in the past is ammonium sulphate, because it was readily available on the world market. It is a very well-conditioned fertiliser, and is considered to be relatively cheap; but this is largely because its effect on making the soil acid has been ignored. If the cost of the calcium carbonate or oxide that must be applied to the soil to neutralise the acidity produced is added on to the cost of the fertiliser, it is an expensive fertiliser; and since there is a strong temptation not to use this carbonate, it is a very dangerous fertiliser if used continuously. Other nitrogen fertilisers, such as urea, or ammonium nitrate, also make the soil acid, but only about one third as much calcium carbonate per unit of nitrogen added is needed to neutralise this acidity. On the other hand ammonium nitrate — calcium carbonate blended fertilisers have little effect on soil acidity, though they tend not to be so well-conditioned as the others. It is far from certain that the Governments of some developing countries, when they have been deciding on what type of nitrogen fertiliser to manufacture, have allowed for the cost to the farmer of the calcium carbonate he should use regularly to maintain the pH of his soil in an acceptable range.

There has been a considerable body of work on the phosphate manuring of tropical crops. At one time the statement was made that tropical soils fixed phosphate strongly, in a way different from that of temperate soils. In general, experimental work has not borne out this earlier belief, and in fact most tropical soils hold phosphate in much the same way as temperate soils. Where they often differ is that their initial phosphote status is much lower than was found on well-farmed temperate soils. This has the consequence that the residual effect of a small dressing of placed phosphate is often small compared with its effect in the season of application; and it may take a number of small applications for the phosphate level of the soil in bulk to be raised. Tables 2 and 6 illustrate the response of crops to a single dressing of superphosphate for a number of years afterwards. The Makaveti site is an area very subject to failure of the rains, so only rarely have two crops per year come to harvest, the Ghana sites were in a more reliable rainfall area; and the Kano site, in Table 6, is also in an area of fairly reliable rainfall. These residual effects are as striking as any found in the temperate regions.

Repeated small dressings of phosphate fertiliser would therefore be expected to build up the phosphate status of tropical soils, and this is illustrated by some experiments by Evans (1963) the results of which are given in Table 3. On

TABLE 2 — *The Residual Effet of a Single Dressing of Superphosphate.*

(*a*) on a basement complex soil at Makaveti, Kenya (BOSWINKLE 1961). Phosphate given as double super, in 1952. Yields in kg/ha

Year Crop	1952 millet	1953 beans	1954 maize	1954 millet	1955 millet	1956 millet	1957 beans
No Phosphate	405	755	1920	410	1290	790	785
Response to							
19.5 kg/ha P	525	160	585	120	105	85	40
39 kg/ha P	720	250	785	175	190	120	125

Bulrush millet: *Pennisetum typhoideum* Beans: *Phaseolus vulgaris*

(*b*) Savanna zone in Ghana. Results of a number of experiments. NYE, 1954) Percentage Response to a single dressing of Superphosphate

	Direct			First year Residual			Second year Residual		
Level of P applied kg/ha		9	18		9	18		9	18
Cereals	(9)	14	25	(15)	13	22	(4)	5	25
Groundnuts	(8)	10	8	(6)	8	14	(3)	19	16

Numbers in brackets: number of experimental sites averaged.
Cereals include bulrush millet, sorghum and maize.
Groundnuts (peanuts): *Arachis hypogaea.*

TABLE 3 — *Build-up of Response to Phosphatic Fertilisers.*

(*a*) Adequate Rainfall: Nachingwea, Tanzania

Fertiliser 9 kg/ha P as superphosphate,
plus 47 kg/ha N as ammonium sulphate

Yields in kg/ha

Year	Control	Maize Response to fertiliser	percent response	Control	Sorghum Response to fertiliser	percent response
1954	2050	380	19	1330	320	24
1955	1950	950	49	1210	695	57
1956	1650	745	51	1065	660	62
1957	1800	1090	61	1405	965	69

(*b*) Erratic Rainfall: Mwanhala, Tanzania

Fertiliser 9 kg/ha P as superphosphate,
plus 23 kg/ha N as ammonium sulphate to maize

	1957	1958	1959	1960	1961
Groundnuts					
Control	980	525	275	675	785
Response to P	185	205	70	605	950
percent Response	19	39	25	89	121
Maize					
Control	1760	750	415	1135	795
Response to NP	925	1165	975	1870	2660
percent Response	53	155	235	166	334

both these sites the response to phosphate builds up over the years, which it can only do if there is little fixation, in the sense of reversion to a form of such low solubility that it is of little benefit to crops. Phosphate is much less mobile in soils than is nitrogen or potassium, and roots can only take their phosphate from soil within about 1 mm. of their surface, so crops can only take up the large amounts of phosphate needed per day for high yields if the general body of the soil is well supplied.

There appear to be very few examples of soils in which crops will respond to fresh phosphate but not to residual. The soils one would expect to show this would be soils high in active iron oxides and hydrated oxides, but in most tropical surface soils these iron oxides are well crystallised and therefore have a small surface area. Soils high in active aluminium and low in phosphate could also fix phosphate strongly, but these soils are usually young soils derived from the weathering of basic igneous rocks which do not seem to be very phosphate responsive, although capable of supporting high yields. It is probable that as these soils age, the aluminium hydroxide becomes converted to kaolinite, which is not a strong fixer of phosphate. It is in fact probable, but not yet conclusively proven, that soils in the savanna tropical and subtropical zones have appreciably smaller surface areas of iron and aluminium oxides and hydrated oxides than temperate soils, and that they would in consequence be expected to fix phosphate less strongly.

The introduction of potentially high-yielding crops with an associated higher use of nitrogen and phosphate in the savanna zone is resulting in an increased probability of responses being found to other fertilisers. In the past potassium fertilisers rarely gave any responses, and often reduced yields somewhat, in this zone when only low yields were being obtained. But increasingly potassium fertilisers are becoming essential for high crop yields, as shown by HEATHCOTE and STOCKINGER (1970) in Northern Nigeria. This is largely because, as shown by WILD (1971), the potassium reserves in these soils are low, as they typically only contain small amounts of micaceous clay, which is the source of extractable but non-exchangeable potassium.

Sulphur responses have been found erratically in tropical Africa, particularly with groundnuts and some other legumes in continental areas. As long as single superphosphate and ammonium sulphate were the normal forms of phosphate and nitrogen, sulphur deficiency was rarely noted; but it is clearly uneconomic to supply phosphate to crops merely requiring sulphate, or to use single superphosphate instead of ammonium phosphate or concentrated superphosphate simply as an insurance against a possible sulphur deficiency. In regions where sulphur responses are found, it may be more economic to use elemental sulphur, either by itself or as a dust, or mixed in the suitable proportion with concentrated superphosphate, where it is needed. Little is yet known about the return of sulphate to the soil in rainfall, but in some areas this is likely to be of the same order as the amount removed from the land by relatively low-yielding crops.

Intensive cropping may lead to the soil calcium supply falling too low for calcium-demanding crops, but as will be mentioned in the section on liming, the calcium in calcium mono-phosphate appears to be a useful source. However small regular applications of calcium carbonate may become increasingly necessary as the use of nitrogen fertilisers extends. There is still little evidence that trace elements are seriously deficient in most African soils. Continued high-intensity cropping is probably leading to boron levels that are too low for high sustained yields in some soils, for there are increasing number of instances where the application of a boron fertiliser is giving enhanced yields. Molybdenum deficiency is probably the cause of a small loss in yield of leguminous crops on some acid soils, but this can be rectified by liming, which is probably the most appropriate way of correcting it. Copper deficiency has been found on a few volcanic soils, but is not known to be widespread or of significance outside these areas. Zinc deficiency is probably found more with tree crops than with the arable food crops, with which this paper is being devoted. I am not aware of any examples of manganese deficiency on soils of reasonable potential fertility.

Effect of Fertilisers on Crop Quality

This is a subject on which very little work has been done, but some American work by MILLER et al (1964) has shown that the protein content of sorghum is very dependant on the level of available nitrogen. They found that in one country of Kansas 90 kg/ha N increased the yield of sorghum by 1150 kg/ha and the protein content of the grain from 7.8 to 10.1 percent; and in another country 135 kg/ha N increased the yield by 3000 kg/ha and the protein content from 6.8 to 10.7 percent. If this finding is generally true, it would be of great nutritional importance in those areas of Africa where sorghum forms an important source of food for the local population; though it would be very difficult in practice to arrange for the farmers producing high protein sorghum to receive a higher price for the crop.

In most of Africa at the present time sorghum yields are much less responsive to nitrogen than in America, probably because most African sorghums tend to grow to heights of 3-3½ m. compared to the 1-1½ m. of American sorghums, with the consequence that most of the extra dry matter produced by nitrogen fertilisers goes into increasing the yield of stover in Africa, rather than into grain. Thus GOLDSWORTHY (1967) finds that in N. Nigeria 1 kg/ha N increases maize yields by 15 kg/ha, under good conditions, but sorghum yields by only 6.5 kg/ha, though SCHUMAKER (1967) using an improved short sorghum in Uganda finds responses of 15-25 kg/ha sorghum grain per 1 kg/ha N in the presence of adequate phosphate, showing that the semi-dwarf improved sorghums behave in the same way in East Africa as in Kansas.

The Need for Liming Tropical Soils

This is a topic that has not received much critical attention, largely because early work showed that liming many acid tropical soils, whose pH was usually well above 5, either had no effect on crop yield or even reduced it slightly. There have however been a few exceptions. Thus HOLME and SHERWOOD (1954) showed in a series of experiments with wheat in the Kenya Highlands that this crop only responded to lime on soils with a pH below 5.0 — a result quite out of keeping with temperate experience. NYE and GREENLAND (1960) in their review of fertiliser responses in Africa, also concluded that there was little evidence for the value of liming on soils with a pH above 5.0.

More recent work has aimed at obtaining a better appreciation of the conditions under which liming may be beneficial. They are (1) to neutralise aluminium ions (2) to supply calcium (3) to supply molybdenum to the plant. Unfortunately there is still regrettably little good critical work which can be used to forecast how much lime should be added to any particular soil, but the present position appears to be as follows. HEATHCOTE (1970) showed that, for the Nigerian soil he was using, liming the soil to a pH of 5.1 (in 0.01 M $CaCl_2$) reduced the exchangeable aluminium in the soil to a very low level and was the optimum level for the variety of maize he was using; it also raised the level of molybdenum in the foliage, which was at a very low level in the plants growing on the unlimed soil. Work elsewhere indicates that other, possibly most other, tropical soils have a low level of exchangeable aluminium when the pH exceeds about 5 — though different workers use different methods for measuring pH so their results are not strictly comparable. It is unlikely that most tropical crops benefit from a soil pH above that at which the exchangeable aluminium becomes small.

Some crops definitely require a certain level of calcium for good yields, but this can be supplied as effectively by calcium sulphate, which is present in single superphosphate, and probably also by calcium mono-phosphate, which is the principal component in triple superphosphate FOSTER (1970) working in Uganda finds that groundnuts normally only respond to the calcium in lime or in gypsum on acid soils, so is apparently relatively tolerant to aluminium, whilst beans (*Phaseolus vulgaris*), sweet potatoes (*Ipomoea batatas*) and cotton have both a calcium requirement and a sensitivity to aluminium.

Continuous arable cropping of land, without the use of fertilisers or manures, reduces the pH of the soil through a continuous reduction in the level of exchangeable calcium and magnesium. Further the continuous use of ammonium sulphate as a nitrogen fertiliser also leads to a marked continuous reduction in the pH of the soil, for, as in temperate countries, 100 kg. of ammonium sulphate removes the equivalent of about 110 kg. calcium carbonate from the soil, if the soil contains adequate amounts of calcium, (DJOKOTO and STEPHENS 1961 and STEPHENS 1969). There is a considerable body of field experience which indicates that on many soils, the regular annual use of ammonium sulphate leads to loss of crop due to the build-up of soil acidity, even though the pH may not have fallen as low as pH 5.1; and it is possible that soils made acid artificially will contain exchangeable aluminium at appreaciably higher values of soil pH than natural soils at this same pH.

There is also evidence that, in some areas, one of the consequences of soil acidity, particularly if it has been caused by ammonium sulphate or continuous cropping, is a loss of crop yield due to molybdenum deficiency. There are definite examples from Kenya which show that yields on some highland acid soils can be increased either by applying lime or ammonium molybdate, and at Samaru in Northern Nigeria it is likely that at least a part of the harmful effect of increasing acidity on crop yields is due to an increasing unavailability of molybdenum (HEATHCOTE and STOCKINGER 1970). There is an urgent need for the causes of the loss of crop yield due to the acidifying effect of ammonium sulphate to be examined critically because many developing countries are importing this fertiliser.

The reasons why liming often puts down yields has not been critically assessed. HEATHCOTE and STOCKINGER (1970) showed that, for the savanna soils of N. Nigeria, it was probably due to it reducing the concentration of potassium in the soil solution. Adding lime to a soil will increase the calcium ion concentration in the soil solution. which would be expected to reduce the potassium ion concentration, which could induce a potassium deficiency if the potassium ion concentration is low in the first place. They found in four of the five experiments they made with cereals at Kano that the crop only responded to lime if a potassium fertiliser was given. Thus in one experiment the yields of sorghum grain in tons per hectare were: No lime, no K 1.30, lime, no K 1.19, no lime K 1.96, lime, K 2.78. DJOKOTO and STEPHENS (1961) concluded from the results of 30 longterm fertiliser experiments in Ghana that there was a good correlation between the response of cereals to potassium fertiliser and the ratio of exchangeable calcium to exchangeable potassium in the soil. This conclusion is consistent with HEATHCOTE and STOCKINGER'S results, but it highlights the need for more extensive experiments on the effect of lime when the effect of all known ancillary factors have been allowed for.

The Role of Organic Manures

It is of great importance to determine how far it is possible to maintain high crop yields on the principal types of African soils using fertilisers only, for there would be great difficulty in introducing a system of agriculture requiring the production, storing and spreading of farmyard manure in many parts of equatorial and inter-tropical Africa. There is unfortunately only little direct information available on this from Africa itself, because all the long-term fertiliser experiments that have been running for more than five years have relied on ammonium sulphate as the source of nitrogen, and in no experiment has any calcium carbonate been used to neutralise the acidity it causes. Thus in so far as fertilisers fail to maintain yields, compared with farmyard manure, the cause could be the harmful effect of increasing soil acidity.

BACHE and HEATHCOTE (1969) have given an example of the effects of annual dressings of manure and fertilisers for a 15-year period on a loamy fine sand overlying a loam to sandy clay loam subsoil at Samaru, N. Nigeria, and some of their results are given in Table 4. The manure increases the cation exchange capacity, the exchangeable calcium, magnesium and potassium, the organic carbon and nitrogen content of the soil, and its pH, but decreases the exchangeable aluminium and manganese compared with the unmanured soil; superphosphate behaves like manure, but its effect is not so marked, but ammonium sulphate decreases the exchangeable calcium and magnesium and pH, but increases the aluminium and manganese.

The general experience of research workers has been that the benefits of the manure lies in the minerals it contains rather than with the organic components. Thus SCAIFE (1971) working at Mwanhala Tanzania, in a semi-arid region, found no evidence that over a 9-year period, manure had any cumulative benefit over an NP fertiliser, or that yields suffered less on the manured than the fertilised plots in years of low rainfall. On the other hand, J. E. PEAT and K. J. BROWN (1962) working at Ukiriguru, not far from Mwanhala, but with a rather more reliable rainfall, found a dressing of 15 t/ha of manure, once every three years, progressively increased

TABLE 4 — *Effect of Farmyard Manure and Fertilisers on some Soil Properties.*

Samaru, N. Nigeria

Soil sampled after 15 annual applications; topsoil 0-15 cm.

	Farmyard Manure		Ammonium Sulphate		Superphosphate	
	0	5 t/ha	4	24 kg N/ha	0	8.8 kg P/ha
% Carbon	0.24	0.43	0.31	0.34	0.30	0.36
Cation Exchange Capacity m eq/100 g	2.17	2.83	2.42	2.50	2.40	2.57
Exch. Ca	0.73	1.14	1.03	0.83	0.73	1.12
Exch. Mg+K	0.44	0.68	0.60	0.53	0.54	0.57
pH (water)	5.42	5.82	5.95	5.36	5.62	5.64
pH (0.01 M $CaCl_2$)	4.03	4.44	4.56	3.98	4.14	4.36
Conc. in 0.01 M $CaCl_2$						
Al 10^{-6} M	78	11	7	78	57	19
Mn 10^{-6} M	36	14	10	40	36	13

the response of cotton to an NP fertiliser, as is shown in Table 5; but unfortunately it is not possible to decide if this is due to the additional minerals which it supplies, for the Ukiriguru soil is light textured. HEATHCOTE (1970) found that at Samaru maize responded better to the ashes of farmyard manure than to fresh manure ploughed in, and GREENWOOD (1949) showed that at Kano, the sole benefit of farmyard manure was due to the phosphate it contained, as is shown in Table 6. On other soils and for other crops, its value may lie in its potassium content, as STEPHENS (1969) showed for sweet potatoes, (*Ipomoea batatas*) in Uganda, or with its phosphate and potassium content for crops which respond to

TABLE 5 — *Response of Cotton to an NP Fertiliser in the presence and absence of Farmyard Manure.*

Ukiriguru, Tanzania: Seed Cotton in kg/ha

	Control Yield	Response to 15 t/ha manure	Response to NP in presence of manure	Response to NP in absence of manure
First cycle 1950-53				
Season of application	1030	425	885	680
First residual year	350	135	355	210
Second residual year	1250	385	620	585
Second cycle 1953-56				
Season of application	760	595	710	470
First residual year	990	850	1430	1010
Second residual year	870	585	1060	730
Third Cycle 1956-59				
Season of application	870	770	1195	770
First residual year	1040	735	1050	530
Second residual year	1050	330	380	260

both of these nutrients, such as finger millet (*Eleusine coracana*). There is still no good evidence for the fertilizer value of nitrogen in the manure, but this is generally low, due to the inefficient methods of storage usually adopted.

The Role of Resting Crops

Traditionally the African allowed his land to revert to natural vegetation after a period of cropping, which would be grazed by domestic stock during the rains and often burnt

TABLE 6 — *Comparison of the Direct and Residual effects of Farmyard Manure and Superphosphate.*

Manure and Superphosphate applied before the 1937 crop

Yields in kg/ha

Year	Crop	Control	17 kg P/ha as superphosphate	17 kg P/ha as 7.5 t/ha manure
1937	Millet	427	900	676
1938	Sorghum	692	876	979
1939	Groundnuts	880	1090	959
1940	Millet	408	504	441
1941	Sorghum	400	515	363

Bulrush Millet: *Pennisetum typhoideum.*

during the dry season. It was natural that the early agronomists should try and improve this system by using a planted resting crop, to increase its efficiency as a soil improver as well as to increase the fodder available for the stock. Much of the early work is now irrelevant, as it was based on the premise that fertilisers would not be used; but there is still little critical evidence to show under what conditions a resting crop is essential if good arable crop yields are to be maintained using fertilisers.

The resting crop, particularly if it is burnt on the land or is grazed, increases the pH of the surface soil, due to an increase in its exchangeable calcium, magnesium and often potassium content. At a low level of yield on soils of moderate fertility, the total yield of food crops may be less, over a 6-year period, from a 3-year cropping after a 3-year rest than from continuous cropping, though most of the very few experiments that have been made were only continued for one or two rotations.

As would be expected, some of the early work tested the value of a leguminous resting crop compared with a grass crop or with natural regeneration; but the experiments were usually inconclusive because of the poor growth the leguminous crop made. Only very few results have been published of the effects of good legume or grass stands on the yields of the following crops. Stobbs (1969) at Serere, Uganda, showed that applying superphosphate to a *Hyparrhenia rufa* - *Centrosema pubescens* ley not only increased the liveweight gain of cattle grazing the ley but also the following cereal crop gave an appreciably higher yield on the fertilised ley area, probably largely due to the extra nitrogen left in the soil following the more vigorous growth of the legume. It has also been found that if the ley was not fertilised, and a legume adapted to poorer soil conditions was used — *Stylozanthes gracilis* — the following crop may need additional phosphate if it is to derive the full benefit from the ley. If the grass is cut and removed from the land, for use elsewhere, it may be necessary to give additional potassium to the following crop, if it is not to suffer from this removal.

There is still little information available on the rate of run-down of the benefits obtained from putting land down to grass or to a grass-legume ley for one or more years. Foster (1971) has shown that the benefit lasts for at least six crops taken in three years on the relatively productive soil at Kawanda in Uganda, as is illustrated in Table 7. In this experiment the arable crops did not receive any fertiliser, and the fertiliser treatments applied to the elephant grass did not have any appreciable residual effect on their yield.

The present position on the need for resting crops, if high sustained yields based on the use of fertilisers are to be obtained, is that there is still no critical evidence that they are needed on any soils, but that they may be dangerous in areas

TABLE 7 — *Mean Yield of Crops following a 3-year Elephant Grass Ley.*

Kawanda, Uganda

Yields from Unfertilised Plots in kg/ha.

Cropping Sequence	Seed Cotton	Maize Grain	Sweet Potatoes Tubers	Beans Grain	Maize Grain	Beans Grain
Previous Cropping						
Continuous arable	255	1580	4080	925	1545	565
3-year elephant grass undisturbed	645	3140	6970	1130	2285	770
3-year elephant grass grazed	755	3830	6180	1460	2330	925

Elephant grass: *Pennisetum purpureum* beans: *Phaseolus vulgaris*

subject to erratic rainfall, for they will use more water than short season crops and the following crop has a greater risk of giving a low yield, or being a failure, due to lack of water in the deeper subsoil. The other difficulty which may arise is that if rhizomatous grasses, such as species of *Digitaria,* develop in the grass resting phase, any benefit the ley confers on the soil structure is likely to be lost due to the extra cultivations needed to kill this grass, unless chemical weed control methods can be used, as shown by PEREIRA et al (1954) at Kawanda.

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DISCUSSION

Chairman: F. VAN DER PAAUW

HERNANDO

In page number 8 you talk about the effects that long-term experiments produce upon the fertility of the soil, pH and an amount of cations in the soil. Well my question is: is there only a problem of pH and cations, mostly calcium and magnesium, or is there also a problem of microbiological life and organic matter reduced in the soil?

RUSSELL

We have not found any definite evidence that we need to pay any specific attention to the microbiological activity in the soil, apart from the activity of soil-inhabiting plant pathogens. However, the better the crop grown on the land, the larger the amount of root and leaf residues left in the soil.

HERNANDO

On page 12 you present a point which is the same as the one Prof. PRIMAVESI presented in relation to tropical conditions with potassium, and both of you say that potassium fertilizer sometimes reduces the yields if you apply it in small amounts. In my opinion, in temperate countries it is not as different from tropical countries as we think. It is only a matter of focussing the problem. In the centre of Spain, there are no tropical conditions, it is dry but not at all tropical. We found the same result: with low potash level we get a reduction in yield, but by increasing the potash level we get increase in yield. I never found an explanation for these things in the literature.

BRAMAO

Your brief but very complete exposition on African agriculture and African life was very interesting. As far as soils are concerned, you divide the soils into two broad groups, the forest soils and the savanna soils; this is a division according to the vegetation. I believe you said that the soils of Africa were low in calcium, but which soils? The soils from the savanna areas or those from forest areas? I think you said that liming in Africa was not necessary. Again I would like to know if you meant both soil groups or only one of them.

My other question is: the application of ammonium sulphate — does it provoke further acidity of the soil? Is ammonium sulphate applied into savanna soils or forest soils? Would acidification by ammonium sulphate be produced because of the very low buffer capacity of the soil? Those are my questions.

RUSSELL

Since these soils have a very low cation exchange capacity, they can only hold small amounts of exchangeable calcium, so quite small losses of calcium from the soil will result in a large drop in its percent saturation. Ammonium sulphate is equally harmful on savanna and forest soils since they are both usually kaolinitic. Montmorillonite soils are usually well supplied with calcium, so ammonium sulphate can be used safely on them, but they are usually restricted to a few valley sites. Ammonium sulphate gives the same loss of calcium from tropical as from temperate soils, if there is an adequate amount of calcium in the soil, namely about 40 kg of calcium per 100 kg of ammonium sulphate applied. This is the reason why it is such a dangerous fertilizer on kaolinitic soils, as it is on sandy soils in temperate regions if regular liming is not used. I agree that there is a need for much research on the need for liming and on its effects on the soil in the tropics. Little attention has yet been paid in the tropics to the relation between the aluminium ion activity in the soil, the soil pH, and the response of a crop to lime.

BRAMAO

In comparing, in a broad way, the soils of Africa, with those of South America, one sees that their distribution is quite different. In the beginning of the Soil Map of the World Project we thought that the two continents would be more similar. While in Africa the savanna soils have been often recharged with calcium, the corresponding savanna soils in South America are usually acid.

RUSSELL

On the whole, soils like that are not cultivated in Africa because they are too poor. We have got areas of quartzitic soils that are not cultivated because the amounts of fertilizers needed for good crops are quite uneconomic to apply.

ARATEN

Prof. RUSSELL mentioned if one uses herbicides in tea then the response to phosphorus is bigger. I spent, a year and a half ago, two days in the Central Tea Research Station in Nairobi, Kerucho, not far from Lake Victoria, and the story I heard there is the following: They never got a response to phosphorus in tea cultures and they came to the conclusion that phosphorus is fixed in a way by this soil which is never giving back the phosphorus, and the yield of tea was low. The Director of this research station, Hainesworth, went through the jungle on a trip and he found there the same soil as they have in the tea region of Kerucho, and the leaves of the trees in the jungle were very rich in phosphorus, whereas the leaves of the tea were very poor in phosphorus. He noticed what happened and he saw that all the leaves that fell down formed a kind of a layer and the roots are coming up to this layer to get the phosphorus and so the phosphorus is not coming into contact with the soil. He introduced this in the tea cultures having a layer of tea leaves and giving a lot of phosphorus to this layer, the roots came up, took the phosphorus and he got twice and three times the yield of former years. This was his explanation.

SAALBACH

You said in your paper that if you build up the phosphate level in the soil, the non water-soluble phosphate fertilizers have the same effect as the water soluble fertilizers. Is this true only for African tropical soils or also for other tropical soils?

RUSSELL

I can really only answer for Africa and Southeast Asia, particularly Malaya and Thailand. We find that high quality rock phosphates, like the North African rock, are very effective fertilizers for maintaining the phosphate content of most of these soils.

THERON

I think I can say that the problem in Africa is not one of fertilizers but a human factor. It is ingrained in the black African that the man may not touch his hand to the plough or to the hoe or to any cultivation instrument. That is the work of the women. As long as that remains they will never progress. If you build up the infrastructure which Dr. RUSSELL mentioned here in the latter part of his talk you could produce there as well as anywhere else. You could have cattle there that would not only be bred for starvation, you can get any kind of breed; in many places you can use sheep — you simply have to eradicate tsetse fly as we have done and mosquitoes. But build up that infrastructure, get the people right, and all these problems will disappear.

RUSSELL

This problem of who does the work varies with the tribe. In some tribes the men do all the hard work, the women do the planting and the weeding; in other tribes the work is shared equally. But on the whole, overpopulation and underemployment is making men work on the land because they have nothing else to do. In old days they were the warriors but they are not allowed to fight each other now, so on the whole they are cultivating the land.

PRIMAVESI

Referring to your very interesting paper, I will say, that there are many examples also in South America of the use of fertilizers being uneconomical in case like you mentioned in Africa.

I think you said very well, that fertilizers are only one of the many aids farmers have for increasing production. Being only one factor, it is necessary to fullfil and to take into consideration all the other factors indispensable for production. It is necessary to think about all of them. On this occasion I recall your excellent paper « The Importance of Soil Structure in History of Humanity » presented at the Second Latin American Congress on Soil Biology, with scientists of 24 countries, especially from the Tropics and Subtropics, but also from Austria, Spain, Germany, France, Great Britain, Italy, United States of America and so on. All scientists assembled were of the same opinion that you are right when you showed that the soil structure is of maximum importance for soil productivity in the tropics and subtropics and that fertilizers will give an economical response only when the soil has a good structure.

PESEK

There was one point I want to raise with regard to Prof. RUSSELL's paper, his quoting of information from Miller on yield and percent of protein in sorghum. Did Miller indicate the change or improvement of the biological value of the sorghum protein? In some cereal grains, as the protein increases in response to nitrogen fertilization the biological value decreases, so without more evidence, the conclusion that we are improving the lot of people who eat this grain as a primary stable may be misleading.

OBERLÄNDER

I understood, Prof. RUSSELL, that one of the main objections to the application of organic matter might be the transportation problem. So may I ask for your opinion about using green manure or just stopping burning of crop residues on the field or stopping removing them from the field.

Russell

About green manuring. It is very difficult to persuade a small subsistence farmer to grow a crop, which will have cost him money and hard work, and then to plough it in. About crop residues — The African farmer is a very economical person and he uses his crop residues. Thus he uses his maize and sorghum stover for fences and for roofing his house. He does move quite a lot of the crop that he grows to his house, and when the village moves to another site, the fertility of the soil around his old house is noticeably higher than the soil a little farther away.

Bornemisza

Referring to the quality aspect. Actually there is some evidence that fertilizing beans does not affect the quality. There were some rather careful tests done with experimental animals and amino-acids analysis, and it was shown that by using fertilizers one can increase appreciably the total protein produced by the hectare, by about 50% in the conditions of the experiment. The protein produced under those conditions is about as good as that obtained without fertilizers from beans. Another quality aspect which again is a result of the fertilizer programme is quite different: it refers to coffee quality. The factors are very complicated, if I recall that coffee taste is determined by a large number of natural products. This crop is very sensitive to boron. Boron-deficient coffee is invariably low quality. So is also high nitrogen fertilized coffee. It is a little similar with sugar cane. If one overdoes nitrogen fertilization with sugar cane one gets a lot of tonnage but the sugar content will not be very high. These are a few examples I found about quality as a result of fertilizer application.

Russell

I agree that quality of crops like coffee and tea are very dependent on fertilizer. Unbalanced fertilizer or wrong fertilizer gives poor quality.

PESEK

Another factor of protein quality: in the case of maize, of course, we know that the increase in protein nitrogen is mostly in the form of zein which is of little value for monogastric animals. However, experiments we have had recently in which we crossed *Avena sterilis* with normal oats and increased the protein content up to 25% or 28%, we found that the increase in the protein is an increase in the whole protein of the oats, so that the biological quality of the oats protein increase derived in this way is also a net gain in terms of biological value on an area basis.

COLWELL

I would like to ask Prof. RUSSELL to expand a little more on the residual value of phosphate in tropical soils. He says that there is without any doubt a build up of phosphate in soils which shows that fixation is not a serious problem. Has he figures indicating the amount of applied phosphate that eventually gets into a plant. We do not expect it all to get in in the one season — but if over a period of years say, 50 kilos of phosphate has been applied, can we expect to get 50 kilos back in plants, or is a certain amount tied up in a form in the soil which the plant will never get?

RUSSELL

First of all, we have done very little work in Africa on tbe amount of phosphate harvested by a crop. We have really only been looking at the actual crop yield rather than the phosphate harvest. At Rothamsted, in England, phosphate was put on a field for about 50 years and was then stopped about 70 years ago. We are still harvesting phosphate from this fertilizer in crops growing on tbis land and I don't know if we will ever harvest 100% of the phosphate that was applied.

I would like to give an example just to show there are problems of phosphates in African soils which I have not touched on: P. Le Mare in East Africa has shown that in a few East African soils adding 10-15 kg/hectare P to the soil as superphosphate actually decreases crop yields and phosphate uptake; adding 20-30 kg/hectare has no effect on yield or uptake; but higher levels of fertiliser increases both yield and uptake.

COLWELL

Is the first part of that curve fixation?

RUSSELL

The following crops show the same behaviour, if no further additions of fertilizer are made, though the magnitude of the depression of yield for the low phosphate addition and of the increase for the high addition, become smaller with successive crops.

PESEK

I had a question on Dr. CAPÓ's paper this morning. In the equation of percent composition as a function of fertilizer it appears to me that the A-value should be dependent more on the crop — on the variety of the crop grown — and be relatively independent of the soil because you have supplied fertilizer in increasing amounts in addition to what is in the soil. Therefore, given the same type of plant growing on it you should approach the same value of A. I would expect, however, that in the case of b, b would vary among soils. Did I misinterpret your discussion at the board this morning?

CAPÓ

You are right in saying that that particular value A depends more on the variety of crop that is being used. But there are slight variations, depending on the concentration of the other elements. For example, previous work I have done under conditions of very high phosphorus deficiency in which applications of nitrogen were made, the plants did not grow enough and there was an accumulation of nitrogen in excess of the normal amount. Under such conditions you might get a value of A that is not representative. But in general when the concentration of the other elements are near adequate for good yields then the value of A depends on the variety. The value of B, of course, depends not only on the variety but on the fertilizer material that is applied to the soil, because we are relating or trying to estimate the concentration of the elements in terms of the fertilizer material applied.

FRIED

I would like to throw out the general question of nitrogen fertilization of legume crops or the inoculation problem with legume crops, in other words the supply of nitrogen to legume crops which has not been specifically mentioned by the previous speakers. This is particularly important in relation to the problem of increasing the quantity of protein produced. This can be done by increasing the quantity of high protein crop produced or increasing the protein content at a given yield level. Where does nitrogen fertilization fit into this picture?

RUSSELL

We have a number of examples from Africa where groundnuts have responded to a nitrogen fertilizer, possibly only on a soil rather low in available nitrogen. I think the reason is that the fertilizer gives the young plant a good start in life before the nodules have time to contribute to its nitrogen supply. Also nodules die or become inactive as soon as the surface soil becomes dry, even if the plant is taking water from the deeper subsoil.

BRAMAO

I would like to come back to Dr. BORNEMISZA's explanation particularly in relation to the liming of savanna or cerrado soils. In 1965 we were making a long soil expedition across the South American continent, for the soil map of the world, we heard that an entity that was just moving into Brazilia, as you know located in the centre of the cerrado country, had difficulties in establishing a garden due to soil conditions. The soils are deficient in practically all minerals. They are high in clay minerals but very low in silicate-clay minerals, therefore there is very little exchange capacity and a limiting factor is calcium. When one applies calcium to the soil, calcium remains on the surface, it does not go down, and the roots are restricted to the area where there is the calcium. Even if the rain is adequate as it is sometimes — the rain percolates but because of lack of calcium the roots cannot follow and get the water which is in lower layers. So the improvement of this soil, which we call in the Soil Map of the World, Acric Ferralsals, is very difficult.

ARATEN

I would like to propose to the members of the Study Week that the concluding remarks of Dr. WALSH this morning about the cooperation between agronomists and physiologists, be one of the conclusions of our Study Week. A lot of trial and error experiments would then be avoided. We should also engage bacteriologists in this group.

HERNANDO

I have a comment in relation to Prof. PRIMAVESI's paper because it is in the same line with my first idea to prepare my paper to bring here. It is the problem present in Spain concerned with the application of pesticides to protect cotton growing in south and southeast Spain. We are actually reducing the area devoted to cotton because the price of the pesticides used to get a good yield is too high for farmers. It is not good to use pesticides, before we know if the soil has the proper fertility to grow the plant. When the cotton is grown in better conditions maybe we don't need to apply pesticides as used before, and we don't disturb the biological equilibrium of the environment. Now the worst problem is the red spider. This never was a problem ten years ago for cotton, but now with the use of pesticides we kill so many insects that are good for plants; the red spider remains a problem in these areas and the use of such high amounts of pesticides needed for them is too expensive.

This would be an important point in our final conclusion at the end of the week.

PRINCIPLES AND PRACTICE OF FERTILIZER USAGE IN THE SEMI-ARID TO SUB-HUMID AREAS OF THE REPUBLIC OF SOUTH AFRICA

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Introduction

The southern part of the continent of Africa is endowed with a harsh climate except for the south-western tip known as the Western Province of the Republic. This part enjoys a Mediterranean type of winter rainfall with adequate moisture for profitable farming. For the rest of the country the climate varies from arid desert conditions in the West changing gradually through semi-arid to tub-humid towards the East. This paper deals with the latter parts where arable farming demands considerable skill for success. The major part of agricultural production takes place in these areas.

The rainfall is confined almost entirely to the months of October to March. Rain and hail storms of tropical violence are relatively common alternating with dry weather and sometimes crippling droughts. A considerable proportion of the precipitation is in small ineffective showers of a few millimeters which is rapidly lost by evaporation. Due to long intervening periods of dry hot weather the evapo-transpiration rate is high. The rainfall is very erratic; poor and good seasons are the commonly accepted features of the climate.

In the semi-arid areas the rainfall averages about 400 mm annually increasing to about 700 mm in the sub-humid Eastern parts. The summers are generally warm to hot and the winters relatively mild and dry. To have no rain for five to six months during winter is not uncommon.

The soils appear to be the products of severe weathering and erosion over many millenia. Over considerable areas they are today barely more than skeletons of partially consolidated latosol debris locally known as "Ou-klip" covered by a thin layer of surface soil. Only on the more recent sediments of the Karoo geological system which are fortunately extensively broken up by intrusions of basic volcanic rocks, are reasonably good agricultural soils found.

For the greater part dryland farming is practised i.e. dependent on rainfall only. Maize is the main crop grown. Sorghums and peanuts are also grown to a lesser extent. Irrigation is practised where water from storage reservoirs is available but this takes place on a very minor scale compared with maize production. Wheat, citrus, tobacco and vegetables in selected areas are the main crops grown on the irrigation schemes. In recent years dryland wheat has also been produced in the more humid areas but this is at best a hazardous undertaking.

Up to the beginning of the present century farming in these areas was of a pioneering and pastoral character. Only after the first world war a gradual change to arable farming took place. By the year 1920 the use of fertilisers of all kinds was still little known but early trials had by then shown that the soils were generally and rather extremely deficient in phosphates; applications of relatively small quantities of phosphatic fertilizers — 150 to 200 kg. per hectare — gave startling improvements in yields. No response was obtained from any other plant nutrients applied as fertilizer. In fact nitrogen and potash in relatively small applications seemingly depressed yields in many cases. This very general and rather extreme degree of phosphate deficiency was experienced not only in respect of cropped soils; it was also reflected in the quality of the grazing. The phosphate content of closely grazed pastures was so low that the grazing animal developed a phosphate-hunger which drove it to eat old bones of any kind often contracting botulism poisoning thereby.

Early fertilizer practices

During the early years and up to about 1950 fertilizer practice was based on the conviction that the factors which limited production were firstly the rainfall and secondly the very general deficiency of phosphates. The density of the crop population was thus adapted to the climate and for maize, for example, no more than 10.000 plants per hectare was standard practice. The deficiency of phosphates was remedied by applying 200-250 kg. superphosphate per hectare in the more humid areas and about half these quantities in the drier. Under good management and given an average season about 20 bags of grain of 100 kg. could then be expected in the better farming parts.

Towards the latter part of the 1940's, however, it became evident that the use of superphosphate only, was losing its effectiveness. After some 25 years under cultivation to annual crops the soil's natural supply of organic matter was largely depleted. Acidity had increased and it was assumed that the availability of the phosphates was reduced by fixation in the acid soil. Various rock phosphates or mixtures of super and rock were tried but to no avail.

The gradual deterioration which had taken place was well illustrated by a long time fertilizer and rotation experiment carried out jointly by the Department of Agronomy and the writer and reported on by HAYLETT (1970); this experiment clearly showed that the yields of maize as well as the hay and legume crops of the rotation had gradually declined over the years, notwithstanding the best known cultural practices being applied.

Recent Advances in Fertilizer Usages

1. Fertilization of annual crops on dryland:

A new approach was needed and following on researches carried out at various experiment stations a significant break-through was achieved with the discovery that the productivity of the soil can be revivified and the yields greatly increased by applying in addition to phosphates relatively large quantities of nitrogen provided the plant population was increased from the previous standard of 10.000 to about 30.000 plants per hectare (in the case of maize).

Thus in a nitrogen and espacement trial on the University Farm in Pretoria HAYLETT (1960) reported the results summarised in Table I below. Similar results were reported by a number of other workers. Particular mention should be made of the work done by officers of the Bapsfontein Experiment Station of African Explosives and Chemical Industries Ltd. (1965).

TABLE I — *Nitrogen and espacement trial with maize in Pretoria. The yields are given in bags of 100 kg. per hectare.*

Treatment

Superphosphate	Sulphate of Ammonia	Yields for plant populations per hectare of	
		11.000 plants	30.000 plants
640 kg/hect.	nil	26.46	34.93
640 kg/hect.	320 kg/hect.	26.88	47.60

Greatly increased yields were obtained even on this relatively fertile soil when nitrogen was applied and the plant population increased. Rainfall was found to be a less decisive factor in production from what it was thought to be formerly. Adequate fertility and an adapted plant population is no less decisive than rainfall. In the sub-humid areas the optimum density in respect of maize, was found to be about 30.000 plants per hectare and in the semi-arid parts, as recently confirmed by DU PREEZ (1971), about 15.000.

Improved and adapted cultivars of hybrid maize are of course an essential part of this new viewpoint and have all contributed to bring about a veritable "green revolution" during the past decade or two.

Phosphates are still essential but the "phosphate only" era is definitely something of the past and nitrogen is being used in increasing quantities. The third fertilizer element namely Potassium plays a very minor role. The soils are apparently well supplied with this nutrient and applications have rarely proved profitable even for crops such as potatoes which normally require an ample supply. Signs of approaching potassium depletion have, however, become evident. Thus the application of this nutrient has been found helpful in combatting root rot of maize a malady which has become troublesome in recent years. On the whole, however, it seems clear that this element is included in the fertilizer programme more as a matter of routine than necessity, the amounts recommended being estimated to replace what the crop normally removes from the soil.

The discovery that fertilization with nitrogen in addition to phosphates had become essential for optimum yields has greatly popularised the use of mixtures in preference to single fertilizers and increasing amounts are being sold as "complete" or "balanced" fertilizers — terms dearly beloved by the vendors of these products.

The number and composition of these mixtures are controlled by the State and only such as would appear to have a special purpose are allowed. Thus the K-content of fertilizers sold for potatoes and tobacco would be increased e.g. 2:3:4(21)s the s indicating that the K is present as sulphate.

Some 30 such mixtures are on the market with the one for general usage having the composition 2:3:2(22) and containing 6.3% N, 9.5% P and 6.3% K being the one mostly used.

In Table 2 the total quantities of fertilizers and plant nutrients sold during 1970 are summarised.

TABLE 2 — *Returns of fertilizer consumption in the Republic of South Africa for 1970 in metric tons of 1.000 kg. Department of Agricultural Technical Services, Pretoria.*

Type of fertilizer	Tons consumed	Plant nutrients		
		N	P	K
Mixtures	884.008	79.516	65.606	65.361
Single fertilizers:				
Nitrogenous	302.102	95.881	—	—
Phosphatic	727.808	5.119 (1)	56.875	—
Potassic	31.027	—	—	14.706
Total	1.944.945	180.516	122.481	80.067

(1) As ammoniated superphosphate.

In recent years the tendency has been to offer for sale increasingly concentrated fertilizers and mixtures. Thus double superphosphate, Urea and mixtures such as 2:3:2 (30) have become common. The highly concentrated forms are, however, not generally favoured and will probably find little application until the rather extensive systems of farming practised today become more intensive on smaller units or more institutionalised in large corporations — a definite present day tendency.

There seems, in any case, little to commend the highly concentrated forms except perhaps from the manufacturer's point of view.

In the sub-humid areas the quantities of plant nutrients applied currently for maize and other grain crops under dryland cultivation, are 50-75 kg. of N, 15-20 kg. P and 15-25 kg. K per hectare. In the semi-arid areas the applications are reduced to 30-40 kg. N 10-15 kg. P and generally no K.

Usually a mixture is applied as a starter at time of planting and the nitrogen is then supplemented with top-dressings at a later date. Recent trials have, however, shown that there is little advantage in this latter practice. The full amount of nitrogen may as well be applied at planting. No difference is found in the efficacy of the three usual nitrogen carriers namely Sulphate of Ammonia, L.A.N. or Urea, except for the acidifying effect of the first named. The use of liquid ammonia still lies in the future.

All fertilizers are applied in bands on the side and away from the planted row by means of various types of attachments to the planters.

2. Fertilization of Perennial crops.

As already mentioned phosphate deficiencies of a rather extreme degree have been experienced in cultivated soils from the earliest times. The deficiency was reflected even in the grazing animal. It was surprising therefore to find that when phosphates, in any form, were applied to the natural pastures no response in production of herbage was manifested although the P-content was materially increased in the herbage. Many field trials on natural veld and established pastures confirmed these observations and to throw more light on this problem a comprehensive fertilizer experiment was started jointly by the writer and Professor HAYLETT of the Department of Agronomy, in 1945 on good veld pasture on the University Farm. Astonishing responses to applications of nitrogen were obtained while phosphate interaction was evident only at the highest dressings of nitrogen. This experiment was terminated in 1965 when the results were reported by HAYLETT (1969).

Throughout the 20 years that the experiment was in progress good and poor years were normally experienced but although the hay yields were materially influenced by rainfall, the factor mainly determining the yield was the supply of nitrogen. Better yields were obtained in the driest years with adequate fertilization then in the best years without the application of nitrogen. The average annual air-dry yields of hay for the 20 years of the trial are summarised in Table 3.

TABLE 3 — *The effects of differential applications of superphosphate and sulphate of ammonia to Pretoria veld given in metric tons per hectare. The figures at the foot of the P and N are the amounts applied annually per hectare.*

	N_0	N_{500}	N_{1000}	N_{1500}	N_{2000}	P-effects
P_0	1.15	3.60	4.05	4.39	4.44	3.53
P_{300}	1.46	4.94	5.79	5.05	5.55	4.56
P_{600}	1.81	4.84	5.46	5.77	5.84	4.74
N-effects	1.47	4.46	5.10	5.07	5.28	—

When yields for the five wettest seasons with an average of 689 mm. rain, and the five driest seasons, average 433 mm. rain, are averaged the yields were as follows:

Rainfall	Fertilizer treatment	
	P_0N_0	$P_{600}N_{2000}$
Five driest seasons	1.01	3.74
Five wettest seasons	1.50	6.69

Obviously the low herbage yield of the natural veld is due to a lack of available nitrogen with phosphate availability playing a very minor role. Similar results were obtained in a number of other experiments by other workers elsewhere. [Theron and HAYLETT (1953) HYAM (1968), ALTONA (1965)]. The crude protein yields in kg/hectare are summarised in the table below.

	N_0	N_{500}	N_{1000}	N_{1500}	N_{2000}	P-effects
P_0	72	277	433	458	458	341
P_{300}	85	379	553	555	555	441
P_{600}	110	371	539	642	642	465
N-effects	89	342	508	551	586	—

In nature, and this appears to be the case with all perennial plants maintaining living roots in the soil permanently such as citrus trees, sugar cane etc., the mineralization of humus is maintained at a low level consistent with the annual increment of organic matter so that no net loss takes place. This is accomplished by the control which the living roots exercise over ammonification (THERON 1963).

In the natural veld moderately grazed and left to mature normally the amount of N mineralised was found to be about 5-10 kg/hectare irrespective of the rainfall, wet years yielding more herbage with a lower percentage protein and dry years less with a higher protein content per unit weight.

Hence the need for nitrogen and the marked response to its application. With adequate supplies of nitrogen the yields of herbage was increased four and more fold and the crude protein 8-10 fold of what was produced by the unfertilized veld. Moreover herbage of good quality and in fair amounts was produced in the driest years and numerous grazing trials and several digestion trials with the hay, have shown that the crude protein is of good quality. The herbage of the adequately fertilised grass is palatable and is readily consumed by stock.

The experiments show that our natural grazing which comprises over 80% of the total agricultural area of the country offers us a readily accessible and exploitable source of protein requiring only an economic source of nitrogen. Established pastures are even better adapted to this purpose. The mechanism to achieve an ample supply of protein exists, in spite of the vagaries of the climate and this can be achieved without the danger of erosion and the loss of humus so unavoidably present in arable agricultures. What is more, the natural veld was found able to adapt itself by changes in species to either light or heavy applications of nitrogen as well as to the vagaries of the rainfall. See HAYLETT (1969). Since humus is not lost under a grass sward no difficulty is experienced with the problems of acidity and toxic aluminium which are serious problems in the cultivated soil as discussed below.

Africa is on the whole in desperate need of protein to supplement the diets of the indigenous peoples; with an economic source of nitrogen this need can be readily met.

3. *Fertilizers used under irrigation.*

A limited amount of irrigation is practised in the areas in question. The chief crops grown are wheat and tobacco with citrus in selected areas. The fertilization pattern for these crops is in general similar to that under dryland cultivation except that heavier applications are given. Nitrogen applications have been found necessary from the beginning in addition to phosphates but the response to the latter was generally of a somewhat lower order than on the same soil under dryland cultivation.

For wheat, the main crop, 100-125 kg/hectare of N generally as sulphate of ammonia, 25 kg. P and 20-25 kg. K are usually advised. The acidifying action of the ammonium sulphate is neutralised by the lime in the water. The above amounts of nitrogen are given only for a short straw wheat to avoid lodging; a yield of 50 bags of 100 kg. each per hectare are then expected.

For tobacco heavier applications of phosphorus are given and potassium as sulphate is added. The nitrogen application will depend on the type of tobacco grown and is often applied to the preceeding crop.

Since more than one crop can be produced annually ample opportunity is given to boost the organic matter of the soil by means of green manuring and catch-crop practices and the incorporation of coarse crop residues is practicable.

Discussion

As mentioned above the kinds and quantities of fertilizers being used currently together with the use of adapted cultivars and improved cultural practices have brought about a marked change in our general pattern of farming and, amongst others, animals have practically disappeared from many farms. Considerably more fertilizers will probably be used in the future with heavier demands continually being made on the soil. The question now arises for how long will it be possible to continue using these highly effective concentrated technology products in total disregard of the organic matter of the soil! Already ominous problems have made their appearance mostly connected with humus depletion. Organic matter is rapidly decomposed in the soils of the areas in question. Ammonia is readily liberated by the alternate wetting and drying to which the soils are subject with the consequent loss of carbon from the humus in order to maintain the constancy of the C/N ratio. Estimates place this loss at about 50 per cent of the virginal content after 25 years of cultivation to annual crops and experience has shown that crop residues, manure etc., are rapidly decomposed. It thus seems unlikely that the larger amounts of roots and residues produced by present day fertilizer practices will be able to maintain an effective supply of organic matter in the soil. The problem is of course somewhat different where the soil is not so continuously subject to alternate wetting and drying. Admittedly one of the primal functions of humus is to supply the plant with nitrogen which we now do artificially but the evils of humus loss are manifold. Erosion has already taken a very heavy toll in the early days following on the break up of the natural crumb structure as the humus decomposed. Theoretically it should not be beyond our ability to check its ravages, and this has been accomplished to a large extent at considerable public cost, but in practice one still finds all too many instances where the farmer is fighting a losing battle against this evil.

Another serious consequence of humus loss is the acidification consequent upon the oxidation of the amino nitrogen and the sulphur contained in the natural humus. The acidification is moreover greatly enhanced by the nitrogenous fertilizers applied currently. Acidity has become a serious problem in recent years; the use of lime has grown in leaps and bounds but in many instances the amounts required are beyond the means of the farmer. This is the case particularly on many of the old soils mentioned in the introduction. In these "soil skeletons" the soil is acid in depth and it is practically impossible to reach there with lime. With a pH of less than about 5.5 exchangeable aluminium develops on these soils and this is apparently toxic to most farm crops; potatoes and groundnuts may still grow reasonably well for a time but not for long. The acidity must be corrected with lime and roots will only penetrate to the depth that neutralization has taken place to the above mentioned limit. If the subsoil remains acid roots will not grow into it. They remain on the surface layers thus reducing not only the feeding area but also the supply of water available lower down.

Phosphate fixation is another problem which is closely related to humus impoverishment and acidity. Some of these acid soils fix the phosphorus, in an entirely unavailable form, from as much as 25 and more tons per hectare of superphosphate. This problem has only recently obtruded itself and needs more study but Dr. P. FULS of the National Institute of Soils and Irrigation informs us that in his experience liming the soil does not ameliorate the fixation problem and only organic matter additions have been found effective. In this connection it is of interest to relate that many years ago farmers found that the efficacy of superphosphate was greatly improved if it was mixed bag for bag with fine sifted farm manure. At the time this claim seemed absurd because the quantity of manure per hectare — a bag or two — seemed infinitesimal but one can see the sense in it now.

Trace element deficiencies have become prominent in recent years in the most unexpected places. The use of zinc and molybdenum were known but others have now appeared such as a severe Boron deficiency over a wide area.

How many more such problems will we encounter in time? With technological advances we may be able to meet their challenge successfully and grand horizons of fertilizer usage will no doubt reveal themselves in time; the promise of fluid automated plant nutrient practices, sulphur coated urea and other such products of the future hold out great promise but under the climatic conditions pertaining to South Africa it seems highly unlikely to the writer that any pattern of fertilizer usage that is not calculated to conserve soil humus has any chance of success in the long run. For one thing the deterioration of the surface structure which must inevitably follow on the use of the present day — and future — concentrated fertilizers could easily cancel out their benefits by a simple decrease in the efficiency of the sparse and erratic rainfall.

With these considerations in mind a system of mixed pastoral and arable farming has been strongly advocated, a system in which a quarter or more of the area normally under cultivation to annual crops, is planted to a well fertilised grass pasture. This has, however, fallen on deaf ears. In fact recently an attempt was made by the national Department of Agricolture to familiarise farmers with the advantages of this practice by initiating at great cost, a ley-crop scheme on farms throughout the country but the attempt proved abortive.

The highly exploitive practice of grain production which fertilizers have made possible, mostly with maize in monoculture and which has eliminated the animal on many farms has proved so remunerative that no thought is given to conservation even to the neglect of the elementary measures of erosion control. *But for how long?*

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DISCUSSION

Chairman: M. V. L. Homès

Russell

I was very interested indeed in Prof. Theron's paper and I would like to make one or two comments. The first point is this — and this is obvious — the more food one produces from a hectare of land, the more minerals and nitrogen is removed from that hectare of land. I do not think it is any criticism of agriculture that nitrogen, calcium and phosporus, for example, are removed from land — that is what happens in crop production, but we could be criticised if we did not put them back. Now about organic matter. I do not think there is any virtue in maintaining the organic matter content for the sake of maintaining its organic matter content. If we are to maintain it, it must be for a reason. What level of organic matter do we really want to maintain in the soil? This depends on the method of cultivation that we use. The more the soil is cultivated the more organic matter is oxidised. Why cultivate the soil? In the past, weed control was an important reason, but as herbicides become more efficient for controlling all the weeds in a field, methods of minimum cultivation become increasingly applicable on suitable types of soil. These methods not only conserve the soil organic matter, they also conserve the old root channels of the previous crops, which serve as channels down which water and air can move easily and into which new roots can grow easily. There are still difficulties in using these techniques on some soils. I think it is impracticable to adopt policies of stopping practicing intensive agriculture because in the past it has involved a loss of soil organic matter. I think we must endeavour to develop new systems of husbandry that involve both a smaller loss of organic matter and of soil structure than our present systems of cultivation, and that this is the way we will be able to make efficient use of fertilizers without causing the condition of our soils to deteriorate, even though the organic matter of the soil is well below that of the soil in its virgin condition.

HERNANDO

I was very delighted to read your paper and also to find the result you present here in the Table because in our central region of Spain the problem is the same. Until 200 years ago, the central area of Spain was covered with forests and natural pastures uncultured but from that time until now the pastures were taken out and the forest was cut, and both areas used for growing barley and wheat mainly. But at the beginning, we had quite a number of animals and they produced farm manure for the soil. Later on, the use of farm manure was reduced for the price of labour and also the amount of animal on the farm was reduced. But the people and the farmers think that the problem of getting less yield is a problem of rainfall and they need fallow year to get increasing water for next year. We proved in Spain 20 years ago that the fallow year is of no use in retaining water in our conditions because the rainfall is between fall, winter and springtime. No rainfall at all during summertime. In summer we have the highest temperatures and the water accumulated in the soil during the spring and wintertime has evaporated before next fall and there is no more water in the soil after growing a crop. On the other hand we found the same with organic matter content. The losing of carbon is increasing in the rotation wheat-fallow and when we use a rotation without fallow we get less reduction in carbon content. But when we use a leguminous crop (vecht) instead of using the fallow year we maintain the level of carbon in the soil and sometimes we increase this level. Many people say that it is not possible, because the level of carbon in the soil remains mostly the same, but we found in very small areas which remain actually in forest condition and uncultured as it was two hundred years ago, that they present from 2 percent to 2.5 percent of organic matter, but cultivated area close to them with the fallow year have less than 1 percent of organic matter. Later we used the other system of putting straw into the soil without having a fallow year. Sometimes we increased the organic matter up to 1.5%. It is not possible to increase it more as Dr. RUSSELL said before, it is not necessary. We do not know which is the right level of organic matter we must have in the soil to get a good yield. I have some other questions to ask you but I dont't like to take too much time.

BRAMAO

I do not want to take much time. I would just like to make a small remark and to ask a question to Professor THERON. The small remark is in connection with soil organic matter. This question was thoroughly debated in a previous Study Week and a big volume was published on organic matter. It was recognised how difficult it is to build up organic matter in the soil. This question was very much debated. Now, my question to Professor THERON: you said that there is very little arable land in South Africa — how little? After all, South Africa is quite a large country. To what amounts the percentage of the surface of your country in arable land? What do you mean by arable land?

THERON

I will just answer this last question. Now, remember that the greater part of South Africa is semi-desert the westem part especially. I am now talking about arable land, just in the areas where agriculture is praticed, including the marginal areas and of these areas it is generally figured that we have about twelve percent which is arable, I can not tell you the exact area in hectares, but it is roughly twelve percent. This may be extended to fifteen percent by clearance of stones and such things but the actual arable soil today is about twelve percent.

PRIMAVESI

First, it is very interesting that you have observed (page 5) that the application of potassium has been found helpful in combatting root rot of maize.

Our experience shows, for example, in a five-year experiment, that a *Piricularia oryzae* Cav. attack could not be induced in a Piricularia susceptible rice variety, planted in sandy soil, utilizing heavy infested seeds and infesting soil and irrigation water, applying a heavy N-fertilization at planting, even under extremely favourable climatic conditions for the fungus, if there were high enough levels of Mn and Cu, which was established as 18 and 2 ppm respectively as a minimum for the soil used.

Second, you mention that trace element deficiencies have become prominent in recent years in the most unexpected places. In Brazil we have the same experience.

WELTE

I want to come back to the last remark of Professor THERON. He asked the question « What is the future of our soils? » (South African soils). « We increase the application of fertilizer: on the other hand the depletion of humus goes on. » I think that is not controversial. Using more fertilizer means to get higher yields, also more root mass and more farmyard manure, etc. If you get more yield, then, of course, you have the possibility to bring back more organic matter to the soil. The real problem of humus depletion has to be seen in relation to the farming system. The natural system can be forest or natural grassland (veld). In these, the organic material comes back to the ground, will be mineralized, and the nutrients will be taken up by the plant again. It is a closed cycle. Beginning with farming means to remove organic matter by the yield and on arable land additionally to bring more oxygen into the soil, so the decomposition rate will be strongly accelerated. Grass land management has only the result of losses of organic matter by yield. But, due to the high pressure of carbon dioxide in the grassland soils, there is a high stability for organic matter. Arable land means a high oxydation rate together with the removal of organic matter by yields. Thus we do attack the level of organic matter twofold. The more we remove without substitution procedures, and the higher the oxydation rate by culture practices will be, the less the possibility to avoid humus depletion. Therefore, I think the solution of the problem may lie between the remark of Professor THERON and that of Professor RUSSELL.

ARATEN

Speaking about organic matter of the soil, we do not take into consideration the bacteria in a 20 cm layer which was calculated by a famous man of McGill University to be many many cubic metres pressed bacteria in one hectare of soil. And in a laboratory experiment he showed that when there is enough molybdenum in the soil and the bacteria are those which are transferring the molybdenum to the root, if you wash the soil with chloroform and then wash out the chloroform, no molybdenum is transferred to the root, because the bacteria are not active. This enormous amount of bacteria are producing many organic substances and we do not know yet the processes; therefore, I am coming back to the proposal of Prof. WALSH to have a cooperation not only between physiologists and agronomists, but also between bacteriologists. This is one of the very important parts of the soil and we cannot say, as some people say, organic matter is not important. There is organic matter and the bacteria are doing some work — so we have to take this into consideration.

OBERLÄNDER

I fully agree with the statements of Professor WELTE. I think it is a wise way he was indicating. But when we are talking about how to compensate for the loss of organic matter only by crop residues, it is a question of what we include under crop residues. If we think this is also the straw, so far as returning it to the soil instead of burning it, we might be successful, but if we think that crop residues are just only those which are left in the field after removing or after burning the straw, then we can really get into trouble. I will not go now into details since I am talking about this point in my own paper, but there are very convincing experiments made at the University of Kiel by Köhnlein and Vetter years ago which have shown that there is no proportionality between the increase in yields and the increase in crop residues (without straw), and that below a 40 percent yield increase you would not obtain any increase in crop residues at all. I do not mean the straw now, but just the roots and the residues left in the field after the straw is burned or removed, and so we have to be careful when saying we can restore our organic matter losses just only by relying on the crop residues.

BUSSLER

I have seen the progress with organic matter as proposed by WELTE in practice in Uganda, here it is the same as you said. They have a rotation for six years and in these six years they include three years of deep rooting elephant grass — the roots are growing to a depth of 5 to 6 meters into the soil and remove the nutrients again to the surface and then they have cotton, peanuts and other crops and then again three years elephant grass and so it keeps the organic matter nearly balanced.

COLWELL

Might I suggest, Mr. CHAIRMAN, that Dr. THERON's paper has raised an issue here on which there appears to be a degree of disagreement, this concerns the importance of organic matter as such. Coming from Australia, I am inclined to agree with Dr. RUSSELL that organic matter in itself is not very important. Organic matter is important insofar as it is linked with soil structure and the supply of nutrients to the plant, so I would suggest that when we are considering improving soil fertility of crop we are concerned with the use of fertilizers and we are also concerned with the effects of cultivation method on structure. I stress that I say, on structure. Insofar as organic matter is concerned with structure we are concerned with organic matter, but if it is not connected with structure and if structure is not a problem I raise this matter as a point of possible disagreement.

HERNANDO

I would like to say something now, as I think it is important to explain many of the things we are discussing here now. We have made field trials in Spain with wheat in cooperation with farmers. After 15 years we got a comparison between the rotation vecht-wheat and fallow-wheat and we found that in the rotation of fallow-wheat the amount of carbon in the soil decreases and in the other rotation not. We only use a deep plough but we do not plow down the soil to get a good tilth. We make only a cultivation to move the first few centimetres' layer of the soil, to leave the grains of the vecht of the wheat. depending on the crop in the rotation. At the beginning the farmers said that with this system it is not possible to get a good crop of wheat, but we get a better yield after four or five years than they got with the normal fallow-wheat rotation. And also we found in the case the precipitation is higher when the farmer thinks it will be the best yield, the yield is lower. This means that rainfall in the area is enough with 500 millimetres and the reason for these results is the distribution of rainfall. In Central Spain the total rainfall by applying North American criteria, corresponds to dry farming conditions. But the rainfall in the Central Area of the United States is not like that in Central Spain. There is not enough rainfall for crops, but when I was there I found that this rainfall is summer rainfall and it evaporates and they need to retain this water for winter because the time they get rainfall they have high temperatures, like in Nebraska, but we have the contrary. We have the rainfall exactly in the right amount for wheat in November, in winter and especially in spring and we found that we get a correlationship using a more simplified method that Prof. PESEK will explain to us later on. We got good correlation between rainfall in March and yield independing on the rest. When we got 100 mms. between March and the beginning of April we know that it is possible to get in this area more than 3000 kg/ha but if we get less than 50 mms it does not matter how much it is spread over the year, then the yield will be always less than 2000. I think it is a very interesting comparison.

OBERLÄNDER

I just want to make a short remark concerning the statements of Prof. RUSSELL and Dr. COLWELL. Certainly nobody would try to maintain the level of soil organic matter just for the sake of itself, but the point is, nobody knows which is the « correct »

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level of organic matter, and so we are risking something if humus drops below this level, and since there are enough risks in agriculture, so I don't know why we should not avoid this particular risk unless it were combined with unreasonable costs or difficulties of application.

RUSSELL

I just want to add to what Prof. BUSSLER has said about elephant grass in Uganda. Recent work there has shown that the principal effect of elephant grass is to raise the calcium or calcium-magnesium-potassium status of the soil. On the particular soil he is referring to, continuous cropping causes a drop of about 0.07 pH units per year, due to the removal of calcium and other cations in the harvested crop. These can be put back equally effectively using a calcium containing fertilizer (calcium-ammonium nitrate was used) as by growing elephant grass for 3 years.

THERON

I wish to refer to the questions raised by Dr. COLWELL and Dr. RUSSELL about cultivation. You must remember that under our conditions the organic matter is decomposed rapidly and there is no such thing as being able to keep it over from one year to the next and as Dr. RUSSELL told me yesterday that when the soil is dry then there cannot be any loss of organic matter — that is quite correct, but the soil never dries below ± 15 cm. Below this depth the moisture remains nearly constant at the wilting point and at that point I found that mineralization takes place perfectly well; the loss therefore is much more controlled or subject to the temperature than to the moisture. When the temperature falls, the bacterial activity drops. Now, as regards organic matter for organic matter's sake, certainly I agree we have had plenty of experience that shows that it is no use just adding organic matter. If your soil is in a perfectly good condition adding organic matter is just a waste of time. What we find is that with our rainfall which is sometimes rather heavy and rather slight sometimes, that we cannot get a rapid breaking up of the crumbs on the surface soil and a continual washing down of fine material. That is one of our troubles. You have to return this to the surface which you cannot always do. Sometimes it washes down to a fairly hard layer similar to a ploughsole. In general the structural condition of the soil determines the efficiency of our rainfall. You see we have to have an efficient rainfall or, as I should say, we have to make very good use of the very little rainfall that we do get and unless we have a good soil structure, on the surface particularly, and see that it does not get too fine, we cannot make efficient use of our rainfall. It just simply runs off the surface or it stands on the surface and evaporates. That is why we are particularly interested in the organic matter, to keep that soil structurally favourable, and this we must maintain to use our scarce rainfall efficiently.

WELTE

Only an additional remark to what Dr. COLWELL has said. Organic matter should not be considered alone from the nutrient point of view, it should also be considered in relation to soil structure, soil texture generally speaking to the physical conditions. I'd like to show by the following graph the need for humus in relation to soil texture from the more qualitative side of this problem: along the abszissa first the sandy soils, then in the middle the loamy and loessial soils as are widespread in Germany followed by the clay soils on the right. For humus as a high qualified material with respect to water storage capacity, ion-exchange capacity, soil aeration and the N-cycle the level should be high on sandy soils, low on the loamy soils and then again increasing toward the heavier soils — but on the clay soils not so high as on sandy soils because the main function here is to improve aeration and water permeation. According to our findings the optimal level in humus on the loessial soils in Germany should be about 1.5% because this kind of soil is very good in structure, has an optimal water holding capacity and also a good aeration. Therefore we do not need a high humus level but for clay soil it should be higher and for sandy soils still higher.

Coïc

I quite agree with what Prof. WELTE has said. I will add this: the use of fertilizers increases the production of organic materials and thus increases the restitution of organic materials to the soil. These organic materials are metabolised much more quickly than the humus of the so-called « stable » humus of the soil and these transformations are important from the point of view of the physical chemistry of the soil (structure, provision of mineral ions by the soil). The fertilizers therefore increase the speed of partial turnover of the soil humus. It would be important to measure the importance of this factor particularly when a change in the system of culture tends to bring the humic equilibrium to a lower level.

COLWELL

The point I was making is that we keep referring to organic matter when, in fact, we mean structure. I suggest that instead of measuring organic matter, we should measure structure, and if we are concerned with decreases in productivity due to physical cultivation we should measure the deterioration in structure rather than losses of organic matter. From this point of view we are interested primarily in structure, and in factors that determine structure — organic matter is just one of these factors.

OBERLÄNDER

I am afraid that I have not the same opinion as Dr. COLWELL since organic matter is not identical with problems of soil structure only. Organic matter is also a source of growth substances, and I think particularly of the research of Chaminade, Flaig, Hernando and others. We know that the importance of organic matter is not only due to its physical-chemical influence on the soil, but also to its influence on the metabolism of the plant and so I would not say that it is only related to soil structure. Measuring just this soil property would not give us the complete picture of the influence of organic matter on the growth of plants.

HERNANDO

I should like to remark on the problem Prof. OBERLÄNDER raised, about leaving the straw in the field. Well, in the experiment I talked about it, we left the straw in the field and we found in our conditions of low rainfall (maybe in conditions of high rainfall it would be different) nearly tbe same as in very dry conditions. In our conditions of medium rainfall, we found that if we left the straw on the soil during summer, it remained there like a mulch reducing the loss of water from the soil. Later, before sowing, and mixing the straw with surface soil, we had not the problem of nitrogen shortage because we do not get any other type of problem like trat in the last 15 years. We found that during winter and springtime the straw disappeared, the straw is only cut and put in the soil no more than 10 cm deep, very near the surface. After the fifth year it was possible to see that the carbon composition and the conditions of the first 20 cms of soils was structurally good in comparison with the other area where no straw had been incorporated. Actually we recommend to the farmer to grow the vecht and to cut it at 10 to 20 cms distant from the soil, leave the straw there, and after one month to dig this in the soil to about a depth of 20 cms, and next year to sow the wheat without any more labor in the soil. After the wheat harvest we leave the straw spread on the soil in small pieces and leave it on soil surface until we sow the next crop when we put first very little of this straw into the soil. Then we do not have problems and we get increased carbon in the soil with this system, as compared with others.

BORNEMISZA

Going back to soil structure. I think we have to consider in tropical soils also something which did not come up so far. In a couple of papers, mostly from tropical Africa, I have noticed something which we also have observed over in America in the really tropical part, and that is that structure is also very much influenced by the cohesive forces between coalinite and iron-aluminium oxides so that the influence of organic matter is only a secondary, and there are so many soils with some absolutely beautiful structure, ideal permeability and excellent aeration.

ARATEN

I would like to remark on what Prof. HERNANDO said about straw in the soil. Some time ago I read about experiments that straw is not really converted into organic matter during a period of even four or five years, however it improves the structure of soil so that the amount of organic matter in the soil is not increasing very much during the first years, but the effect that the small pieces of straw are there is improving the structure of the soil.

THE EFFECTIVE USE OF FERTILIZERS UNDER TEMPERATE CONDITIONS — AN IRISH CASE STUDY. (*)

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Introduction

There is a voluminous literature on fertiliser use under temperate conditions, from that which has set out general principles to that which has dealt more specifically with local problems. Indeed, in the developed countries, it might be said that a high degree of sophistication in fertiliser use has been reached.

In a 1958 survey by OECD [1] it was in fact revealed that in some countries the level of use was above what might be considered the economic optimum. The overall picture in 1969 [2] was that over 81% of all fertilisers were used in the developed regions. The ratio of fertiliser use per capita in developed to developing regions was 10:1, representing of course a position of great imbalance.

After over a century of relatively intensive research in the developed temperate countries, the main individual response

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(*) This paper was prepared in co-operation with my Colleague T. F. Gately B. Gr. Sc. NI.S.

components have been quantified and the methods whereby near optimum fertiliser use can be achieved have been established. These, from our experience [3], involve a number of factors (Table 1), most of which can be quantified; they range from basic data on soil and environment, husbandry and confronting policy makers are, on the one hand, how to exploit and capacity of the farmer. Today the two main problems confronting policy makers are, on the one hand, how to exploit the potential of fertilisers in moving from subsistence type agriculture to intensive enterprises and, on the other hand, where a high level of intensity has already been achieved to ensure the most rational use of fertilisers as a basis for further progress.

Obviously each set of conditions while part of the broad canvas requires its own approach with regard to technology and economics, involving not only methods of production but also the framework of governmental, farm organisation and co-operative structures. Naturally a main concern at this point of time must be with those under-developed countries ... where subsistence farming now prevails, and where fertiliser use is a highly important tool in moving towards business-type farming as an essential first step in economic and social development. The way in which technology can be transferred from the developed to the underdeveloped countries or regions is obviously of major significance in this context. On the one hand, there is a major pool of know-how and on the other hand, a major deficiency. The bridging of this gap becomes ever more important.

Against this background, we thought that the best contribution we could make might be by way of a broad case study of developments in fertiliser use in our own country, a country where only a quarter of a century ago, our agriculture was under-developed, where we had in effect a subsistence extensive type farming and where in 1958, we were using nationally only 20% of the optimum economic amount of fertiliser [1]. Today, we have arrived at a situation where our feet are firmly on the *fertiliser* [3].

FACTOR GROUP		VARIABLE	FIXED
ENVIRONMENT	(1) Climate	Water supply Temperature Light intensity } greenhouse conditions	Rainfall Temperature Light intensity } field conditions
	(2) Location		Aspect, altitude, slope Accessibility to transport Convenience to roadways
	(3) Soil type		Inherent soil physical conditions Effective root feeding depth Inherent major and trace element supplying power Inherent soil biological state
HUSBANDRY	(4) General	Drainage Previous manuring (major and trace nutrients) Crop rotation Use of inoculation organisms	
	(5) Specific	Date of sowing Planting pattern and rate of seeding Rate and method of fertiliser * application Yield and quality potential of crop (species or variety) Weed, disease and pest control	Crop tolerance of nutrient deficiency or imbalance
	(6) Farm Enterprise Structure	Farm enterprise opportunity - no restriction (i) Cultivated crops: relative proportion of manured components (ii) Fodder crops: (a) for conservation (hay and silage) (b) for zero grazing and grass meal (c) for direct grazing - type of animal stocking intensity, seasonality of production and sale	Farm enterprise opportunity - restricted use possibilities arising from environmental factors above (i) cultivated crops: relative proportion of manured components (ii) fodder crops
ECONOMIC	(7)		Size of holding Availability of input capital and labour Availability of markets and geographical location Price of inputs Price of products Premium on quality of product
	(8)		Management capacity Advisory services available Availability of relevant technical data

ladder of farming intensification against the background of a "farmer in business" approach to development. In these developments, the build up of soil fertility has played a major role.

Perhaps we have also another of the attributes for such a case study in relation to developing nations – the dependence of our economic and social progress on the capacity of our farming sector to act as a primer of the economy by providing food for sale abroad. This has resulted in not only much needed industrialisation and employment deriving directly from agriculture, but also in the provision of finance for the development of the economy as a whole. In this way, our position is relevant to many newly emerging economies where there is now an appreciation and acceptance of the fact that agricultural development is the first and highly important step on the road to economic development.

The Irish situation - Background information

Climate and Soils

Ireland, which is located between 51° and 55° N latitude, has a typical west maritime climate, with mild (5-7°C) damp winters and cool cloudy (13-21°C) summers. The mean annual rainfall in different regions ranges from less than 750 mm to over 1,800 mm. There are 200 to 270 rain days annually. Annual precipitation deficits range from less than 25 mm in the west to less than 50 mm in the east [4]. It is this excess of rainfall over evaporation that has determined our soil-forming process which is primarily one of leaching and podzolisation where the soil is free draining. Where soils are impermeable the characteristics are determined by the degree of drainage impedance; 29% of our lowland mineral soils are wet. The climatic position has also led to conditions of relatively high organic matter in our soils, shown as an extreme in the low-elevation blanket peats of our western area. It has been shown [5] that the carbon content of Irish pasture soils is in the region of 2 to 17.8% with a mean content of 5.30%. This has important implications in relation to storage, release and re-cycling of nutrients. The nitrogen content of our soils is in the region of 0.2 to 0.7%.

Agriculture in the Economy

Agriculture occupies a major role in the national economy, contributing 45% of total exports, of which about 83% is currently animals or animal products [6]. Consequently, grassland farming is pre-eminent and, in fact, some 87% of the land is under grass. There is a wide range in farm size as shown in Table 2 [7]. We have a well established farm

TABLE 2 — *Number of agricultural holdings exceeding* 0.4 *hectares in* 1965 [7].

Size of Holding (hectares)									
0.4-2	2-4	4-6	6-12	12-20	20-40	40-60	60-80	80-120	120
Number of Holdings in '000s									
23	23	22	69	61	55	17	6	4	3

advisory service with somewhat more than one graduate adviser per one thousand farmers. The total male labour force engaged in agriculture is still relatively high [7], although it has decreased rapidly in the last quarter century (Fig. 1). It was 38% of the total male labour force in 1966.

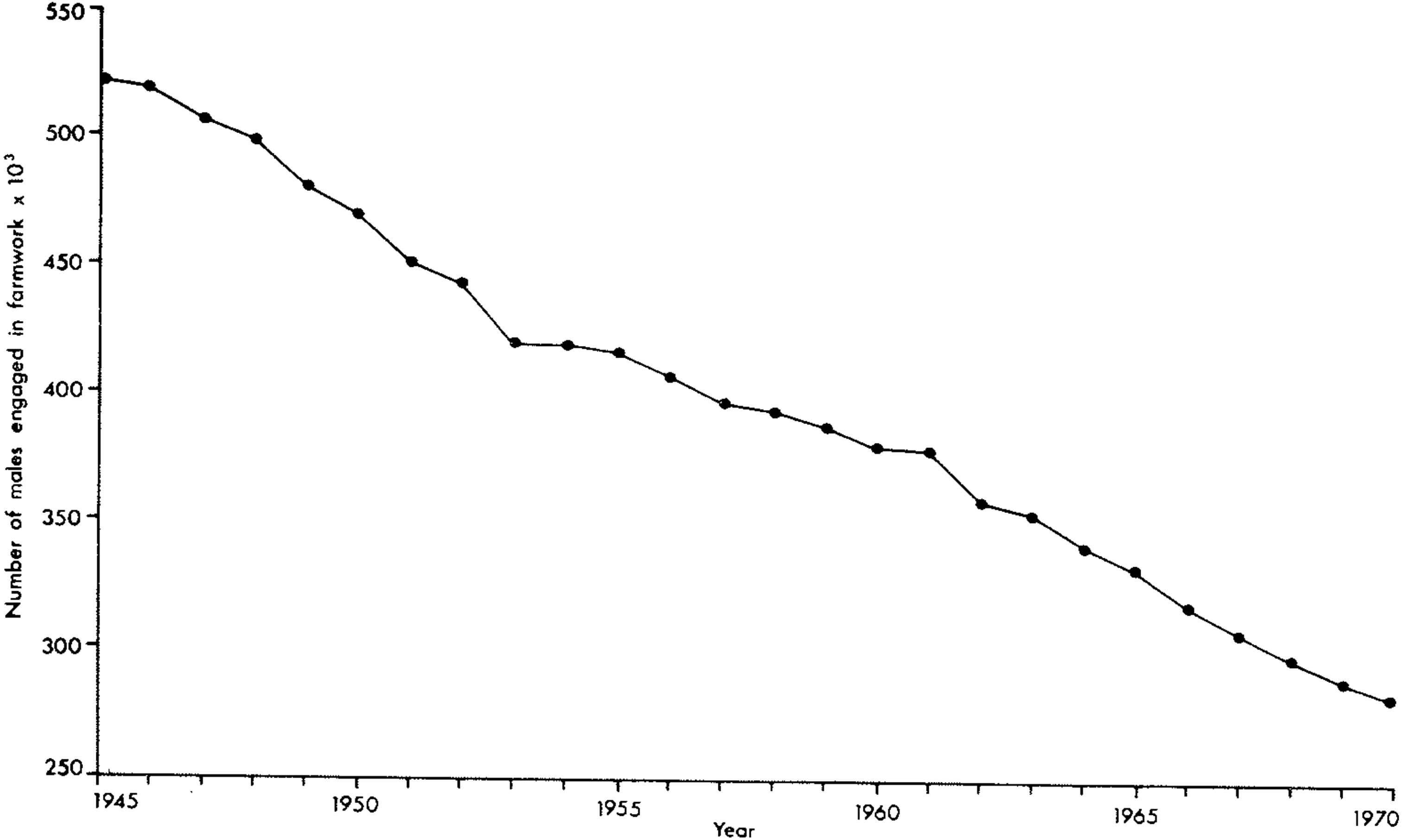

FIG. 1 — Estimated number of males engaged in farmwork 1945-1970.

Source: Central Statistics Office

THE BACKGROUND DEVELOPMENTS IN FERTILISER USE

For this case study, developments over the past quarter of a century are being selected as this has been the period of change. At the beginning of this period the production capacity of our soils was at a relatively low level as reflected in low crop and pasture production. We had emerged from a time of extremely low fertiliser input as a result of the non-availability of nutrients during the war period. It was naturally a time of assessment which in effect began with the compilation of a national nutrient balance sheet [8]. This showed that not more than about 5% of our soils were satisfactory for phosphorus, about 20% for potassium; that in fact there had been a long period of nutrient depletion where the main source of nutrients was farmyard manure and imported feeding stuffs. In general, we were in a cycle of nutrient depletion. It was shown also that lime deficiency was widespread even on some of our limestone soils; that we were applying only a fraction of the lime required. This situation resulted from the continuous leaching of lime from soils under our climatic conditions.

At this time a number of steps from a technological aspect were taken to rectify the position. These were based on the concept that efficient land use was the key to progress, this concept being translated into practice through scientifically identifying the potential of our soils, establishing crop and animal response to nutrient input data and through monitoring of changes in both physical, economic and social terms. This approach provided facts as a basis for an action programme. Let us see some of the changes which have taken place.

The expansion of fertiliser use since the mid '40's aided by a fertiliser subsidy at the end of the '50's (Fig. 2) has given a marked improvement in the levels of nutrients in our soils. The extent of this improvement is shown in Table 3 [9]. This increased fertiliser input, side by side with the use of improved

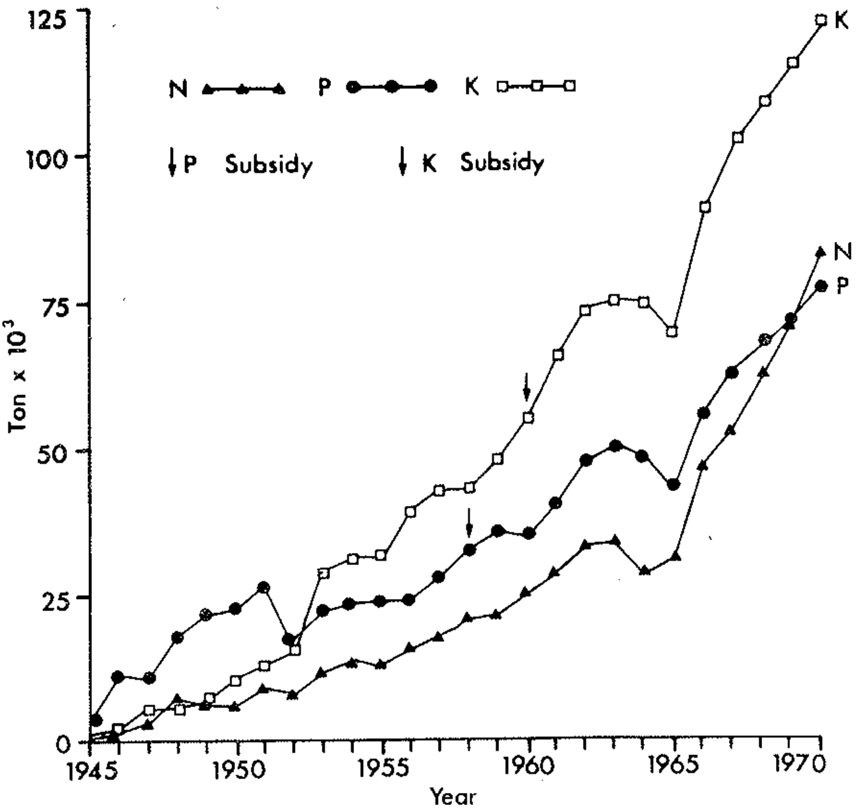

FIG. 2 — Use of fertilizers in Ireland 1945-1970.

Source: Central Statistics Office

TABLE 3 — *Changes in levels of soil P and K since* 1954 [9].

Year	Percent of advisers' soil samples classified as very low in P and K	
	0-½ ppm P	0-24 ppm K
1954	77	66
1957	49	32
1965	0	6
1970	0	2

cultivars and better crop husbandry practices, has given us a more or less continuous increase in crop yields and animal output (Figs. 3 and 4).

THE APPROACH TAKEN

Let us look first at some of what might be described as the soil technology developments which have taken place in achieving the present position.

Assessing the capacity of our soils

We have a long history of field experimental work on fertilisers, especially since the Department of Agriculture was established in 1900. This was mainly testing-demonstrating work somewhat similar to the FFHC field programme reported on by RICHARDSON [10]. The fertiliser recommendations based on this approach were average values which took account of variations in soil type or previous cropping history only in a general way.

In the 1930's, interest had been aroused in the application of more scientific techniques of assessing soils against the

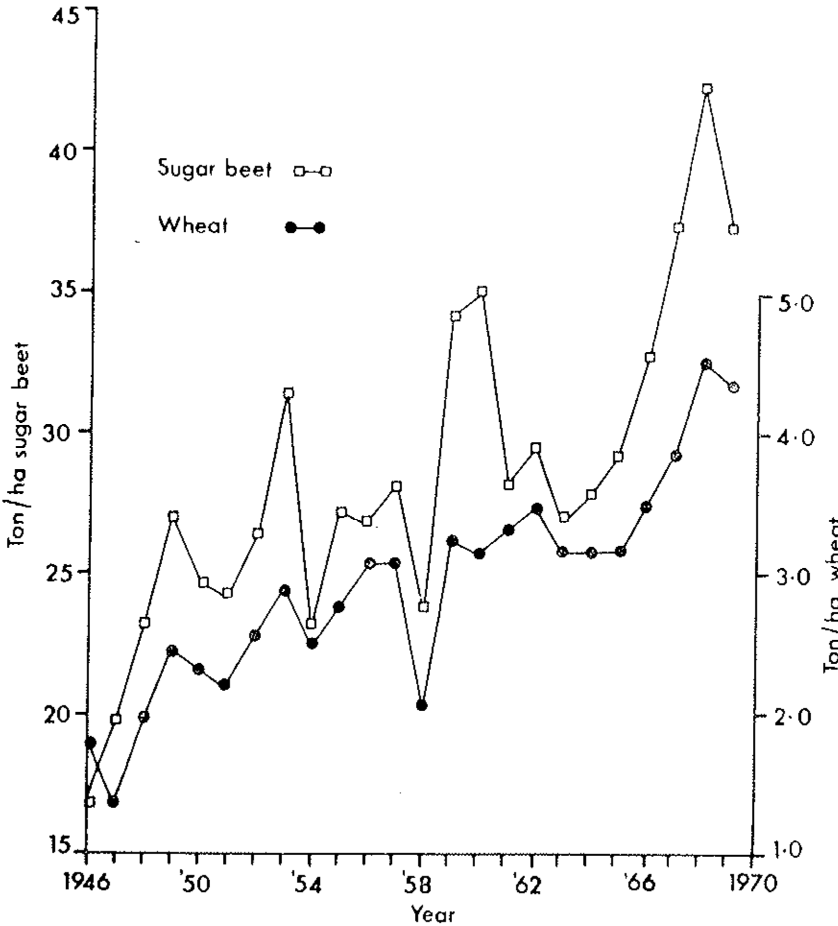

FIG. 3 — Sugar beet and wheat yields 1946-1969.

Source: Central Statistics Office

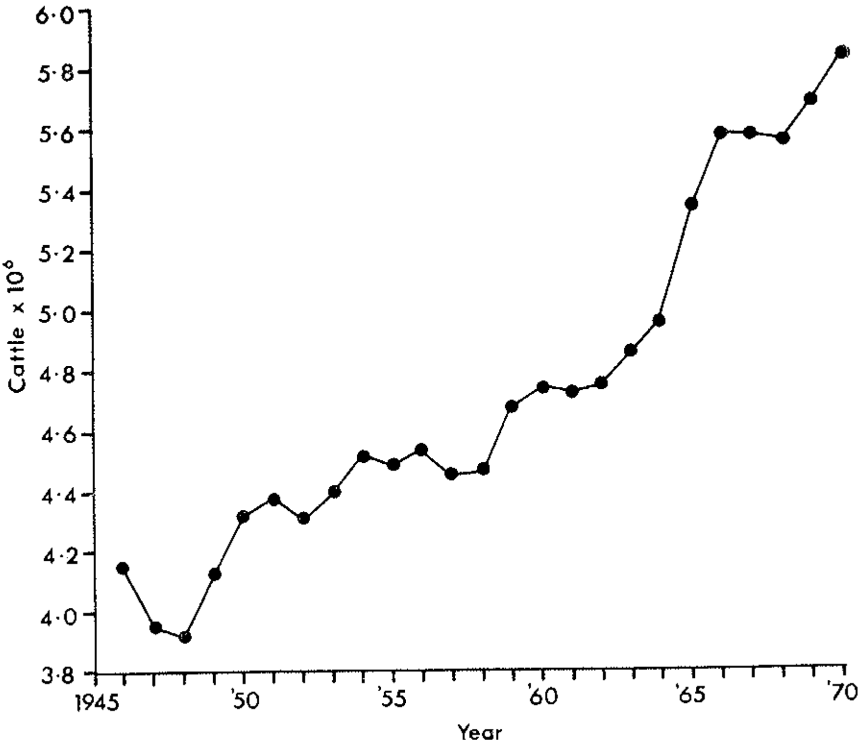

FIG. 4 — Cattle population 1946-1970.

Source: Central Statistics Office.

background of the work of the Russian School of Soil Scientists. Taking soil type as a criterion, work was undertaken in Ireland in the late '30's which clearly established that a more specific approach to fertiliser use based on these new concepts could be rewarding. Some of this early work [11] showed that Irish soils had quite distinct characteristics, depending on conditions of formation – the podzolising process predominated. This work was soon found to have a practical application when grey-brown podzolic soils with a high level of calcium were found to have a high capacity to fix fertiliser K [12]. It was also noted [13] that wheat cultivars bred on a moderately Mn-deficient soil were more resistant to deficiency than wheat cultivars bred elsewhere. It was established [14] that rapid chemical tests, which had been developed in the United States and elsewhere, could with care be used to assess the pH, P and K values of our soils.

By 1946, a substantial amount of basic data had been accumulated as a basis for under-pinning future developments. Although the deficiencies of soil testing were recognised, it was decided to proceed with the development of a national soil testing service bearing in mind the soil type differences which had been established. This service was meant primarily to be an aid or guide to graduate advisers in dealing with their day-to-day problems of fertiliser and crop production recommendations for farmers. We were insistent that the soil samples should be taken by advisers or specially trained samplers and that the fertiliser recommendations should also be made by them. This is the approach we still adopt. Demand for the soil testing service expanded rapidly and 100,000 soil samples were being analysed per annum by the mid '50's. With soil analysis and increasing knowledge of our soil types a generalised map showing lime deficiency in the country was produced in 1948 as the basis for a national lime subsidy scheme, which was introduced in 1951 and which led to a rapid increase in lime use (Fig. 5).

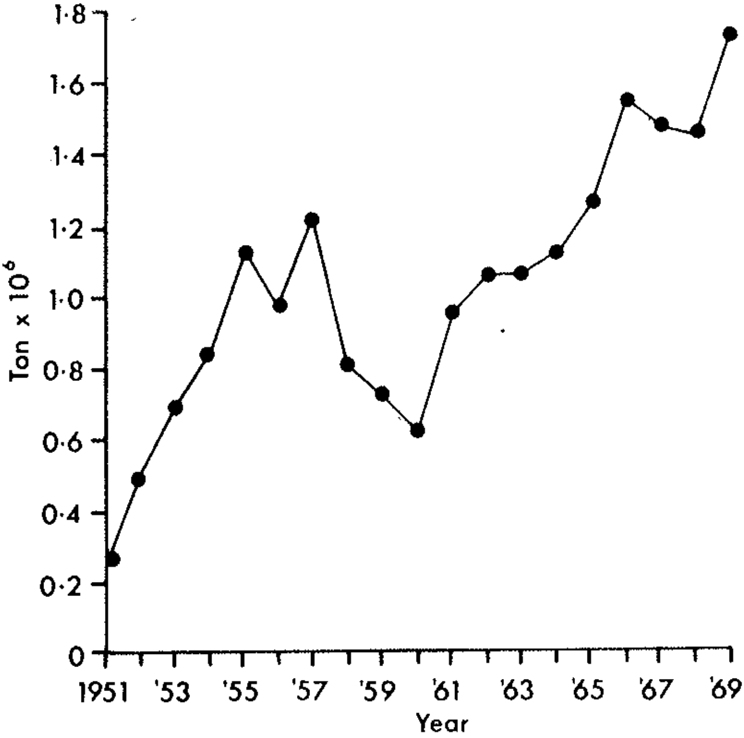

FIG. 5 — Use of lime in Ireland 1951-1969.

Source: Central Statistics Office

Side by side with the introduction of this nutrient assessment procedure and integrated with it, we proceeded with a research programme to characterise and map our different soil types and to establish their nutrient relationships both from a major and trace element aspect. A schematic soil map produced in 1955 [15] was the first attempt to delineate broadly the major soil areas of the country. Against this background, experimental findings on major and trace elements were systematised on a soil type basis. Growth response curves for different crops on an economic optimum basis were published in 1956-57 [16].

In the early stages of this work, we were especially concerned with the relationship between soil types and the availability of major and trace elements and with nutrient interactions. The problem of P and K fixation in some soils was of great concern and interested us in fertiliser placement techniques, an approach which may be of special significance in countries where fertiliser use is still limited. The primary objective here was of course to feed the plant and to minimise loss of nutrients through fixation, i.e., to get the maximum effect out of the least possible quantity of nutrient.

A major effort was made to delineate trace element areas with relation to soil types, particularly where trace elements affected animal health such as Mo-conditioned hypocuprosis, Co deficiency, and Se toxicity. This approach was attended by considerable success. It was possible for instance to correlate cobalt status with parent material and with leaching, podzolisation and gleying processes, in this way establishing cobalt hazard areas [17]. With this interest in trace elements, especially in solving crop production problems which did not respond to major elements, the usefulness of plant analysis quickly became apparent. This led to the establishment of a plant analysis service for essential elements. As the emphasis on quality has increased this service has been invaluable in our research into such important quality factors as the digestibility and protein content of herbage and the protein content of wheat and malting barley.

With the more systematic development of agricultural research in 1958, our research effort was intensified. Major research centres were established in different regions of the country. Our soil survey effort was expanded through the establishment of the National Soil Survey and the first general soil map of the country was published in 1969 [18]. Factorial trials testing several rates of N, P and K on different tillage crops were conducted at many centres throughout the country. Special attention was paid to the establishment of an appropriate research methodology for determining optimum fertiliser use in pasture in relation to animal production. This showed the need for large-scale animal trials on a farmlet, test farm and adoption farm basis as a means of bridging the gap between the information obtained from cutting or small-scale grazing trials and the information required by the farmer.

In addition, because of the influence of weather on crop production and especially on seasonal production, weather recording stations were set up at the major research centres to supplement the national grid.

We will now refer briefly to some research findings in order to show more clearly what has been achieved to date and to set a background for a discussion on the road to follow in the future.

Climate

It is generally accepted that such climatic factors as water supply (precipitation), temperature and light intensity bave significant effects on fertiliser efficiency. With our wide diversity of soils, some of which have impeded drainage, weather effects, particularly excess rainfall, are of special significance. Yields of sugar beet were found [19] to decrease with increase in latitude and there was a tendency for decreasing yields with decreasing maritime influence. Deviations from trend yields in spring wheat were greatest in years of unusually high or low rainfall [20] and this obviously affects returns from fertiliser input. It was noted [21] that low rainfall during the growing season gave poor fixation of N by white clover (Fig. 6). Nitrogen applied to sugar beet significantly increased yields and grain nitrogen content of the following barley crop, when the November to February rainfall was less than 280 mm [22].

Where animal production is concerned, climate, especially precipitation, apart from its direct effect on grass growth, is highly important in deciding grazing method and capacity; in this respect precipitation must be considered in conjunction with soil type and fertiliser use. It was observed [23] that on a soil of a highly poachable nature, if nutritional conditions are such as to stimulate plant growth, poaching can be very much reduced in severity. With no fertiliser at higher levels of stocking, poaching was very severe, while with the application of nutrients it was much less so.

Work at one of our research centres on a heavy textured soil is showing that a significant loss of nutrients occurs in run-off when precipitation follows recently applied fertiliser [24]. This, of course, is significant in slurry or "gulle" spreading and in timing of fertiliser application.

Soil type

Reference has already been made to the emphasis we have placed on defining the inherent characteristics of soils as a basis for fertiliser use. We have found that soil type *per se* has a highly significant effect on crop growth and on the amount of nutrients required for optimum crop growth or animal production. An example of soil type effect on crop productivity and consequently on fertiliser efficiency was shown with sugar beet [25] where yields of sugar varied from 8.1 t/ha on a grey brown podzolic soil to 4.9 t/ha on a gley soil.

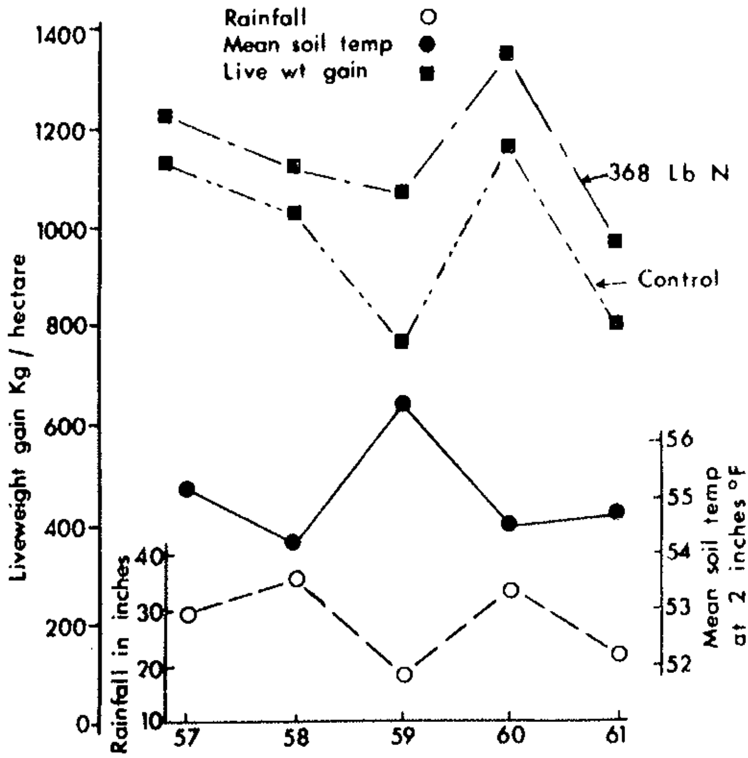

FIG. 6 — Rainfall, mean temperatures and live-weight gains, March to October, 1957-1961 — Maloney and Murphy (1963).

In seasonal production of grass, large response differences between soil types (Fig. 7) have been reported [26]. In another study [27] output from Irish pastures varied from less than 500 to almost 4,800 kg of starch equivalent per hectare. The lowest yields occurred on soils which were poorly drained or on shallow soils.

It is generally accepted that soil type as reflected in the origin, physical, chemical and biological nature of the soil may profoundly affect crop response to fertiliser. What, however, is of more immediate interest to our subject here is the effect of soil type on the inherent major and trace element supplying power of soils and on the availability of plant nutrients.

(*a*) Major elements

Nitrogen

Soil type has been shown to affect N mineralisation and the ecology of the white clover nodule bacterium (*Rhizobium trifolii*). A grey brown podzolic soil was observed [28] to release much less N than several other soil types tested. In a large-scale trial to compare productivity between major soil associations, wheat yields of around 5,800 kg/ha were obtained on heavy limestone soils in plots which received no N for three years. On lighter soils, the corresponding yields were considerably less [29]. In the same trials, crop rotation was found to have a significant effect on mineralisable N over 17 sites [30]. After two years' cropping, with roots or cereals sown alongside each other in the same fields, the mineralisable N was higher after the cereals than after the roots.

White clover is indigenous to Irish soils and many ecotypes occur. Soil wetness has been found [31] to be a major factor influencing the ecotype found as far as symbiotic properties are concerned. Nodule isolates from dry soils are mostly effective with commercial white clover types whilst isolates from wet soils show, in contrast, a predominantly ineffective respon-

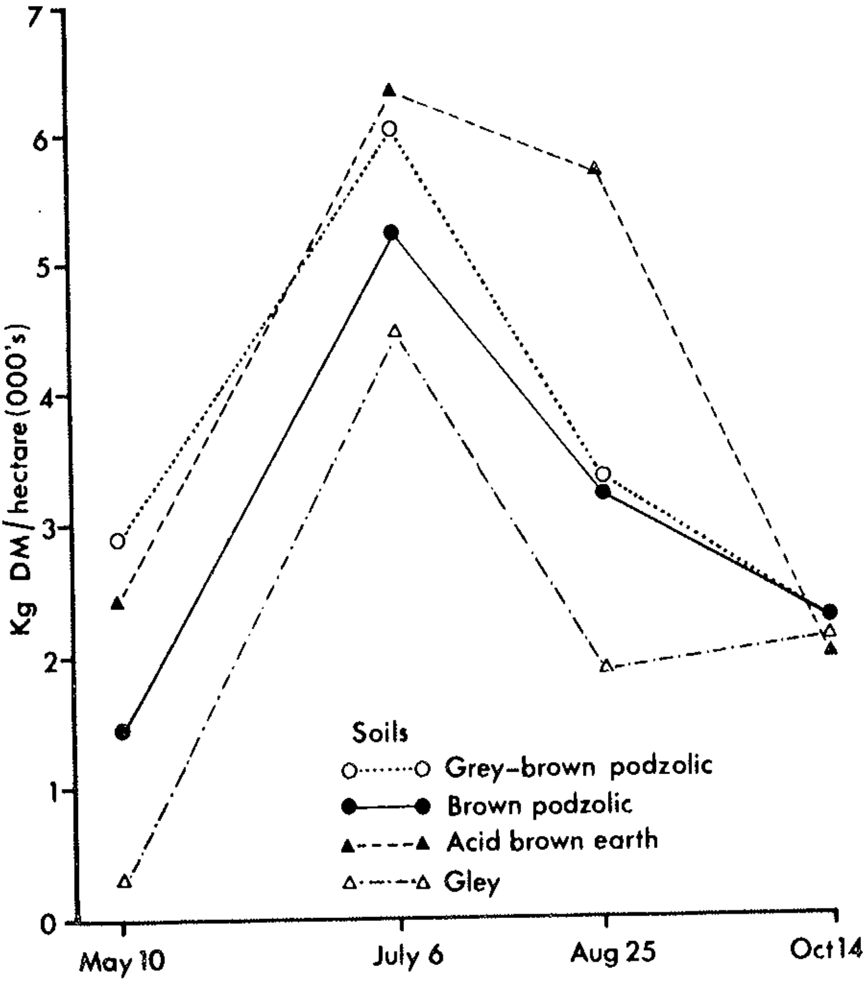

FIG. 7 — Seasonal distribution of maximum yields — Ryan ond Murphy (1969.

se. This is due to selection of different populations of *Rhizobium trifolii* by the various clover ecotypes occurring on the different soil types.

Phosphorus

Phosphorus occurs in soils mostly as relatively insoluble calcium, aluminium and iron phosphates or as organic P. Aluminium phosphate (0.5 normal NH_4F extractant) was found to be the main source of plant available P on acid soils [32], whereas on moderately acid soils calcium phosphate was more available [33]. A study of the types of P present in some old pasture soils [34] showed the presence of relatively high levels of total P, up to 1,250 ppm of which 80% was associated with the organic matter in some of these soils. This work also showed the effects of moisture on the organic P status of a shale soil in hydrologic sequence; the free draining area was found to have a much higher organic P content than the impeded area although neither area had received fertiliser for about a century. In a study of 24 Irish major soil series in a pot culture experiment, it was noted [35] that soils varied greatly in their P-supplying power. One soil, a gley, produced 62% of its 3-year yield in the first year, whereas the corresponding figure for another soil, a grey brown podzolic, was 25%. The response to P varied from 1 to 86% with a mean of 12%.

Potassium and sodium

In many soils the amount of adsorbed K is low and it is the release of K from the lattice of minerals which determines the natural K fertility of soils. The reverse process, K fixation, is also important on some soils. A direct correlation was found between the occurrence of partially expanding and expanding 2:1 lattice minerals and K fixation, with the presence of higher levels of the latter in the soils showing highest K-fixing capacity

[36]. Recently, it has been noted [37] that these K-fixing soils contain high layer charge vermiculite which would account for their high K-fixing capacity.

It has been shown that the annual yields of K in ryegrass can vary from 22-70 kg/ha depending on soil type [38]. This is of course important in determining the amount of K fertiliser to apply.

In view of the ability of Na to partially substitute for K in plant nutrition and of the importance of Na in animal nutrition, it is of significance in fertiliser use. Where several cuts of silage are taken annually with large applications of K, it is possible that the Na content of the silage could be inadequate for animal nutrition. We have obtained [39] an appreciable difference in the seasonal distribution pattern of Na in the herbage of perennial ryegrass and two other grass species (Fig. 8).

(*b*) Trace elements

The actual content of trace elements in soils is closely correlated with the composition of the parent material. This influence of parent material is shown in the trace element content of the two profiles in Table 4 [40]. It will be seen

Table 4 — *Trace element content of soils in ppm* [40].

Type of soil	Horizon	Cu	Co	Mn	Mo	Zn
Brown podzolic soil on granite	Ap	8	2	250	1	40
	B1	7	3	250	<1	40
	B2	7	4	170	1	46
Acid brown earth on Ordovician shale	A11	20	10	3500	<1	100
	A12	20	15	3500	<1	100
	A/C	25	12	3500	<1	150

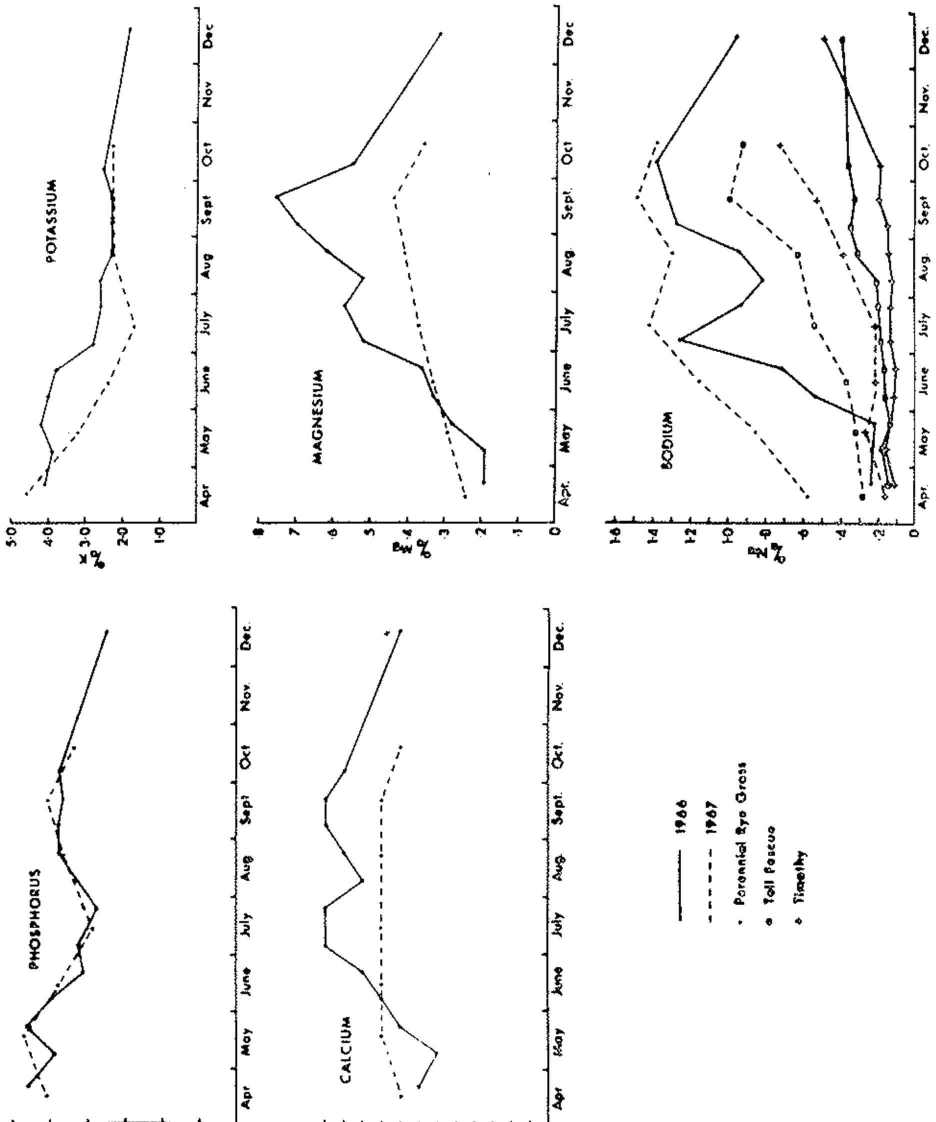

FIG. 8 — Seasonal variation of phosphorus, potassium, calcium, magnesium and sodium (39).

that the granite soil is relatively low in such nutritionally important elements as Cu, Co and Mn. The Ordovician shale soil, on the other hand, is well supplied with all trace elements with the possible exception of Mo.

Our aim has been to produce trace element maps, similar to that shown in Figure 9 for cobalt [41], to provide a record of trace element deficient areas in the country. In this respect, we have found geochemical surveys using stream sediment analysis a useful technique in delineating areas with anomalous levels of elements of interest in agriculture [42]. Because of the difficulty of identifying trace element deficiencies in plants the use of enzyme activity tests has been explored [43] and seems promising.

Boron

It is well known that the availability of B is low on alkaline soils. However, B deficiency in swedes has been reported [44] in a podzolic gley at pH circa 5.0. More recently, a varietal difference in response to B has been noted on a brown earth soil [45]. Boron is the only trace element we include in our N P K fertilisers and this is only included in sugar beet and swede compounds. In fact, we have consistently advised against the "shot-gun" treatment of several trace or secondary nutrients in fertiliser compounds as a preventative measure. Rather the techniques of soil survey and of soil and plant analyses should be used to identify the nutrient deficient areas. Field trials must then be conducted to determine the correct amount of an element to supply on these particular areas.

Manganese

Manganese deficiency is associated with calcareous soils or soils of relatively high organic carbon content, limed reclaimed podzols and limed peats [46]. Where the soil level

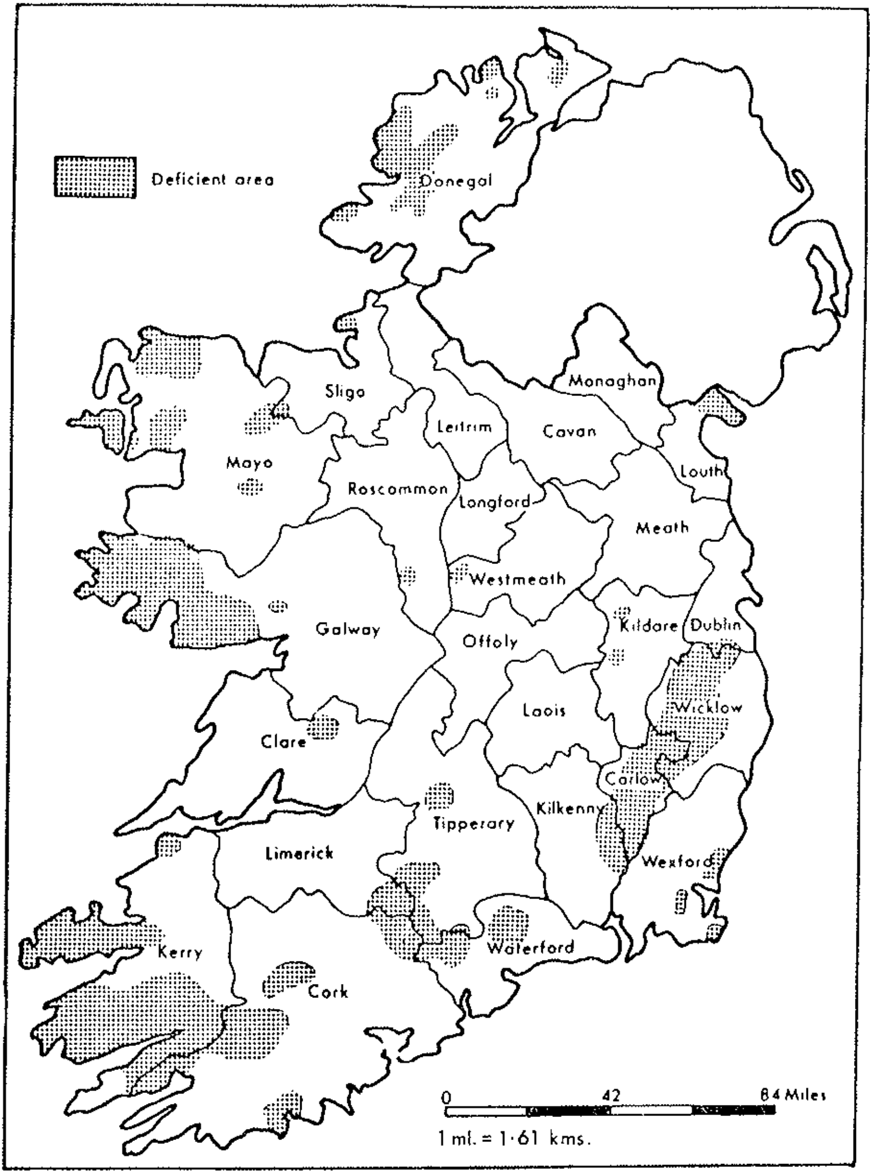

Fig. 9 — Cobalt distribution showing potentially deficient areas (41).

is below 50 ppm easily reducible Mn, we recommend application of Mn and the best results have been obtained from drilling about 30 kg/ha of manganese sulphate for cereals at sowing time [47].

Molybdenum

Walsh *et al* have found molybdenum deficiency in *Trifolium subterraneum* on a sandy loam soil of pH 5.3 [48], and these workers also reported the incidence of Mo-conditioned hypocuprosis on a loam soil derived from limestone. Recent work [42] using stream sediment analysis has helped to identify the extent of one molybdeniferous area. Rock analysis showed that high Mo (75 ppm) arose from black shale strata occurring in Namurian sediments. On such a soil, caution is recommended in the use of lime.

In general, we have found that the availability of nutrients is influenced by many soil factors, including pH, moisture, texture and organic matter content. Each soil can in effect be seen as an individual dynamic entity in which many factors interact to regulate the supply of nutrients to plants. Research into plant nutrient availability must be approached against the background of this concept. This approach is also essential in studying the lime requirement of soils. Our work has shown that the physical nature of the soil, its organic and inorganic colloids, the level of bases especially calcium, moisture status, the level of such elements as aluminium, manganese, phosphorus, molybdenum and boron and the interactions between these elements all influence the amount of lime required for plant growth.

Field trials, forms of fertiliser and rates of application

(*a*) *Field Trials*

When one reviews the literature on the fertiliser requirements of a particular crop, it is easy to understand why every young fertiliser agronomist feels compelled to repeat field trials which have been reported on previously. The literature is brimful with reports of fertiliser trials, but it is almost impossible to compare one with the other. There is obviously a need for international criteria relating to some of the factors at least, such as soils and climate, which should be quantified and included in scientific reports on fertiliser trials. Progress in this respect has been very slow, although the International Nitrogen Long-Term Experiments (ISDV) are a welcome development in this direction.

In our experience well-conducted field experiments carried out on the major soil types are essential in establishing a basis for correct fertiliser recommendations. These experiments must be conducted for at least three years in order to take weather effects into account, and in the case of fertiliser N the sites should have the same previous cropping history for comparisons between sites to be valid. Even with good experimental data, general recommendations should be modified to suit local farming systems and allow for residual effects, dates of sowing and other management factors which deviate from the average. Thus, to get the research results into practice, a fairly intensive advisory service is required apart from back-up services such as soil and plant analyses.

(*b*) *Forms of fertiliser*

The actual form of fertiliser which should be used depends on a number of factors including the soil type, crop, farming system and in particular the level of intensification reached by the farmer. Where our farmers were once satisfied to have one livestock unit per hectare, they are now, with additional cereal feeding, aiming to carry three. At this level of production, it is not possible with conventional fertilisers to supply the total nutrient requirement of the grass with a single application at the start of the growing season. This is especially so in the case of N for grazing and N and K for silage.

(1) *Nitrogen*: In common with other countries, there has been a rapid decrease in the tonnage of ammonium sulphate (21% N) used in Ireland. This has been due to its relatively low N content and also because when used at high rates it increased the acidity of the soil and tended to make the herbage unpalatable [49]. Since anhydrous ammonia is the first product of N fixation, it should, in the long run, be the cheapest source of N to farmers. We found that when it was applied in the autumn it was nitrified over the winter and gave lower yields than similar amounts applied in the spring [50]. Urea (46% N) proved equal to calcium ammonium nitrate for sugar beet [51], but on grassland, it was never better than calcium ammonium nitrate and sometimes considerably worse [52].

(2) *Phosphorus*: On our P-deficient soils in the '50's the aim was to feed the plant rather than build up the soil levels of P. The technique of combine drilling already referred to, and the use of water-soluble superphosphate enabled us to achieve satisfactory yields even on very P-depleted soils. With the build up of soil P levels, which occured at a much faster rate than expected (Table 3), the use of water-soluble P sources is not as critical. Under maintenance conditions, it is possible that any form of P which reacts with the soil would be satisfactory especially for grassland, and economics will decide the actual form used. In trials conducted on grassland in Ireland, basic slag applied in the autumn gave equivalent yields to superphosphate applied in autumn or spring [53].

(3) *Compounds*: There is a definite trend in the temperate zone towards compound fertilisers and for an increase in the concentration of these compounds [54]. This trend has occurred to a marked extent in Ireland as shown in Fig. 10 [55]. The reason for concentration of fertilisers has been attributed to economics in bagging, storage, handling and transportation. We feel that there should be a reappraisal of this emphasis on NPK compounds since it is questionable if

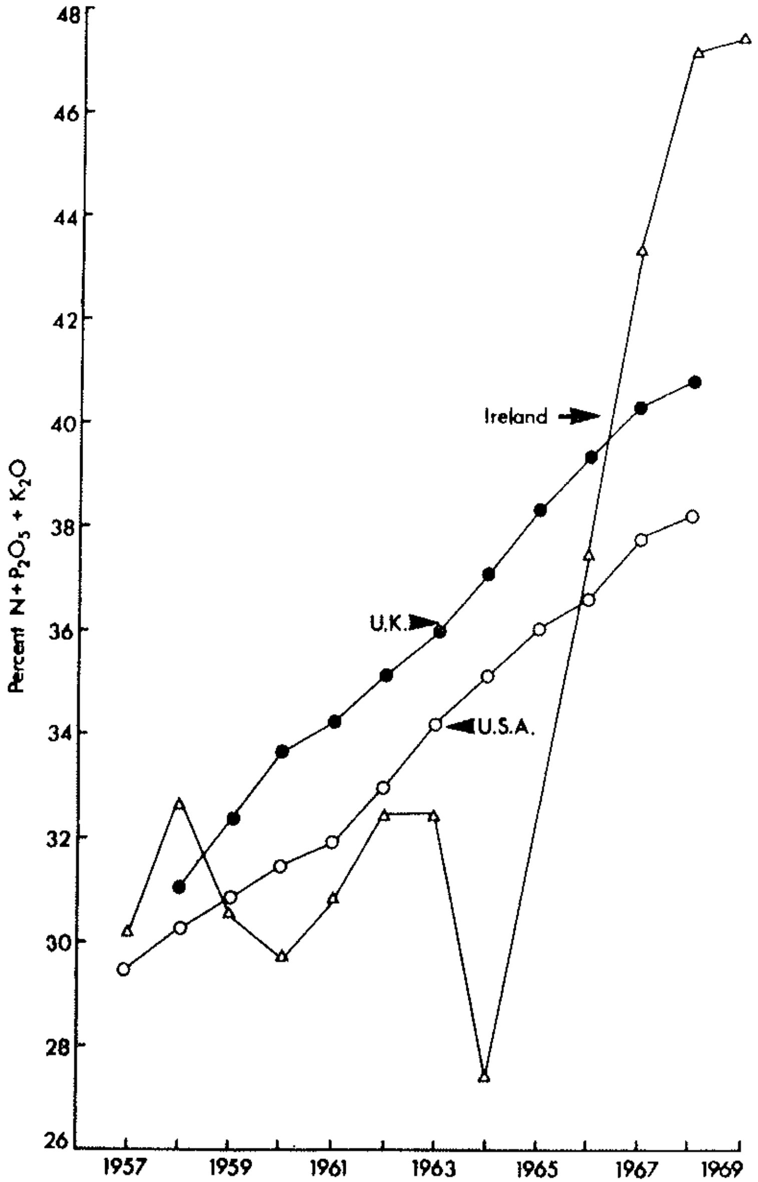

FIG. 10 — Trends in Nutrient Concentration of Compound Fertilizers, after Hanley and Walsh (1971).

conventional water-soluble N sources should be linked with P K compounds. From an agronomic viewpoint, P and K fertilisers can be used to build up soil reserves of these nutrients and then only maintenance dressings are required. These nutrients can be supplied by almost any cheap source of P or K which reacts with the soil. They can be applied in any season, except where booster effects are profitable, and indeed are usually cheapest in the dormant season.

Nitrogen on the other hand, a mobile growth-stimulating nutrient, should be applied when active growth is expected or during such growth. On a crop such as grass, it may be required several times annually. On such a crop, it controls to a considerable extent the yield and quality. It seems logical then to treat its use, as far as possible, separate from that of P and K.

(c) *Rates of application*

The response levels we have obtained to N, P and K have changed considerably over the past quarter century. When soil levels of P and K were low, large responses to fertiliser P and K were obtained even on relatively unresponsive crops such as cereals. As the soil levels of P and K increased through fertiliser use these responses tended to diminish and N became the critical nutrient (Table 5). This was especially so in the case of cereals [56]. Nowadays, we do not see as great a need for combine drilling P and K for cereals where the soil test levels are high, since broadcasting is more economic. It appears as if our soil testing service for these nutrients will in future be used not so much to indicate areas of deficiency but as a check to ensure that soil levels of P and K are being maintained under each farming system and for crop growth problems.

Our N, P and K recommendations for grassland, cereals and roots are shown in Tables 6, 7 and 8 respectively [41]. The P and K rates for individual crops are based on correlations between yield response and soil test levels using the Peech

TABLE 5 — *Crop yields with zero and with maximum levels of N, P and K in 1967-1968 (tonnes/hectare).*

Crop	N_0	N. Max	P_0	P. Max	K_0	K. Max
Grass (dm)	6.0	11.7	7.1	9.3	8.6	9.6
Wheat	4.1	4.4	4.3	4.5	4.2	4.3
Barley	4.1	5.0	4.9	5.0	4.9	4.9
Potatoes	38	48	35	45	27	49
Swedes	50	51	44	53	44	50

TABLE 6 — *N, P and K recommendations (lb per acre) for grassland* [41].

	N	P		K	
		Soil P ppm		Soil K ppm	
		0-3	4-25	0-75	76-300
Grazing	50	40	15	80	30
Hay at closing	50				
Silage at closing	40-80				
Hay or silage after cutting *	0-20	20		100	
Cutting - 3 or more cuts per year	250**	40		150	

* The rates for hay or silage are in addition to those for grazing and are independent of the soil P or K levels.

** Not more than 80 lb N should be applied at any one time.

TABLE 7 — *N P K recommendations (lb per acre) for cereals* [41].

	NITROGEN			
	After most tillage crops, hay or sillage		After good pasture, peas, grazed swedes, kale or where much F.Y.M. or slurries were applied	
	Average « summer » rain (inches)		Average « summer » rain (inches)	
	Less than 20	More than 22	Less than 20	More than 22
Winter wheat	50	35	20	15
Spring wheat	50	35	20	15
Feeding barley	50	35	20	15
Malting barley	30	20	Do not sow	Do not sow
Oats	40	25	15	10
	PHOSPHORUS *			
	Soil P 0-3 ppm		Soil P 4-25 ppm	
All cereals	25		15	
	POTASSIUM *			
	Soil K 0-50 ppm		Soil K 51-300 ppm	
All cereals	50		30	

* At low soil P or K levels, where continuous cereals are grown, or where the previous crop was hay or silage the fertiliser should be combine drilled; at the higher soil P or K levels, broadcasting or combine drilling is satisfactory.

TABLE 8 — *N P K recommendations (lb per acre) for root crops* [41].

	N		P		K	
	Low soil N[1]	High soil N[2]	Soil P ppm		Soil K ppm	
			0-5	6-25	0-100	101-300
Potatoes	90	50	80	40	200	100
Sugar beet	80	40	100	50	300	150
Swedes	50	20	80	40	150	100(50[3])
Mangels	60	30	50	50	150	150
Kale	60	20	50	25	100	50

[1] low soil N = after tillage, hay or silage.

[2] high soil N = after good pasture, peas, grazed swedes, kale, beet tops or much F.Y.M.

[3] 50 lb K is a sufficient maintenance dressing if swedes are grazed.

Note: The levels of soil P and K should be higher for roots than for cereals.

and English modification of MORGAN'S extractant [57]. In common with other countries, we find it difficult to make accurate recommendations for N; this can be attributed to variation in the amount of N mineralised during the growing season which depends on soil type, weather and the previous history of the field. The approach to fertiliser N use on grassland is quite different to that for tillage crops.

(1) *Grassland*: In grassland management, soil type, stocking rate, weather, grazing technique and herbage conservation are all inter-related and influence the amount of fertiliser N which should be used. The objective of good grassland management is to achieve precision in matching fertiliser N use to these production variables. Under intensive management conditions, our research work [58, 59] has shown

that fertiliser N, as a mobile production stimulating nutrient, is a key element in grassland management when its use is adjusted to seasonal growth. Our soils, however, have a sizeable capacity to fix N through white clover (*Trifolium repens*). In terms of costs of production, this is important especially at low stocking rates. However, clover growth is very variable and it is only now with the use of the acetylene reduction test [60] that it may be possible to assess with any degree of precision the contribution of clover.

From our work it appears that where a farmer has less than 95 livestock units/50 hectares he should rely on clover for grazing and use fertiliser N on the grass he intends to conserve. Since almost all our dry land is capable of carrying stocking rates above 95 livestock units/50 hectares it may be that clover will have limited use on our dry land. If it is to have a future on dry soil, it will have to be a cultivar which tolerates high levels of fertiliser N. In this respect, it was reported recently [61] that Blanca clover can tolerate much higher levels of N applied to a mixed sward than several other clover cultivars.

(2) *Tillage*: In tillage, the correct level of N to recommend also presents numerous problems. Thus on sugar beet, N reduced the sugar yield per hectare although many farmers are inclined to aim for the highest yield of roots, despite the fact that it is on sugar yield they are paid. We also find that where farmers have been using a certain rate of a compound per hectare, they still persist in applying it at the same rate when the concentration of nutrients in such a compound is increased. This means that increase in concentration of an existing compound often leads to excess use of at least one element in the compound. In general, the amount of N to use on a particular crop is determined by the length of time the soil is under cultivation as the nearer to grass the more soil N that is released and the less fertiliser N that is required.

Apart from the lack of even a relatively crude soil N test, our biggest weakness for correct N recommendations at present is inadequate weather data for our experimental sites. In addition, we do not have as yet probability maps calculated from long-term weather records showing the probability of obtaining a certain weather pattern in a particular region. Such data are essential for optimum N use.

Quality aspects

Up to now, we have been discussing the effect of fertilisers on crop quantity but their influence on quality is also of major significance. Quality becomes of greater importance in intensive systems. In the early days, we were only concerned with the quality of some tillage crops used for processing such as wheat, sugar beet and malting barley but nowadays, the quality of all crops, including grass and vegetables, and the influence of fertilisers on quality factors are a major priority on our work.

We found that nitrogen applied as a top dressing lowered the sugar content of beet [51]; nitrogen also decreased juice purity, increased amino N levels, whereas P had little effect on these quality factors; with K, beneficial and deleterious effects on quality cancelled each other out [62]. Nitrogen applied as a top dressing also produced excessive nitrogen in malting barley grain [63] and increased the nitrogen content of wheat grain [64]. However, the progressive increase in nitrogen content from fertiliser N was not paralleled by an improvement in baking quality [65]. Nitrogen was found to increase the proportion of blighted potato tubers whereas fertiliser P had the opposite effect [66]. When K was applied as either KCl or K_2SO_4 it tended to decrease the dry matter of potatoes but K_2SO_4 gave the least decrease [67].

Quality in grass production is closely related to the level of fertiliser use. In our work on hypomagnesaemia with certain conditions of N and K use on a ryegrass sward, tetany proneness was created [68]. When N is applied at rates greater than about 60 kg/ha it may reduce the clover content of pastures and a clover-grass sward is more nutritious and has a higher protein content than a grass-only sward. When 672 kg N/ha were applied in increments of 134.4 kg the "critical" nitrate-N level of 0.21% in the herbage was exceeded at a few sites in the May and October samples [69]. It is well known that different grassland management techniques, including stocking rate and fertiliser use, affect the persistence of different grass species and some species, e.g., cocksfoot (*Dactylis glomerata* L.) are less palatable than others. It has also been shown [39] that some of our main pasture species of comparable stage of growth may differ substantially in mineral levels (Fig. 8).

In assessing the effects of fertilisers on quality in grass, we must at all times be concerned with utilisation in the animal as well as by the animal. This fact was clearly demonstrated (Table 9) in comparative experiments on the effect of hay and silage which received the same level of fertiliser [70]. Significant differences were found not only in liveweight gain between the forms in which grass was conserved and fed but also

TABLE 9 — *Body composition of animals (kg) fed simultaneously harvested hay or silage ad libitum* [70].

	Hay	Silage
Liveweight at slaughter	393	378
Hot-carcass	200	207
Non-carcass fats	8	9
Empty bodyweight	308	317
« Gut fill »	77	54
Kidney and channel fats	4	5
Killing out %	50.6	54.8

in their effect on composition of the carcass both by weight and quality. It is obvious that liveweight gain alone is no longer an adequate basis for measuring productivity. As we move towards higher levels of intensification, quality of all farm produce must receive increasing attention.

Economic aspects

It has been conventional when dealing with economic aspects of fertiliser use to consider the most profitable dressing of fertiliser as the level where the value of crop response to an increment of fertiliser becomes equivalent to the cost of the increment. We adopted this approach with considerable success [16], especially as a basis for target setting at national level. The matter is of course not by any means as simple as this, particularly when one must be concerned with response in pasture where not only the effect on liveweight gain of the animal is important but also the effect on the saleable weight of some portion of the animal. We have already referred to results [70] where grass which received the same level of fertiliser, but was harvested in different ways, gave quite different end products and it is of course the end product which matters. Hence the economic optimum level of fertiliser should not only depend on such factors as the farming system and level of intensification but also on the quality of the end product whether it be milk or meat.

Most of the economic factors which relate to optimum fertiliser use are shown in Table 1. In our Farm Management Survey [71] the average expenditure on fertilisers per hectare was greater on the larger farm size groups than on the smaller ones. This indicates that the majority of our farmers have not yet reached a level of intensification where they are substituting fertiliser for land, as otherwise one would expect that fertiliser use per hectare would be greater where average farm size is low.

There is ample evidence of the association between fertiliser expenditure and gross margins, i.e., the difference between output and variable cost of production. In the Farm Management Survey already referred to [71], the average gross margin for milk production in 1968/69 was £ 75/hectare, whilst that from drystock production was only £ 28. The respective fertiliser expenditure per hectare was £ 3.50 and £ 2.25, i.e., increased use of about 55% where net returns justified such application rates.

In the early days, we were concerned with determining the economic optimum use of fertilisers on individual crops at farm level. Capital scarcity is, however, a feature of agriculture and for this reason it is not possible to achieve the unconstrained optimum economic usage of fertilisers on individual crops. We are now looking at each farm enterprise as a whole and the role of fertilisers within clearly defined systems of production for each enterprise. Our economic studies on grassland have progressed from small plot grazing trials to the farmlet production unit through studies in depth on economic test farms on a model basis and finally through our farm surveys and enterprise studies of the problem at farm level. For these studies we have economists and production research people working in close liaison on multi-disciplinary project teams. An example of the relationship between fertiliser costs in the context of the farm business as a whole is shown in Table 10 [72]. In this table, it can be seen that the stocking rate on the intensively stocked farms was approximately double that of the lowest stocking rate group; this resulted in a family farm income 2½ times greater, although fertiliser costs were over twice as high at the high stocking rate.

Our approach to the development and investigation of these production systems which offer the most profitable opportunities and within which fertiliser is regarded as playing a critical part is demonstrated by the work of Conway [73] in his analyses of Irish data relating to grazing steers. He

TABLE 10 — *Family farm income on dairy farms as related to stocking rate and fertiliser use* [72] - £.

Ha. per L. U.	Gross output per adj. ha.	Net costs per adj. ha.	Family farm income per adj. ha.	Fertilizers per adj. ha.	Working Capital per adj. ha.
0.58	101.27	44.95	56.32	4.57	118.56
0.75	74.59	33.84	40.76	3.66	80.82
0.89	59.28	24.45	34.83	2.96	81.51
1.13	41.74	17.78	23.96	1.98	61.75
Average (0.77)	74.35	32.85	41.50	3.46	89.41

says: "It only pays to produce additional grass by fertilisation if grass can be profitably converted into an animal product(s)". In that event the optimum stocking rate is given by:

$$(1) \qquad N/No = 1.75 + 1.25 \; [(\Delta P - C)] \; /(G_oP)$$

where N is the number of animals per acre

No is the maximum number of animals per acre that can achieve appetite intake (a measure of stock-carrying capacity)

W is the initial weight per head of the animals

P is the price per unit weight at the end of the grazing period

ΔP is the change in price per unit weight over the period

C represents the current costs per animal (excluding purchase price).

G_o is the liveweight gain per animal associated with appetite intake.

The returns (R) from an acre of pasture before fertilisation is given:

$$R = NoX - Z \qquad (2)$$

where Z is the fixed costs per acre

$$\text{and } X = G_o\,[1.4\,(N/No) - 0.4\,(N/No)^2] \qquad (3)$$

$$P = W\,(\Delta P)\,(N/No) - C(N/No)$$

We can see by reference to equation 2 that return per acre depends not only on the level of grass production or stock-carrying capacity (No) but also on X. By reference to equations 1 and 2 we see that X depends on prices and costs, the type of animal as this affects W, No and along with pasture quality affects G_o. These parameters affect the optimum expenditure on fertilisers and equations 4 and 5 show how fertiliser response data can be integrated with equation 2 which deals with the utilisation of grass by grazing steers. Expenditure (F) on fertilisers gives an increase (ΔNo) in stock-carrying capacity and the associated change in returns per acre is given by equation 4.

$$\Delta R = \Delta NoX - F \qquad (4)$$

In the typical case of declining marginal returns on fertiliser expenditure, the optimum level of fertiliser expenditure (F) is given by equation 5.

$$\frac{d\,(\Delta R)}{d\,(F)} = 0$$

implies

$$\text{(5)} \qquad \frac{d\,(\Delta No)}{d\,F} = X^{-1}$$

While the left hand side of equation 5 is given by the response of grass growth to fertilisation (equation 6), the optimum fertilisation can only be

$$\text{(6)} \qquad \Delta No = f\,(F)$$

decided if eqnation 6 can be integrated in a model of grass production and utilisation as shown here by equations 2 and 6. Equation 5 shows that the implications of the fertiliser production function (equation 6) can only be assessed in a grazing situation by reference to the animal grazing function (equation 2).

In future then, we must concentrate on the mix of inputs and present recommendations to farmers tying up in a package, as it were, the various levels of all the controllable inputs to be used in a production system for each commodity. In each proposal for an intensive production system, we must set out details of the quantity and type of commodity to be produced per unit of land together with the package of inputs, including fertilisers, but especially service inputs, such as capital, labour or management necessary to make this system technically and economically efficient.

Monitoring Fertiliser Use

In any economic assessment of fertiliser use, it is essential to have checks on the types and quantity of fertiliser being used, where and when it is applied and its effects on crop yields and soil fertility. We monitor the effects of fertilisers on soil fertility through soil analysis (Table 3). In addition, we use fertiliser use surveys [74] as an integral part of our Farm Management Surveys to study trends in fertiliser use practice. In order to ascertain where best to concentrate research and development effort, attempts are made to predict future trends in fertiliser use [9, 75]. These have been based mostly on estimates [76] of the stock-carrying capacity of our different soil types. An example of these estimates are shown in Figure 11 [41]. Since almost 90% of our soils are under grass, the stock-carrying capacity is obviously the factor which will have the most influence on the economic optimum of fertiliser to use.

Personal Aspects

In an assessment of the factors affecting the economic optimum use of fertilisers the "personal" one is an important consideration since it takes into account the management capacity of the farmer. There is no doubt but that the managerial ability of the farmer to exploit the productivity potential of fertilisers is a very significant factor in their effective use. A recent study on the relationship between the use of various information sources by farmers and the adoption of approved farm practices [77] showed clearly the importance of the individual characteristics of the farmer in decision-making at farm level. It was found, for instance, that 32% of the farmers interviewed had followed the recommended farm practice of using N for early grazing. The adopters of this practice differed from the non-adopters in the following ways. A greater proportion were (*a*) yonnger, (*b*) married, (*c*) had formal education beyond primary school and (*d*) were operating larger holdings. The adopters also differed from the non-adopters in uses of information sources such as the press, radio, television, other farmers and the advisory service.

In general the results of this study suggest that it is possible to obtain significant relationships between the adoption of

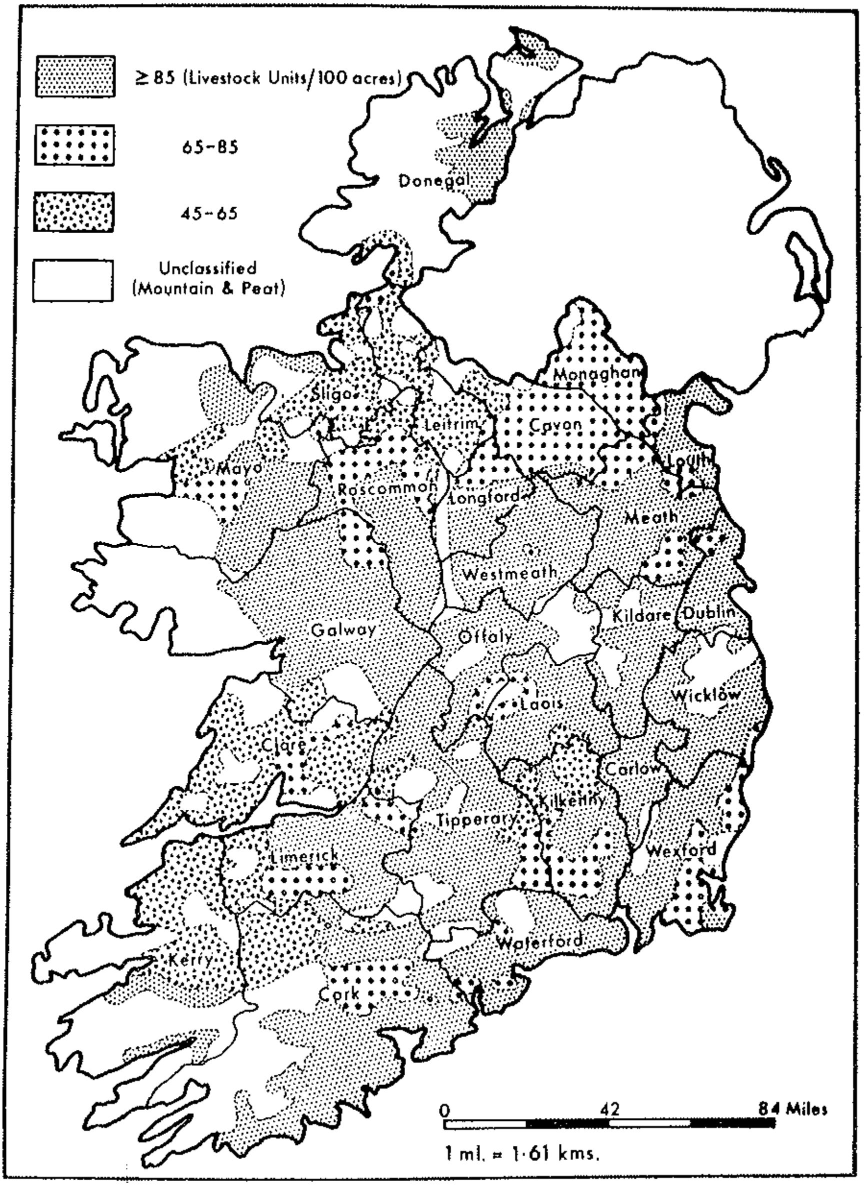

Fig. 11 — Reduced and simplified representation of map showing estimated grazing capacity of Irish soils (41).

approved farm practices and the sources of information used by the adopters. It is our experience, however, that the "personal" factor is, of its very nature, one of the most difficult to quantify and considerable research is still required in the field of rural sociology before precise explanations can be given for the reason why some farmers are motivated to use large dressings of fertilisers whereas others use very little.

In retrospect

Looking back on our progress in fertiliser use, it is seen that a cycle of development has almost been completed: starting with soils in a very poor state of fertility where responses to fertiliser were exceptionally large and where in fact most of the nutrients added to soil came through farmyard manure and animal feeding stuffs. Inputs to agriculture were low and farming was extensive rather than intensive. Tillage crops received whatever fertiliser was used but grassland was almost entirely neglected. In this situation, animal health was poor and in fact aphosphorosis and cobalt deficiency were common in some areas. We have seen that yields of tillage crops were relatively low and those of grassland were considerably worse. It was in effect subsistence farming, where there was a large labour pool and the use of machinery was negligible.

Our progress really began when fertiliser became freely available, when soil testing showed just how depleted our soils were and when lime became relatively cheap through a substantial government subsidy. Research and field demonstration plots at this stage created an awareness of the potential of our agriculture. An expanding advisory service helped considerably in getting the information across to farmers. Progress was slow especially in grassland farming where poor pasture species and low stocking rates combined to give low returns. Lime and fertiliser use, however, continued to increase and the '50's could be described as an era of nutrient build-up. Gradually the botanical composition of our pastures improved and we became very aware of the ecological significance of the different nutrients. During this period too, some of our trace element problem areas were delineated with the use of soil survey and soil plant analyses. The important role of N as a mobile growth-stimulating nutrient was not fully appreciated in the '50's and we were aiming for good clover in our grassland recommendations. However, when the lime, P and K levels of our soils were reasonably satisfactory, we entered the N era.

This commenced in the early '60's. Here the aim was to intensify crop production and livestock carrying capacity per hectare to the economic optimum level. Where there was a guaranteed market, farmers continued to increase the level of N aiming for still higher yields or stocking rates. Improved techniques in herbage conservation for winter feeding gave a further boost to the demand for fertilisers. In this era of increasing intensification in agriculture our approach was one of developing greater sophistication aimed at removing barriers to progress. This was especially so in the case of grassland where we progressed from cutting and small plot feeding experiments to farmlet and economic test farm trials, with ultimate integration into farm practice. Greater emphasis was placed on herbage conservation and on the processing and marketing of quality agricultural products.

Progress was rapid in the '60's. There were many reasons for this including improved markets and greater educational and advisory facilities for farmers, with research findings creating the necessary confidence for this progress. We have seen that fertiliser use increased rapidly during this era and, apart from research, this expansion was assisted by a number of governmental programmes including the fertiliser subsidy and credit schemes, fertiliser legislation, milk and beef subsidies, target setting programmes and the establishment of a modern fertiliser industry.

Basic to this whole programme was an ecological approach which ensured that the environment in its entirety would be maintained in a suitable condition for growth and development. In this respect we are now concerned with the waste of valuable nutrients, whether they be fertilisers or the nutrients in slurries, and in particular with the prevention of the eutrophication of our waterways as agriculture is intensified still further.

In Ireland, we now see the same trends as elsewhere when farming is intensified. Fertilisers, especially fertiliser N, will be substituted for land and machinery for labour. Farming has become more capital demanding and in fact the availability and use of capital is determining the rate of intensification. There is increased emphasis on specialisation and on vertical integration in the farming sphere. Farmers have been stimulated to use business methods and to intensify production. They are now more willing to try out new farm practices and to utilise the sources of information available in order to improve their farming systems and to meet specific market demands.

From a fertiliser use viewpoint, this business approach has important implications. There is a greater consciousness of the need for the adoption of a more scientific approach to land use. Soil productivity rating systems are the basis for such developments. Current fertiliser experimental programmes measure seasonal variation in the productivity of different soils with a view to developing farming systems best suited to each particular soil type.

The road ahead

It can be seen that major developments in fertiliser use have taken place over the last quarter of a century and especially in the last decade. It would be hazardous to attempt a prediction of what will happen in fertiliser use over the next quarter century. Perhaps we might best approach this matter by looking at some of the problems which we feel should be researched in the years immediately ahead.

Land-use systems must be developed not only to meet agricultural requirements but also societal needs as a whole, including demands for recreation and enjoyment. We appreciate how with the continual increase in fertiliser use over a relatively short number of years problems of run-off and subsequent eutrophication can occur. Allied to this, increased animal numbers give rise to problems of excrement collection and disposal. Nowadays our work shows that the best thing to do with slurry or "gulle" is to return it to the land. This raises questions about the nutrient value of this slurry and the amounts of it that can be applied before doing physical damage to the land, affecting the herbage or increasing the risk of run-off or eutrophication. The enforced use of well-preserved slurries could change the whole pattern of chemical fertiliser use since such slurries contain valuable amounts of nutrients.

Transport of plant-available nutrients in surface run-off and ground waters as related to fertiliser use has not been studied in sufficient detail. A number of well-conducted studies are required to examine the relationship between fertiliser use in catchment areas and water quality in these areas. These studies must be carried out on several major soil types, under different cropping systems and in different climatic zones.

There is need for much closer co-operation between the plant breeder and the agronomist. Our work has shown such differences in the behaviour of cultivars to suggest that there is a future in systematic breeding programmes for different soils and different farming systems. The most suitable systems of farming should be developed for each particular soil type and the place of fertiliser as a component in such systems must be ascertained. Specific market requirements must be met by production systems based on soil, plant and animal capacity. It is axiomatic that quality of our agricultural product will play an ever-increasing part in our ability to obtain and keep markets. Our understanding of quality and what constitutes a quality product is too ill-defined and this whole subject requires much more research.

In tillage crops the emphasis must be on determining optimum fertiliser dressings for the whole rotation rather than for individual crops. Herbage production presents the greatest possibility for expansion in fertiliser use. It is also here that the least information is available on such important questions as maintenance versus residual values and on the re-cycling of nutrients. Indeed there is still considerable effort required to determine the optimum fertiliser dressings for the many different grassland farming systems being practised at present. In this respect, we see promise in the use of mathematical models of the total system to achieve optimal allocation of resources provided the relevant research results are available. Some years ago, the complexity of the functions relating yields to their causative factors would itself have been a problem in finding optimal solutions, but with the availability of high-speed computers and the developments in mathematical programming this is no longer the case.

In describing the influence of fertilisers on animal production from grazed pastures, models should be especially useful. Such models will have at least two components. The first will relate fertiliser applications to quantity and quality of herbage produced and the second will relate animal performance to herbage availability and ultimately we hope to the quality and quantity of different animal products. The formulation of an equation for the second component must take account of the effect on animal production of stocking density [78].

In conclusion

Finally we would hesitate to suggest that any appreciable amount of the techniques we have developed and the experience we have had in relation to economic and societal aspects of fertiliser use can be used elsewhere. The problems of under-development in a country have, of course, to be solved mainly within that country. Each country, if it is to have a proper basis for development, must by and large develop its own know-how. For optimum use of its land resources a thorough knowledge of soils and climate is a sine qua non. It must be clearly recognised that fertiliser use, which as we have seen is an essential primer in the agricultural development of a country, can often be uneconomic if the other factors of production are not developed concurrently. In this respect, for instance, fertiliser applied to grassland without additional capital for the extra stock that can be carried is largely a waste of money; there should be adequate marketing arrangements for the extra stock units produced.

In the future we are convinced that farmers will require an integrated programme for the proper development of their farms; they cannot be expected to be satisfied with anything less than a "package deal". It is wasteful and unrewarding that they should have to fit the bits and pieces of research — the individual bricks of the production wall — into systems. Such synthesis is an important field for research. Against this background it is essential, of course, that there should be an adequate field advisory service to ensure that the farmer receives the necessary help with the adaptation of such systems to suit his own particular requirements.

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DISCUSSION

Chairman: M. V. L. Homès

Hernando

I am surprised to know that you find different types of soil give different types of yield response in general. We get different answers in our conditions but the effect of management is more important, especially for NPK but I do not know if you are talking about minor elements. For major elements we get a greater effect from management than from soil differences. On the other hand, I try to tell you that we agree with you about that: to apply trace elements to the soil as a preventive measure to avoid the deficiency of elements which is mostly very dangerous.

Walsh

I would answer this question by asking another question. Have you systematically examined in controlled work, soil type effects. In the paper I have given several instances of our results on such effects. We thought at one time like you we would have a blanket situation where fertilizer use is concerned. But this was not so. In our experimental work — and it has been quite definite, some 40 different major experiments, on as many soil types, and carried over a period of years, distinct soil type effects emerged. I do not know if you have approached this matter in a similar way in Spain. As you know soil productivity is made up of quite a variety of components and even if the yield results from two different soils were the same, it does not mean that the contribution from the different components is the same for both soils. It is reasonable to ask what is the quantity of yield due to, for instance clay minerals, to textural components, to structure, to moisture, to nutrients inherent in the soil or applied as fertilizer. I think it is time we began looking at this situation in terms of the different components of yields from each specific soil type. We look at it this way, and we are quite definite about the differences which have emerged. The recognition of what each component contributes to total yield is of course highly important in an advisory programme.

HERNANDO

Well, maybe in your country the farmer uses amounts of fertilizer very similar in the same area. In our conditions it is very different. In the same village there are farmers applying, maybe 100 kg/ha of nitrate, phosphate and potash, and there are farmers applying much more than 100 kg/ha. And that happened in the last 200 years, in some places for more than 200 years. The application of farm manure, before and after fertilizers, explains why we found so much difference, and we think it is more interesting in onr country to study or evaluate the soil productivity than to study the soil type and its differential conditions for fertilizing.

WALSH

Soil type is, of course, part of the soil fertility complex. In my paper I pointed out that not so long ago we were using the techniqne of combined drilling of cereal seed and fertilizer —

getting the maximum effect with minimum fertilizer. To-day we do not need to place fertilizer any longer because the general nutrient status of the soil has been raised. Nevertheless we get substantial differences in yield both quantity and quality wise from different soil types. We must of course be careful how we define soil type, and that the sort of classification system we use is meaningful soil fertility wise.

COLWELL

I would like to carry on this little point of disagreement that Dr. HERNANDO has brought up. Spain must be like Australia because in Australia we certainly find that the usefulness of soil type is not always obvious. We have looked at this very carefully and I would refer you to some of my publications; there is one in the Australia J. Soil Research, comparing features of soil groups. To make things simple we set out to compare soils where there was an ohvious difference — a chernozem type of soil compared with a podsolic — you could hardly imagine a greater contrast — also a red earth and, what we call, a red brown earth. Four soils where the difference is obvious. Now when we looked at these soils very carefully we found that in fact there were differences in certain chemical properties. For example pH. It is not suprising that we found that a podsolic was more acid than a chernozem. We also found potassium was different. But unfortunately these features of the soil do not effect productivity in the area of this study. The chemical factors that effect productivity in this area are phosphorus and nitrogen and these two compounds are certainly related more to cropping history than they are to soil type. We found no statistical association between the levels of these nutrients and the soil classification. I think that it is important though to note the difference between Ireland, Spain and Australia, and other countries in this respect. When we classify soils in the field we classify them on the basis of what we can see and what we can feel. You can not see nitrogen, you can not feel phosphorus, so you do not have to be surprised when we find that in fact some of these things that we can see and feel, which are used to classify soils, do not tell us much about important controlling factors of soil fertility. In an environment such as you described for Ireland where obviously drainage is very important, the effect of soil type shows up. I do not doubt for one moment the importance of soil typing in your environment and I think the same must surely apply in the Netherlands, possibly more so, but when you go to a different sort of country, I have not been to Spain, but certainly if you come to Australia you will find that there drainage is in general not a problem. It is general lack of water which is our problem. In that sort of situation a soil type does not show up to be nearly such an obvious important factor as it does in other environments.

WALSH

May I ask you a question Dr. COLWELL on this one. In the experiments you describe did you get one increment for instance of nitrogen giving the same yield effect on a podsol and a chernozem?

COLWELL

Yes. Well, I should say we get the same scatter of responses on both soil groups. Sometimes we get positive responses, sometimes we get negative responses. The thing that determines the crop response we get is the recent cropping history.

WALSH

I must say we had some experiences of that type. When however we got down to looking at the matter in a very detailed, critical fashion, we could identify substantial soil type effects. I have shown I think quite clearly in the slide dealing with the annual carrying capacity of our soils. Perhaps we are classifying our soils in a different way than you are in Australia. We use basic production characteristics of soils in our survey and classification work.

ARATEN

As Dr. WALSH said results reached in Ireland are staggering. However Dr. WALSH called Ireland's agriculture of former days underdeveloped. I would like to ask Dr. WALSH how many years farming goes on in Ireland and then you will agree that you can not compare it with other underdeveloped countries where no farming existed a few years ago. I wouldn't call Ireland's agriculture some years ago — underdeveloped — in comparison with agriculture in underdeveloped countries.

WALSH

That is a substantial question. I would want to have my history book alongside to answer it fully. We are an old country in every sense and farming has been going on a great many years, but it was near subsistance farming at a relatively low level in some districts. Perhaps by real underdeveloped standards we were reasonably good but not in relation to our potential. Our use of fertilizer was quite subnormal. We have moved, as shown, in 25 years, and especially in the last ten years into a new farming league.

PRIMAVESI

In your contribution, Dr. WALSH, you showed in an excellent way how a given situation is well developed. Your exposition showed how a very good program was being executed. Very interesting are your studies to delineate trace element areas to soil types, particularly where elements affected animal health. In Brazil there exist studies in this sector with Co, Cu, B and Zn deficiencies in relation to plant and animal health. I think these works are very important because we must see always the whole: Soil - Plant - Animal - Human Health. And your work in Ireland is a good support for further studies on the human health. The man receives his nourishment from plants and animals. Deficient plants or deficient animals for food produce a sick man. However healthy plants and animals give healthy people.

I agree with you that soil type *per se* has a highly significant effect on crop growth, and this is valuable, especially for the soils in temperate climates. In the Tropics and Sub-tropics the soil type is also important, but we have to see always the *conditions* of the soil type he showed an importance like a great number of cars, for example: Ford, General Motors, Chevrolet, Austin, Fiat, Dodge, Renault, and so on. But giving only the name of the car will tell us little about the car. We have to know the conditions of the car. It can be a new car, it can be a car without motor, without spark plugs or without other important parts of the car. And it is possible, that the best brand has no value for us, when it is not working. With the soils in the Tropics and Sub-tropics we have the same situation. It is possible to have a very good soil type but completely leached, completely decayed, etc.

I agree also, that there is no possibility to compare climatic and soils conditions in Ireland and the Tropics and Sub-tropics. When in the Tropics the Soil Structure is one of the most important factors for Soil Productivity, perhaps the most important of all, to permit an economical response to fertilizers, in the soils of temperate zones the soil structure may be a factor of second degree, because climatic and other factors care for the soil structure and the fertilizers are readily available.

WALSH

I could not agree more with you on one thing and indeed feel rather strongly about it — I believe, too many people have gone out from Europe and other developed countres preaching the gospel to people in tropical and other underdeveloped ones without the necessary experience of such areas. I have said in my paper that each country must take care of its own problems. There is one point I should have intervened on yesterday but I did not want to prolong the discussion and that was your diagram dealing with the chain from the soil to the human. We only know of one experience in this respect, i.e. the effect of high levels of selenium in plants on humans, affecting hair and finger and toenails about a century ago when people were of course living mainly from the produce of their land. We have of course several instances of soil — pasture — animal, complex problems i.e. aposphorosis, hypocuprosis (due to copper - molybdenum imbalance), osteodystrophia in horses, due to copper molybdenum — phosphorus — calcium interaction, « pine » due to cobalt deficiency and other similar problems. These effects do not come through as far as I am aware in the meat but will of course be reflected in poor animal thrift and consequently in reduced meat production. I do not know, for instance, if meat from a phosphorus or cobalt deficient animal will affect the human.

With milk the problem may be different apart from reduced yield. Nevertheless our information on this whole matter is too little to allow meaningful conclusions. We know, for instance, that high molybdenum intake may be reflected on mare's milk and affect the foal but this is a limited experience. We have not the appropriate facts for humans.

BRAMAO

Since our kind chairman recommended in his initial statement that we should discuss disagreements I would like to give my point of view concerning soil types, the kind of experimentation and results of experimentation. I am sure I am on the side of Dr. WALSH. I think that besides the nutrient levels you have many other characteristics to influence production. Such as for instance texture. For instance a wheat field would give poor results in a sandy soil, and potatoes would produce badly in a heavy clay soil like vertisoil. Other characteristics such as exchange capacity of the soil are very important. Other soil characteristics that are taken into account in soil classification may influence soil productivity and interfere with agricultural production in a very significant way. Soil type is also an important basis to extend results from experimentation. Otherwise how can you extent such results?

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FAO'S EFFORTS TO INCREASE FOOD PRODUCTION BY PROMOTING FERTILIZER USE

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This paper will review FAO's past and present work in a small sector of its activities, namely introducing fertilizer use in the developing world in order to increase the low hectare yields of huge areas mainly in the tropical regions.

The paper will not give a complete record of all that happened or that should have happened, but will give some highlights, and then in more detail, of crucial phases in this work, so that this supreme audience may judge more clearly what the past problems were and how they were solved, what the present problems are and where FAO needs specialized help from the scientists of concerned institutes.

This is an inside story. Some of you might know parts of it, but the greater part of the story none of you have ever seen. I mean by this the huge amount of data material, which was in the course of our work and still is the basis for any assistance we could give to our member nations in that sector and which has increased the food supply for the needy millions more than any other single programme item. Even the effects of the miraculous high yielding grain varieties are based on their ability to convert more fertilizer nutrients into larger amounts of grain. I would not like to imply that all improvements are due to fertilizers but it is one of the outstanding means for increasing yields on short term.

FAO does not normally publish results obtained in its projects in international journals. These results or summaries of them are printed in the form of reports which are presented to the recipient countries, where the work was done. Also the original files are in the concerned institutes of these countries.

This paper is also an inside story because the people who have carried out several hundred thousand fertilizer trials and demonstrations during the last 10 years in some 40 countries, the supervisors and those who responsibly lead the projects, each one involving a million or more dollars and working with a staff of some 100 selected people will also largely be unknown to you. They too do not publish and have little time to attend meetings, except in the country and region they work in.

I must say here a word of praise for these devoted men who form the executive of FAO in the field.

Before 1950 FAO's programme of work was not involved in actual technical assistance in the field. This started only in about 1950 with the so-called Expanded Technical Assistance Programme and immediately was very popular among the developing countries, which in those days needed expert advice in nearly all technical fields. At that time many of our member countries did not use fertilizer. Also the farmers in Europe and America did not use fertilizer regularly in those days, except for some densely populated areas such as Belgium, The Netherlands and few others. But the effects of fertilizers were known, many response data were available and also in the tropics fertilizers, mainly ammonium sulphate, was used on plantation crops.

When in those years FAO was asked by some member countries to provide technical assistance in the field of fertilizer use for increased crop yields, the problems involved were enormous because the method generally applied in those days was to carry out fertilizer experiments on the fields of experimental stations under closely controlled conditions and to base on the obtained results fertilizer recommendations for the farmers.

Doing this work at home is one thing. Being placed as technical assistance expert in the middle of a huge unknown country without any modern facilities and being requested to introduce fertilizers on an economically feasible basis, is quite another thing.

In those days all these experts, some of them with tropical experience, started the traditional type of field experimentation, combined with chemical soil analysis, which was done in Europe and America since decades. This was a hard test on that old method and one can say that as a means for quick assistance for needy countries, it was not adequate. A responsible field expert cannot take the risk of basing a recommendation on a few controlled fertilizer experiments, whatever the statistical reliability of these experiments may be. Because he has no means to find out what will happen if farmers would use these recommendations under their own working conditions. Their farm methods and soil fertility conditions are usually very different from those of experimental stations, if there were such stations at all.

It has now become common knowledge to all of us that two things are required to be successful in fertilizer promotion.

a) The trials must be made under farmers' field conditions in order to obtain results which are the proper basis for recommendations under such conditions;

b) The trials and also demonstrations have to be made with the farmers in order to convince them of the true and honest effect of fertilizers, and get them to cooperate in this work.

The classical research in that field did not show ways how to realize these two requirements. On the contrary the trend was to believe that farmers' conditions are too hazardous, growth conditions cannot be controlled sufficiently, variability is bound to be very large, interpretation is not possible, farmers may interfere even unwillingly, etc.

It is typical that the solution, how to meet the two requirements above in a proper methodology has come from a poor, rather low developed country in pressing need for more food, — from India. This method was exactly what FAO needed urgently in those days. It is still in use in a better developed form with more success than with any other approach. What was required then was not a precision to the second decimal but a quick determination of the average fertilizer requirement for food crops and others to arrive at highest but still paying yield increases.

We call this methodology "dispersed experiments on farmers' fields" because only one experiment is laid out in each fairly uniform sub-area, consisting of a large number of replicates which are spread at random over the area's fields. This method has never been adopted nor was it needed by highly developed countries in this form. There are not two replicates on one site but only one. There is no interest in the results obtained from one or another of these random chosen fields, but only in the area averages.

The precision of the area averages increases mainly with an increasing number of fields included in the experiment, while the precision within fields is of less importance. Therefore, we must aim at many replicates per area.

A suitable and feasible coverage of project areas was developed in the course of the very intensive work in many projects and was found to be approximately one replicate per 1000 ha per season. A field crew of one leader with 4 assistants can cover an area of about 100.000 ha in one season. This area is not much for an Asian country, but in the course of time many millions of hectares were covered by this type of soil fertility surveys.

During that work a stream-lining of the methodology has taken place. The first step was a standardization of field work including the lay-out, control and harvest, with special devices and methods to prevent mistakes. The lay-out of a replicate with 12 plots on a farmer's field takes ½ to 1 hour, for inundated rice sometimes longer. The harvest takes about the same time, except for cotton when several pickings must be done.

The control of the plots during the growth period was always the main question mark for visiting western scientists. Usually they were already perturbed by the insufficient control of growing conditions, (in their view), by the shabby looks of some plots, growing under the same conditions as the poor farmers saw fit to manage, and on top of all that the plots were left alone for undetermined periods; well, not undetermined. Each site is visited once a week on average by the field man in charge mostly with the farmer, and all observations are recorded. Our experience in that regard is two-fold. *a*) We can fully trust our field experts. They know more about the people they work with, than any visitor; *b*) the results obtained have been confirmed in the course of our 15 years experience with this method by all kinds of checks and tests. Naturally, this is the basis for our confidence in the methodology.

Another technical detail, interesting for this audience, is the matter of experimental designs or treatment combinations. For streamlining the work it was essential to have as few as possible plots per site. But on the other hand one had to aim at obtaining all useful information from the very beginning of the work. Even in the early stages the question was never "does fertilizer increase yields". We know it does, but the question was "how much nutrients should be applied to give the farmer a reasonable profit under his traditional farming system and the existing price relations".

One design was recommended in these early days by many scientists as being very efficient. It consisted of only eight treatments which was very attractive. It was the $2 \times 2 \times 2$ design. This design allows to calculate the interactions between N, P, and K but not the optimum rates. It turned out after some time had passed, that in bigger sets of trials interactions always tend to cancel out to zero or to insignificant levels. An even greater disadvantage was the impossibility of estimating return curves, as only two application rates for each nutrient were included.

This design was not very helpful for the work, and FAO developed special simple but very efficient designs particularly tailored for dispersed experiments for various purposes. One can find these designs in the FAO Soils Bulletin No. 11 which is a guide for conducting dispersed experiments with various crops for various purposes.

So far the methodology which enabled FAO to do the required soil fertility surveys with enough precision and sufficient speed for practical application on large areas.

You might ask how large were the areas covered by these soil fertility surveys. The following listing might give you a quick impression of the areas covered during the last 15 years:

In the projects under the Special Fund UN Development Programmes there were:

— the whole of Iran

— the whole of South Korea

— the major part of the Philippines

— the whole of Pakistan and the present Banghla Desh

— the dry zone, or 4/5 of Ceylon

— a part of Cambodia and Vietnam

— the larger part of Thailand

— a large part of Ghana

— a first start has been made in Nepal.

The projects in Cambodia, Thailand and Nepal are still under execution. India was covered by their own experiments completely.

With the exception of certain crops in Thailand, offering special difficulties, and of Nepal where the work has not advanced far enough to draw conclusions, the results were always satisfactory. The first tentative fertilizer recommendations were available after about two years of work, and a complete set of information on special needs for certain plant varieties, water requirements, in some cases trace elements, salt effects, etc. were worked out within five years.

The projects of this group were and are designed to carry out more work in the field of applied research than on simple farm demonstrations. The total number of trials in these projects since 1961 was about 65.000.

Since in most of the developing countries a stock of basic data for fertilizer use is available by now, the trend of the applied research in these projects is toward a multipurpose approach including improved seed, improved management and irrigation methods, rational plant protection, and other means by which the level of general farm management is raised. Also in this diversified research dispersed experiments are used for certain purposes with great advantages, while for other purposes fields are rented from farmers for longer periods.

It is rather fascinating to see how this development progresses, how countries which started ten years ago at grass root levels have gradually built more and more modern technology into their originally traditional farming practices, accompanied more often than not by a rather steep increase of production. Each world region has one or more of these more progressive and leading countries, while other countries are in the beginning of the road or in various intermediate stages.

The second group of projects is the FAO Fertilizer Programme under which a large number of fertilizer trials and demonstrations are laid out with the stress on farm demonstrations. 34 countries have been covered by this project since

1961 wholly or partly in Central Latin America, in part of West and East Africa, in North Africa, in the Near and Middle East, and lately also in the Far East, and the number of trials and demonstrations conducted during the first 10 years of that programme was 180.000, of which about 12,000 were trials.

The trials are made in this programme only to have a sound basis for the simple farm demonstrations, and not for extended applied research. It is a fertilizer extension type programme aiming at a general, rational fertilizer use by all farmers.

Usually the farmers are quickly convinced of the advantage inherent to fertilizer use but their shortage of cash is a serious block. Therefore, after an initial demonstration phase the project arranges so called pilot schemes for credit and fertilizer distribution. These pilot schemes assist not only the farmers but also the concerned Government to organize a regular fertilizer supply and distribution, using and adjusting their bank and extension facilities for this purpose.

It might be interesting for you to know how the farmer's world usually profits from this programme. The large farms and the more progressive middle sized farms adopt the fertilizer practice relatively easily and quickly.

From the small farms, however, especially if distribution and credit facilities are not fully effective, seldom more than 5 to 10% use fertilizer regularly during the first years. From there on it takes more time to get the rest of the farms to use fertilizers and this is usually more successful with cash crops than with food crops as one would expect.

Naturally the achievements of this large programme have been followed very carefully and therefore I can give you some key figures.

The average yield response with the usually very modest fertilizer rates, most beneficial for developing countries, was around 60% of the check yields. Naturally the check yields are usually very low. Such an increase in yield may be for instance from 1000 to 1600 kg/ha of wheat grain, and this situation is typical for soils exhausted by ages of cropping with only little manure returned to it at intervals.

The monetary return of fertilizer costs was on the average 3.3 units back in produce from each unit spent for fertilizer. This is a very high monetary return rate especially if we take into account the fairly high prices of fertilizers in developing countries and the rather low prices of food crops, the crops with which the programme worked nearly exclusively during these first 10 years.

But again this return is typical for the very first part of the return curve where a kilogram fertilizer increases the yield much more than it could do in the upper part of the return curve.

Finally a figure from the Statistical Section of FAO which monitors the fertilizer production and consumption very carefully. In all programme countries together, many of which did not use fertilizers when they joined the programme, the fertilizer consumption increased with an amount equivalent to $ 40 million annually. In this figure are only included the 34 countries of the FAO Fertilizer Programme and not those mentioned previously having had large scale UNDP projects.

$ 40 million annual increase, that is at a return rate 3.3, over 130 million dollars. This return is not a small amount of food crops, and that increase was repeated each year during 10 years on the average.

No doubt this achievement is not only due to the FAO Fertilizer Programme but also to bilateral assistance and others, but knowing these countries and other fertilizer promotion programmes one understands well why the waiting list of countries which want to join this Programme is so long. But funds are limited. They amounted for the programme of 1970 including all contributious to only 2.3 million dollars, a small amount for such a service in 22 countries in that year.

These data show that the method of dispersed experiments has served a good purpose. The question arises, will it do that in the future too. As a methodology no doubt it will continue to be as useful as it was when there was an urgent need for quick results. However, it is a fact that few countries are left where these first steps in soil fertility research have to be made. In many developing countries the basic knowledge is available by now. Furthermore, in cases of sudden jumps in development such as the introduction of high yielding grain varieties, the old data become for a large part outdated and obsolete. And since we cannot go on forever making many thousands of trials, a simplification must be found for the more advanced countries rather soon.

The obvious simplification is the use of *soil tests* for fertilizer use and related recommendations. In most of the high developed countries soil tests are used with varying success since Liebig's time.

Also the FAO guided work in developing countries was geared from the beginning to the aim of using soil test data later on as a basis for recommendation. Therefore all projects in which this was feasible had soil testing laboratories in their work plan.

Any one of these projects, after some data of trials and soil testing had been collected, tried to find a workable correlation between soil test figures and crop responses, usually without success.

To make a long and painful story short, this simple type of correlation, for instance between P tests and P responses are usually not good, and only in exceptional cases acceptable correlations are found. These, however, cannot be trusted at all because repeating the work in the next seasons under exactly the same conditions will usually result in scattered diagrams showing no correlation whatsoever, until again an exception is found.

It has been tried to make these correlations within single soil units. This resulted sometimes in improvements, other times not.

The reason for that situation is quite obvious. The amount of available phosphorus in the soil for instance is only one factor among many which determine the yield, and unless other factors are constant, a good correlation between P-figure and yield cannot be found.

The institutes in Europe and America which base farm recommendations on soil tests have, during many years of research determined the influences of these other factors and their magnitude, and with that knowledge they can now interpret the meaning of soil tests. Al this knowledge is worked into the usual interpretation tables, as they are used by these institutes or laboratories, and they will result in recommendations which, on the average, hit near the right point.

In general any one of these institutes have different interpretation systems and tables in use. There is little if any coordination between them and the confusing picture is complicated from the viewpoint of developing countries, by the very high nutrient levels of the soils in western countries, built up by heavy fertilizer application in past years.

FAO in its attempt to assist developing member nations, naturally tries to draw on knowledge gained in the higher developed nations. As regards the interpretation of soil testing for rational fertilizer use, there is actually very little to draw from, except the very basic concept which says that usable correlations between soil tests and crop responses can only be obtained if the kinds and magnitudes of other yield determining factors are measured and their influence is taken into account. This work-out required decades in developed countries and can hardly be duplicated in developing countries in this form.

It seems therefore that FAO has to look again for a patent solution of its own, or, more hopefully, together with other scientists who are involved in technical assistance in that field and keep close contact with FAO.

FAO's first steps on the new path have already been taken, somewhat shaky but with a light of hope ahead. Again it were the field experts with their idealistic drive who made the beginning. Dr. CULOT started in Chile followed by Dr. BOLLE-JONES and Dr. ABRAHAM in Iran. Others will continue these attempts.

These experts started to combine the soil test data with other factors which obviously had a strong influence on the final yield of the crop in one mathematical process. Such a multifactor analysis shows not only for each factor the magnitude of its influence on the yield but also the interactions between these factors. The mathematics of this method is not very difficult but the calculations involved are time consuming and therefore a computer is required. The work is not proceeded far enough to give many details, but in order to give an impression of what the preliminary results indicate, the following can be said.

Beside the soil nutrients there are many factors influencing crop yield. Some of them are obviously very influencial, such as for instance the water supply especially in arid areas. From other factors the influence may be uncertain, for instance that of pH. In order to account for as much of the total variability as possible one includes many factors in the first attempt. This results in very extensive calculation work but gives the required information. In studying the results one finds that groups of factors are closely related with each other and form complexes or "key factors". In Iran for instance Dr. BOLLE-JONES and Dr. ABRAHAM (Soil Fertility and Statistics specialists respectively) with their very competent national counterparts arrived at probably only four key factors, which accounted for the largest part of the total variability.

One of these key factors was the nutrient status of the soil (P and K), another was the salinity/alkalinity complex (pH, electrical conductivity).

We cannot say yet with certainty in how far the key factors vary from region to region, but it can be expected that in regions with very different climatical and ecological conditions the key factors too will be different or have different influence on the yield.

FAO will be involved much in comparing different regions and the objectivity of the multi-factorial analysis will probably be an ideal tool for the purpose. Hopefully, it will allow us to use the chemical soil tests plus other relevant field information in a more systematic and more efficient way, for giving valid and sound farm recommendations.

Finally, a brief word should be said about another activity of FAO, very closely related with the one described above.

You all know of the Soil Map of the World, a UNESCO/FAO undertaking for which FAO has done all the technical work. The basic work is finished, the first sheets published and the rest of the map will be issued in the course of the next two years.

From this project and from the soil surveys carried out in many member countries, an enormous amount of soil data has been compiled. In order to make systematic use of this material, it is intended to store it on magnetic tapes in a World Soil Data Bank. The systems to be used for the Bank is now being developed in cooperation with specialists of various countries.

Since obviously one of the main functions of this Data Bank will be to provide information on the production potentialities of specific regions of interest, the data fed into the Bank must include certain key factors related to plant production. These key factors are in principle the same as those used for the interpretation of soil test data as described above.

This brief description may show in which direction FAO is working at present in the field of soil fertility, and how it is preparing itself to provide a technically sound basis for planning increased food supply for larger regions of the world for the time when circumstances require this.

DISCUSSION

Chairman: M. V. L. Homès

Capó

In some of the papers the speakers have presented, they have indicated what they have done and what they are planning to do in the future. But we have met here to consider not only what has been done but to discuss what should be done in the future. And that is the remark that I want to make; that we should consider what has been done and try to evaluate it, in order to find out and decide what we should recommend, should be done in the future in each of these programmes.

Hauser

Yes, Dr. Capó, you could not have made a better remark for FAO than you have done, because we hope really that this multi-factorial analysis is applied also in the Institutes of high developed countries. I have talked with many people when I have made a round travel to quite a few Institutes — it is possible to use that system by the high developed Institutes. When they have done this and have obtained experience and publish that, it will be a tremendous help for FAO and this help would go immediately and directly to the developing countries. That would be a big help for them because they are dealing with enormous surfaces, and if such information could be supplied to them it could be very useful.

BORNEMISZA

How is FAO planning to substitute the excellent extension effect of its fertilizer promotion projects if the field trial are discontinued. These field trials serve a double purpose: they produce information and they have a very important extension effect. Now, if they are discontinued, and soil analysis used as the main tool, I can imagine that still a reasonable amount of scientific information will enter, but how will the extension effect be substituted?

HAUSER

That is very easy to answer. Our projects have a provision that a certain follow-up is done. These projects are not selected by FAO but the countries request the projects and therefore the countries take a certain obligation to follow-up on these projects. What FAO is normally doing is to build any one of these actions they take into the infrastructure of the Government. So their institutes have their trained people and there is provision, that the trained people would stay in their business and continue that work and lately very often provisions are made for short term consultants to come there and following up the programme. That is the only way we can do it, but it has had a very good effect in many countries.

ARATEN

The marketing of local main crops, is that possible? Is FAO doing anything to establish a marketing organization in many countries where the people are unable to sell those bigger crops?

HAUSER

The answer is yes: The Marketing Section in FAO works very closely together with all fertility and production programmes and these marketing people make surveys, they give suggestions to the countries, and they follow that up also. We, and the countries are very much helped by such action. It is part of the follow-ups.

III

ASPECTS RELATIFS ENTRE L'ECOLOGIE ET LES CONDITIONS DE LA CULTURE

FERTILIZER USE AND ECOLOGICAL FACTORS

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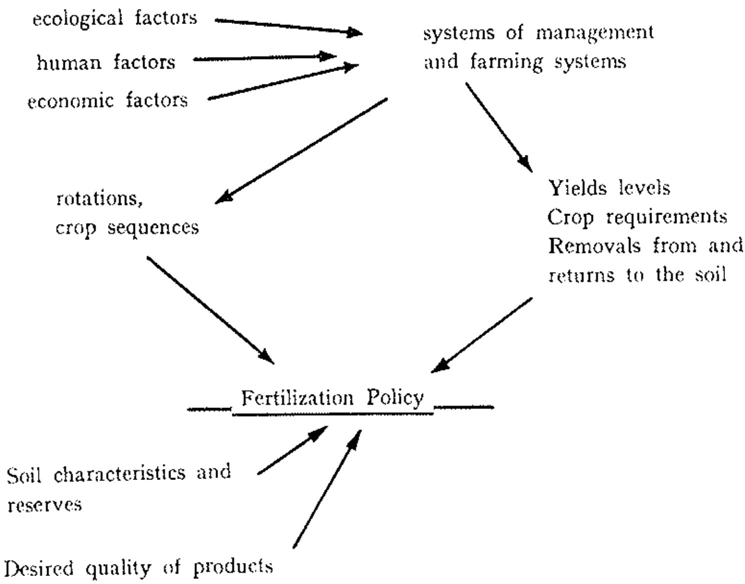
A well-managed, economically profitable agricultural system must bring a variety of factors into play. Among these, fertilizers play an important part, but their use must be determined on the basis of numerous criteria: cropping systems and crop sequences, expected yields, soil characteristics and reserves, desired quality of products, ... Every farmer should therefore, taking these factors into consideration, define his "fertilization policy", whose interrelations we might try to illustrate as follows:

However, the fertilizing advice found in technical literature has too frequently been established on the basis of one given, high-yield crop, not placed in its ecological and cultural context.

Yet this context is determinating by the yield attainable (and hence the amplitude of plant requirements), the soil characteristics and the crop location in the rotation.

As the principles on which a fertilization policy is based are seldom elucidated, we should like now to recall these fundamentals by means of a more extensive analysis of the ecological factors. These come into play in two main ways:

1) Which crops can be raised and the size of their yields are determined largely by the temperature, water sup-



ply, topography and the kind of soil; hence both the crop sequences and the nutritive requirements of the plants are very dependent upon these ecological parameters.

2) The nature of the soil, its physico-chemical properties, its biological activity and its natural or acquired mineral reserves will entail different basic and annual manurings according to the situations, the expected yields and the rotations.

Now the objective of a fertilization policy is to ensure, under the best economic conditions, the mineral nutrition of the crops so that they reach the anticipated yield and quality while maintaining or improving soil fertility within the limits of the farming system practised.

Without going into detail, we will attempt to analyse methodologically the broad outlines of these relationships between inorganic fertilizers and ecological factors. We should like to deal first with the influence of these factors on cropping systems and the yields attainable, followed by the specification of plant requirements, and finally how these requirements can be satisfied according to the soils and rotations.

I - Ecological factors, production levels and cropping systems

To ensure its growth and development, a plant must have access to several *factors* (light, CO_2, water, mineral elements) which it uses when the environmental *conditions* are favourable (temperature, aeration of the soil, etc.). Mitscherlich (1930) incorporated the action of these factors into a general equation which states that yield (y) is more or less distant from maximum yield A depending on the level B of the factor under consideration and its supplied complement:

$$\log (A - y) = \log A - C (B + X)$$

Although this relationship may not always prove to be very precise for specific details, it does indicate the general hehaviour of the phenomena, expressing the role of the limiting factors on one hand and the principle of yield increase less than proportional to increments of the supplied factor on the other. As many authors have pointed out, and recently Shimshi (1969) for example, there are various nuances which deserve particular attention:

— Interactions occur between certain factors, water and mineral elements in particular; the same yield can be obtained with much water and little nitrogen, little water and a lot of nitrogen, etc... (isoyields obtained using varied inputs of water and nitrogen).

— The law of the minimum (LIEBIG), or of limiting factors, also deserves careful consideration: a factor can only act to the extent that some other is not absolutely limiting. Thus, despite the interactions noted above, the relationship between yields and the degree of satisfaction of water requirements is generally quasi-linear (ROBELIN et COLLIER, 1958; PUECH et al, 1968). Serious mineral deficiencies render any growth minimal (CHAMINADE, 1969); certain environmental conditions have an analagous effect, for example serious defects in soil structure (HENIN et al, 1970); it is also well known that temperature has many limiting effects.

With respect to agricultural practice, a distinction should be made between those factors and conditions easily rectified, and others much more difficult to alter. For example, soil acidity and mineral deficiencies can generally be corrected more or less easily, depending on the circumstances, through liming and fertilization; in the case of a shortage of water, irrigation is often more expensive and the required water ressources are sometimes nonexistant. Physical defects of the soil are equally difficult to correct, and here the solution is rather to choose crops adapted to unfavourable soils (grasslands...). Naturally the temperature can only be modified over relatively small areas for protected crops. Finally, although they may not have a direct effect on growth, the topography and a lack of access can prevent efficient agricultural exploitation (mountainous regions...).

Ecological characteristics can thus have varying influences on the levels of production and on farming systems, according to the technical and economic possibilities for the correction of limiting factors. As an example, figure 1 is a diagram of the approximate hierarchy established for a region of about 4 million hectares, situated in south-west France and composed of areas of plains, hills and plateaus, and mountains, with an

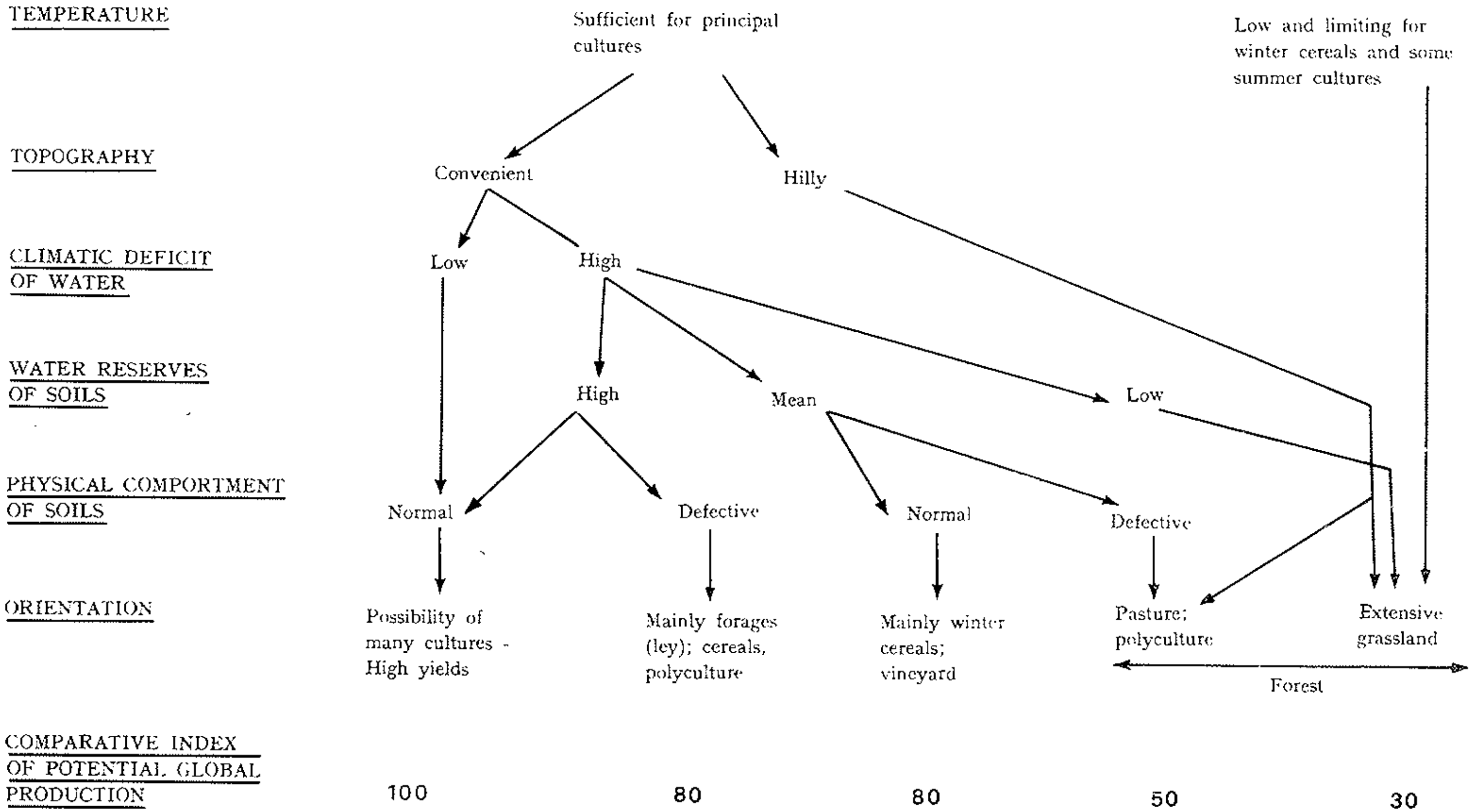


FIG. 1 — Diagram of the hierarchy of the ecological constraints and their consequences for the orientation and level of production.

annual rainfall ranging from 600 to 1200 mm in the different areas.

The hierarchical order of the factors we are considering here is as follows: temperature — topography (possibilities for mechanization and access) — water regime (climate and soil reserves) — physical soil characteristics. Acidity and mineral deficiencies are assumed to have been rectified or to be rectifiable when the topography is suitable. The results of this analysis and of inquiries among the farmers establish that the different natural environment present a great range of possibilities depending on the nature and the importance of the limiting factors; from this two consequences appear:

— The first, which is qualitative, has to do with the nature of the crops which can reasonably be grown; hence extensive grassland farming is only possible when the ecological constraints are very strong, while an absence of constraints allows great flexibility in the choice of crops and the adaptation to economic conditions. Obviously, there are many intermediate cases where farming systems are largely determined by the environmental factors, when at least one of these is far from its optimum level or when many are unfavourable.

— The other consequence is of a quantitative nature: the anticipated yields are a function both of ecological factors and of certain choices made by the farmer (intensive or semi-intensive agriculture, ...). The influence of the environmental constraints is represented on figure 1 by a comparative index of potential global production obtainable per unit of land in the different situations (Blanchet et al, 1970). Naturally variable mineral requirements of the crops correspond to these different yield levels.

Ecological factors thus influence both the kinds of crops grown and their sequences, and the magnitude of their mineral needs. It is this latter point which we shall now examine.

II - Yields levels and mineral requirements of crops

The relationship which exists for a plant between the yield and the concentration of a limiting mineral element in a characteristic organ (a leaf for example: MAUME, 1953) is generally of the form shown in figure 2: at first an ascending curve indicating that the greater the yield, the richer the plant must be in the element under consideration, then an eventual leveling-off corresponding to "luxury" consumption, and finally possible toxicity.

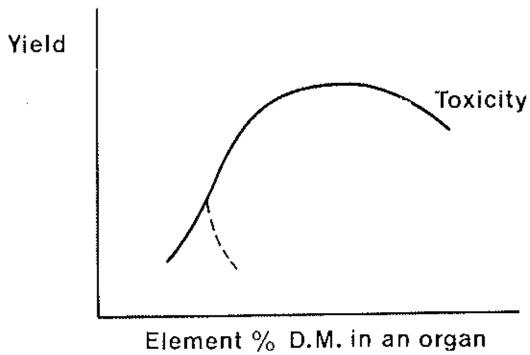


FIG. 2 — Diagram of the relation between yield variations and the concentration of a mineral element in a characteristic organ.

Hence different yield levels have an effect both:

— on a variable concentration c of nutrients in plant organs, the farmer being able to reduce this variation by enriching the plant for reasons of quality, and

— on the mass m of organs produced, containing the amount $q = mc$ of the mineral elements.

In general therefore, mineral requirements increase more quickly than do yields (figure 3), but certain manuring techniques or unforeseen climatic changes can always modify these general behaviour patterns (Coïc, 1956-1960). Also a first approximation for the establishment of a fertilization policy consists of an estimation of the needs per weight unit of anticipated production, such as a quintal of grain, raising the mean norm if a high yield is expected or lowering it in

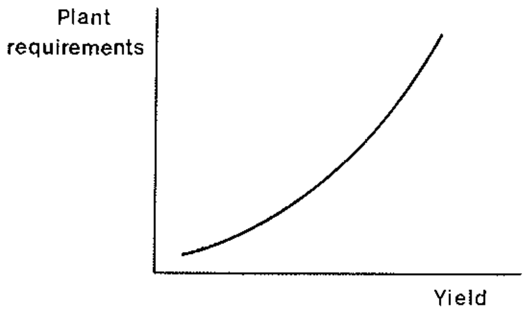


FIG. 3 — General behaviour of crop requirements of a mineral element as a function of the yields obtained.

the opposite case. Table 1 gives an example of such normes for phosphorus, and table 3 illustrates the variation of N - P - - K requirements of crops whose production was more or less limited by the water supply. These tables also indicate the differences between the requirements and the removals, i.e. the returns to the soil in harvest residues; we shall return to this later when discussing the adaptation of fertilization to rotations.

TABLE 1 — *Phosphorus requirements and removals in different crops.*

Cereals and oleaginous plants

Crops	By quintal of grain yielded, kg P		For the indicated harvest, kg P per ha		
	Requirements, whole plant	Removals in grains	Yields q/ha	Requirements	Removals
Wheat	0.63	0.39	45	28	17.5
Barley	0.58	0.37	45	26	16.5
Oats	0.6	0.37	35	21	13
Maize	0.57	0.35	65	37	23
Colza	1.75	0.74	20	35	15
Sunflower	1.4	0.70	25	35	17.5

Potatoes and beets

Crops	By ton of roots or tubers, kg P		For the indicated harvest, kg P per ha		
	Requirements, whole plant	Removals in grains	Yields q/ha	Requirements	Removals
Potatoes	0.8	0.55	35	28	19
Sugar beets	0.8	0.48	40	32	19
Forage beets (15% D.M.)	0.5	0.35	60	30	21

Forages (cutting)

Crops	kg P per ton of hay	For yield, tons/ha	Removals (kg P ha)
Alfalfa	3.5	12	42
Clover	3.2	8	25.5
Italian rye-grass	3	10	30
ley (approximation)	3	10	30
Maize	2.4	10	24

III - Soil characteristics and reserves

Plant nutrition takes place in the soil through a combination of very complex processes, whose two main factors are the exploration of the soil by roots and the possibilities of ion movement toward the roots (Maertens, 1970).

Root system development is particularly dependent upon the physical characteristics of the soil (porosity, moisture, mechanical resistance to penetration, hydromorphy, ...) in the different horizons which constitute the "profil cultural" (Henin et al., 1970). The depth which the roots can explore, either above the parent material or above unfavourable layers is an important factor perhaps too frequently neglected; the same applies to the exploration of crumbles in the surface layers. Thus although NO_3^- ions are very mobile, Maertens (1964) has given some very clear examples of the importance of root exploration for water and nitrogen nutrition of several crops.

The physico-chemical properties of the soil exert their influence on the extent of the movement of the ions retained by the adsorbing complex (cations, phosphates, sulphates partially). Whether a matter of actual diffusion or of transport in the liquid phase, these movements are the more limited the greater the adsorption capacities of the soil (cations exchange capacity, adsorptive ability with respect to phosphorus). These facts are well established (Blanchet and Bosc, 1969; Gachon, 1966), and figure 4 gives an illustration: it expresses the quantities of phosphorus and potassium absorbed per gram of roots, in two soils both initially poor but with different properties, as a function of increasing nutrient additions (Maertens, 1970). Depending on the type of soil, the same root activity can be obtained with nutrient reserves varying by as much as 100%; in weak-retention soils the ion flux coming into contact with the root is actually much greater, and it is not necessary to build up large reserves. Naturally

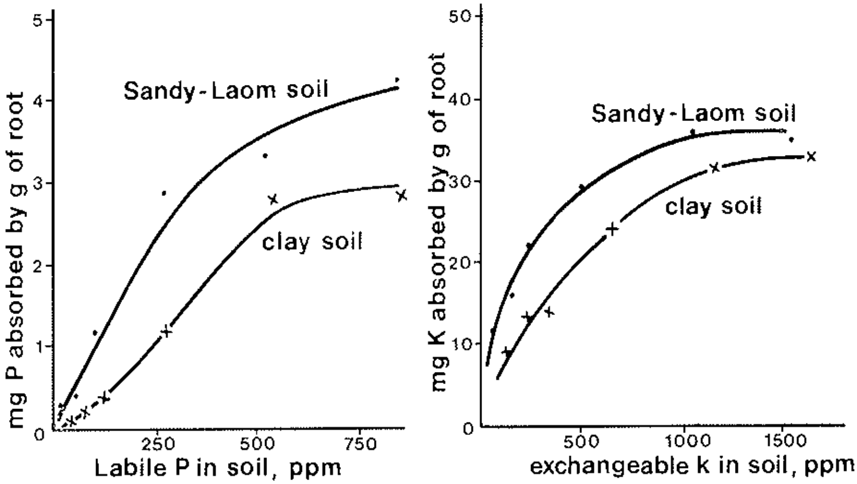


FIG. 4 — Quantities of phosphorus and potassium absorbed by young maize roots, in relation to increasing fertility of two different soils.

the opposite is true for soils of high adsorptive capacity. The water regime is also a factor in these processes (BLANCHET et al., 1969).

The level of reserves to be established and maintained in the soil thus depends primarily on the depth which can be explored by the roots, the physico-chemical properties of the soil, and the crop requirements - a function of expected yields. Other factors contribute to plant nutrition to a lesser degree (biological activity of the soil, water regime, ...).

Depending on the nature of the soil minerals, these reserves can exist in a natural state (phosphated minerals, potassic micas and feldspars) or can be acquired through fertilizing. This building up of soil reserves to ensure the satisfaction of crop requirements is the role of basic manuring, and can sometimes constitute a veritable creation of fertility (CHAMINADE, 1969).

Having reached this state, annual manuring should ensure the conservation of this fertility, by a satisfactory mineral balance (BARBIER et al., 1957; TROCMÈ and DELAS, 1960):

Balance = contributions to soil — losses from soil ⩾ 0

Contributions:

— elements from inorganic and organic manures; returns in harvest residues

— liberation through mineral decomposition

— various supplements from rain, fixation by microorganisms, ...

Losses:

— removals in harvests

— various losses due to leaching, insolubilization ...

In order to establish programmes of basic and annual manures, the quantitative determination of the various parameters requires both laboratory and land studies (eg. a pedological map), and field experiments. In the latter case, simple procedures such as response curves isolating one limiting factor (CHAMINADE, 1970) are often more useful, at least in a first time, than more complex approaches which don't always furnish the desired answers. The response curves, reflecting MITSCHERLICH's law, give results similar to those of figure 5: basic manuring necessary to obtain the desired yield, which determines the subsequent annual manuring necessary. Naturally the basic manure supply only those elements which the soil can retain (mainly P and K), while nitrogen manuring is essentially an annual process.

As an illustration of these facts, our research has shown that to produce around 40 quintals/hectare of wheat and 60 quintals/hectare of maize using an annual manuring to compensate for removals in the crops (20 kg P, 30 kg K), the two

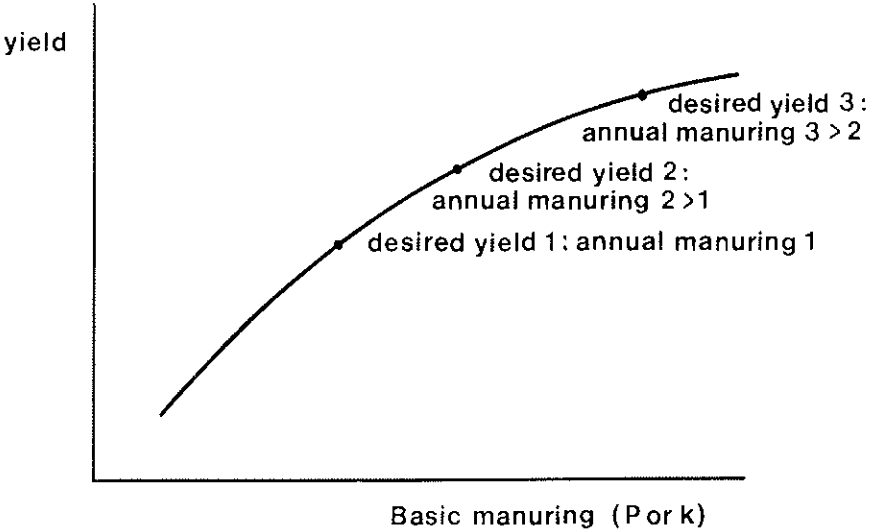


FIG. 5 — Diagram of the action of a basic manuring applied to a deficient soil, producing different yields which can then be obtained by different annual manuring.

soils considered (figure 4) should contain notably the following reserves:

	clays soils	*sandy-loam soils*
usual ploughing depth (cm)	35	25
tons of earth per hectare (arable layer)	5000	3600
P contributing to plant nutrition p.p.m. (L values, LARSEN, 1952)	75	60
kg of P per hectare (arable layer)	375	216
exchangeable K, p.p.m.	180	80
kg of K per hectare (arable layer)	900	288

The necessary stock of reserves to be built up by basic manuring thus differs markedly for these two soils. We should note that in the sandy-loam soil, the facility of K^+ ion diffusion would render futile the constitution of large reserves, as they would be partly lost through leaching or through luxury uptake by the plants. However the reserves are insufficient for certain plant requirements, especially for forage crops, thus necessitating "provisions for cultivation" adapted to the rotations, the details of which we shall now examine.

IV - Fertilization and rotations

Adaptation of fertilization to rotations and crop sequences necessitates the consideration of various factors:

1) *Certain crops require large quantities of the fertilizing elements but restore much of them in their harvest residues.* This is the case of oleaginous plants (colza, sunflower) and even of cereals where the largest part of the potassium resides in the non-reproductive-organs. Hence one possible fertilizing of an irrigated monoculture of maize is outlined in table 2: a generous provision for cultivation, replacing the basic manure, results in the ample satisfaction of the maize requirements, especially in potassium, and in the attainment of a high yield; the annual manuring need only compensate for the removals or losses.

Table 2 — *Fertilization of an irrigated maize monoculture.*

Yield q/ha dry grain	Requirements			Removals		
	N	P	K	N	P	K
88	205	32	200	150	22	35
	Dressings:					
	Provision for cultivation			0	160	360
	Annual manuring			180	25	50

2) *Other crops, particularly those of grasslands, remain in place over several years.* Thus before planting these it is essential to add the elements which diffuse very little in the soil, phosphates in particular, as later surface application will likely be quite ineffective; hence along with basic manuring the notion of provision for cultivation is very important.

3) *Accurate estimations of removals and losses of the mineral elements are difficult to make for grasslands either grazed or successively cut then grazed.* The problem is that some elements are returned to the soil in the animal excrement but only in certain locations (shady places, watering holes), while others are lost through volatilization (NH_3) or leaching (K). The returns, although important are poorly distributed over the area thus losing part of their effectiveness, and causing any estimates to be only approximate.

4) *For farms with livestock, some returns are provided in the manure, whose composition can vary.* However the mineral elements in the manure are not all immediately available: although potassium rapidly becomes soluble, nitrogen and phosphorus can only be used by the plants as their mineralization occurs.

5) *Finally, there are a certain number of practical considerations in fertilizers application*: the farmer, short of time when one crop must immediately follow another, might use compound fertilizers only more or less suited to his needs, despite the great variations in these, or else he manures for two or three successive crops simultaneously, which can be in certain cases a good practice (BLANCHET et al., 1971). Also he cannot always enter his fields when necessary, and weather incertainties often cause his yield estimates to be only approximate.

For similar practical reasons, the concept of fixed rotations is beginning to be questioned in the industrialized countries, ceding to that of crop sequences adapted to the various technical and economic constraints.

Despite the qualifications and inaccuracies related to the practical aspects of fertilization, there remain nonetheless certain valid general principles which we shall now take up, attempting to illustrate them with various examples from our experiments with different rotations.

a) *Rotations with ley*

Table 3 examines one rotation system as applied to three situations, all with the same climate but with different soil water supply constraints limiting yields to a greater or lesser extent. The rotation consists of four years of fescue then one crop of wheat, then one of maize or sorghum (sorghum in situation 1, maize in 2 and 3; their mineral needs are similar). The usual yields appear as follows: due to unstable weather conditions in the spring, the wheat yields are not usually very high; on the other hand good maize yields can be expected if the water supply is adequate. Leys give a good spring production, and the summer harvest depends mainly on the water supply. In accordance with regional practice we have used a spring cutting followed by grazing. For the two deeper soils (numbers 2 and 3) alfalfa would be better than fescue, but only the latter is adapted to situation 1 where excess of water occurs in winter; thus fescue was used for the comparison but the data area readily transposable to alfalfa cultivation in soils 2 and 3, eliminating the nitrogen dressing (similar yields and P and K balances).

We have considered a rotation using no farm-manure. The different soils have no serious mineral deficiencies, and the size of their reserves is in the vicinity of the "reaction limit" for phospho-potassium fertilizer application.

A look at table 3 shows that the yields obtained clearly reflect the ecological constraints of the different situations, particularly that of the limiting factor water; hence the mineral

TABLE 3 — *Yields, mineral balances and dressings of one rotation in 3 different ecological situations.*

Crop characteristics	Situations: Wet winters + springs, dry summer								
	1 Shallow soil small water resources			2 Deep soil - large water resources non-irrigated			3 Deep soil irrigated		
Fescue ley 4 years									
a spring cut then grazed Average annual yield, q/ha		90			112			155	
Wheat, yield q/ha dry grain		25			35			35	
Maize or sorghum, yield dry grain q/ha		25			60			90	
Mineral balances	N	P	K	N	P	K	N	P	K
Fescue:									
annual average requirements, kg/ha	160	20	210	210	28	260	280	45	380
estimated removals+losses, kg/ha/year	110	13	120	150	18	180	190	30	230
Wheat:									
requirements, kg/ha	60	12	60	80	16	75	80	16	75
removals in, kg/ha	45	10	15	65	14	20	75	14	20
Maize-sorghum:									
requirements, kg/ha	55	10	60	125	20	115	205	32	200
removals, kg/ha	35	7	10	85	15	125	130	22	35
Total removals —6 years	520	69	505	750	101	765	965	156	975
Fertilizers applications									
Provision for cultivation (ploughing, before fescue)	0	80	180	0	80	180	0	160	360
Annual manuring for ley	110	0	100	160	10	170	200	10	220
for Wheat	60	15	50	70	15	50	70	20	50
for Maize or sorghum	70	0	0	120	20	50	180	30	50
Total rotation	570	95	630	830	155	960	1050	250	1340
Residues of provision (to verify by soil analysis)	0	26	125	0	54	195	0	94	365

requirements of the crops, a function of these yields, vary with the situations. ["Requirements" has been used here to denote the quantities of the elements contained in correctly nourished plants just before harvesting. They are slightly underestimated due to the omission of the elements contained in the roots and the eventual excretions when vegetation ends (K from maize leaves, for example)]. These variations were taken into account in the fertilizations, both for the annual ones and for the provision for cultivation carried out at the beginning of the rotation. The objectives of the provision were:

— to provide the essentiel phosphorus necessary to the grasses, applying it before ploughing and planting in such a way that it would be accessible to the roots, and

— to constitute a "stock" of potassium sufficient to satisfy the main needs of the grasses for about a year without entailing luxury consumption or disequilibrium in the composition of grasses.

Fertilizers were then applied to furnish the required nutrients and compensate for any removals and losses, taking into account the provision which had been applied. Comparisons between the supplements and the losses over the whole rotation cycle enable the calculation of the soil mineral status, showing tbe residues remaining from the initial provision. At the end of the cycle, soil analysis should be undertaken to verify, through comparison with the initial analysis, that the remaining nutrients can still be available, and also to check the accuracy of the initial estimates of potassium returns for grazed grasslands.

The comparison of the three situations shows the influence of the size of yields and the kind of techniques used in situation 1 (more or less extensive, such as not fertilizing some years) on the determination of appropriate fertilization levels. Had the ecological constraints been serious enough to warrant only extensive grazing, fertilizing could have been limited to periodic dressings of phosphated fertilizers if the flora included enough leguminous plants.

b) *Rotations comprised only of annual crops*

Fertilizing procedures are much simpler for this kind of system, at least when annual ploughing allows for convenient application of the fertilizers. For this system it is advisable:

— to carry out an eventual basic manuring, or provision for cultivation if crop requirements are particularly high, and

— to accomplish the necessary annual manuring with respect to the soil removals and losses.

Tables 4 and 5 give two examples of such rotations used respectively in situations 2 (deep soil, non-irrigated) and 3 (deep soil, irrigated). The rotation sequence is: cut forage sorghum — wheat — colza — barley, and a supplementary crop of ensiled forage maize inserted between the colza and barley in the irrigated situation.

The presence of this forage maize and the higher yields of the forage sorghum under irrigation necessitate a greater provision for cultivation and annual fertilization than in the non-irrigated situation. For the latter, the generous manuring of the colza reduces the amount necessary for the barley because of the returns in the residues of the colza harvest.

In these two cases, the initial provision was not taken up by the plants (comparison of removals and inputs); if soil analysis verifies that the elements have not been leached or rendered unavailable, renewal for the subsequent rotation is not necessary.

Naturally a farmer, in determing his fertilizing programme, doesn't have access to all the procedures we have used, particularly that of analysis to determine removals in the harvests. Since the composition of certain products, such

TABLE 4 — *Fertilizer application for a rotation of annual crops (situation 2).*

Year	Crop	Yields, dry grains or dry matter (forages) q/ha	Requirements, kg/ha			Removals, kg/ha		
			N	P	K	N	P	K
1	Forage sorghum (cutting)	107	211	30	212	211	30	212
2	Wheat	35	80	16	73	65	14	18
3	Colza	23.1	150	35	200	100	30	60
4	Barley	28	56	12	47	46	11	15
		Total	·497	93	532	422	85	305
		Average annual removals:				106	21	76

Dressings, kg/ha:

Year	N	P	K
0 — Provision for cultivation	0	80	180
1 — (forage sorghum)	200	30	200
2 — (Wheat)	80	20	40
3 — (Colza)	150	30 (or 45)	100
4 — (Barley)	50	15 (or 0)	0
Total 4 years:	480	95	340
Average annual:	120	24	85

TABLE 5 — *Fertilizer application for a rotation of annual crops (situation 3, with irrigated forages of sorghum and maize).*

Year	Crop	Yields, dry grains or dry matter (forages) q/ha	Requirements, kg/ha			Removals, kg/ha		
			N	P	K	N	P	K
1	Forage sorghum (cutting)	170	374	48	367	374	48	367
2	Wheat	35	80	16	73	65	14	18
3	Colza	23.8	150	35	200	100	30	60
	Maize for silage	101	130	20	118	130	20	118
4	Barley	28	56	12	47	46	11	15
		Total	790	131	805	715	123	578
		Average annual removals:				179	31	145

Dressings, kg/ha:

Year	N	P	K
0 — Provision for cultivation	0	160	360
1 — (forage sorghum)	350	50	350
2 — (Wheat)	90	20	40
3 — (Colza + maize)	250	60	220
4 — (Barley)	80	15	0
Total 4 years:	770	145	610
Average annual:	193	36	153

as cereals or oleaginous plants, varies relatively little under normal conditions, average norms can provide satisfactory approximations. On the other hand, the composition of non-reproductive organs, particularly of forages, is much more variable. Without the possibility of harvest analysis, only periodic soil analyses (at the end of a cycle, for example) can ensure the maintenance of the soil reserves.

We feel that this kind of examination of fertilization by rotations is from all points of view more useful, and often more economical, than the fertilizing advice based on a particular crop taken out of its ecological and cultural context, and unfortunately too frequently furnished by extension services. The latter is obviously a simpler solution, but its economic and technical merits are partly doubtful.

Finally, we would like to note that although the problems examined here concerned N, P and K, related questions concerning sulphur, magnesium and oligo-elements could be similarly approached.

Conclusions

We have tried to sketch a quick outline of the principal factors contributing to the rational choice of a fertilization policy, one adapted to the ecological conditions, i.e. to the farming system used, to the nature of the soil and to the plant requirements in accordance with their yields and their position in the rotation. We have made few references to the subject of quality objectives, equally very important but too lengthy to develop here.

The data necessary to the establishment of a judicious fertilization policy are thus numerous and varied, derived equally from analysis of limiting factors, from a thorough knowledge of soil properties and from various parameters related to the crops and their sequences.

We are thus a long way from generalized formulas, on the contrary employing complex reasoning procedures based mainly on the organization of agricultural management and its environment. It is in these conditions that fertilization should have a maximum economic effect, for it remains one of the principal determinants of production; however, while plant requirements must be satisfied, excess fertilizing should be avoided as it can provoke soil disequilibrium and may even result in pollution.

A better grasp of the many facets of this problem can only be obtained through more intensive study of relatively theoretical fields and through experiments judiciously chosen on the basis of ecological conditions. Such research would provide farmers with the necessary information to reconcile fertilization with their economic and technical imperatives, while ensuring the best results and the conservation or improvement of soil fertility.

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DISCUSSION

Chairman: J. D. Colwell

Hauser

I have presented something wrong. What I wanted to say in regard to economy is that we are only working according to fertilizer economy and we are not giving much attention to maximum yields because maximum yields are too expensive for the farmers, so obviously what I have said came out the other way around. I meant that we are working mainly according to economy and not according to highest yields.

Colwell

Dr. Blanchet has raised several matters. He has brought out the importance, in some systems of agriculture anyway, of considering not just an isolated crop and its fertilizer requirements but the whole environment in which the crop is produced, other crops, cultural practice, and so on. The paper is now open for discussion.

Hernando

I have several things to ask but one of the most important is in relation to table IV. Have the soil analyses been checked with the residual values in these tables?

BLANCHET

Non, pas encore. Ici, les besoins des cultures ont été estimés d'après l'analyse des plantes au moment de la récolte. Evidemment, cette estimation n'est pas tout à fait exacte, car elle ne prend pas en considération les quantités d'éléments qui se trouvaient dans les racines, d'une part, et d'autre part il a pu intervenir également des lessivages en fin de végétation. Néanmoins, je crois que ces besoins sont à peu près estimés (peut-être minorés de 10 ou 15 pour cent); enfin, je crois que c'est un ordre de grandeur valable. Quant aux exportations, elles sont déterminées par l'analyse des produits enlevés réellement, enlevés du champs, c'est-à-dire les produits vendus, ou en tous cas enlevés du champ. C'est donc par la différence de ces besoins et de ces exportations que l'on peut estimer les restitutions, c'est-à-dire tout ce qui retourne, à proprement parler, au sol. Evidemment, cela est très différent selon la nature des cultures.

No, not yet. Here, the needs of the cultures were estimated according to the analysis of the plants at the moment of the yield. Evidently this estimate is not quite exact, because it does not take into consideration the quantities of the elements which were in the roots, on one hand, and on the other the washings also may have intervened for the sake of vegetation. However, I believe that these needs are approximate estimates (maybe 10 or 15 percent less); I believe that it is an order of valid size. As concerns the exportations, they are determined by the analysis of the products yielded from the field, i.e. the products sold or anyhow carried away from the field. Therefore the returns must be estimated by the difference of these needs and of its exportations, that is to say, everything that returns to the soil, properly speaking. Evidently this is very different according to the nature of the cultures.

ARATEN

I would like to ask Prof. BLANCHET if it would be possible to get some more information about the relation between nitrogen and water he mentioned at the beginning.

BLANCHET

Oui, cette interaction azote-eau est assez complexe puisqu'on admet généralement que la relation entre le rendement et la fourniture en eau, c'est-à-dire le rapport $\frac{\text{évapotranspiration réelle}}{\text{évapotranspiration potentielle}}$ est à peu près linéaire. Mais il existe tout de même des interactions — nous en avons observées quelques-unes — et en particulier je crois que les travaux sur ce sujet du docteur Shimshi, en Israël, sont extrêmement intéressants. Il indique une interaction à proprement parler, en obtenant des isorendements, c'est-à-dire qu'un même rendement peut être obtenu soit avec beaucoup d'eau et peu d'azote, soit avec beaucoup d'azote et peu d'eau. C'est un raisonnement assez complexe mais qui montre bien l'interaction à proprement parler qu'il peut y avoir entre les deux facteurs, les rendements maximums étant naturellement obtenus avec à la fois l'eau et l'azote. C'est un aspect de l'ancienne conception bien connue des engrais économiseurs d'eau, qui prend là une allure beaucoup plus détaillée et exacte.

Yes, this nitrogen-water interaction is quite complex since it is generally admitted that the relation between yield and water supply, namely the ratio $\frac{\text{real evapotranspiration}}{\text{potential evapotranspiration}}$ is almost linear. But there exist all the same interactions — we have observed some — and in particular I believe that the works on the subject by Dr. SHIMSHI in Israel are extremely interesting. Properly speaking he indicates an interaction by obtaining iso-yields, that is to say the same yield may be obtained either with much water and little nitrogen or with much nitrogen and little water. This is quite a complex reasoning but it shows well the interaction it may have between the two factors, the maximum yields, of course, being obtained at a time with water and nitrogen. This is an aspect of the well known old conception of the fertilizer economizer of water which takes there a much more detailed and precise direction.

Coïc

La relation étroite entre la production de matière sèche et l'utilisation de l'eau est une notion chère aux anciens physiologistes. Ayant comparé divers genres végétaux quant à la quantité d'eau nécessaire pour faire 1 kg de matière sèche dans les mêmes bonnes conditions de nutrition minérale, j'ai constaté *par exemple* qu'une plante « grasse » utilisait 2 fois moins d'eau que d'autres plantes. Ceci signifie que pour la plante grasse il faut deux fois plus d'azote pour la même quantité d'eau utilisée (la matière sèche ayant approximativement la même richesse en azote que celle des autres plantes). Cette notion de « bonne utilisation » de l'eau par certains genres végétaux (sorgho par exemple) est importante.

The close relation between the production of dry material and the utilization of water is a notion dear to the old physiologists. Having compared different plant species as to the water quantity necessary to produce 1 kg of dry material under the same good conditions of mineral nutrition, I observed *for instance* that a "fat" plant used two times less water than the other plants. This means that a fat plant needs two times more nitrogen for the same quantity of water utilized (the dry material having approx. the same richness in nitrogen as other plants). This notion of "good utilization" of water by certain other plant species (sorghum, for inst.) is important.

Blanchet

Je crois que ce problème est effectivement très intéressant et important. Je l'ai schématisé ici d'une manière approximative. D'abord, je crois qu'il faut bien voir que nous avons ici une relation générale avec l'eau consommée, mais sous forme du rapport [évapotranspiration réelle/potentielle], qui tient compte des variations des données climatiques. Mais je crois que ceci est une donnée provenant des physiciens de la biosphère, une relation intéressante, bien entendu, mais dont il me semble — comme à vous, je crois — qu'on entrevoit nettement les limites. En effet, si la transpiration était uniquement une fonction de l'énergie reçue, les plantes grasses devraient transpirer comme un maïs ou un blé... Or ce n'est pas vrai. En tous cas, le rapport consommation minérale sur consommation hydrique est tout à fait différent. Il me semble qu'on devrait peut-être, dans ces problèmes-là, revenir un peu plus à des conceptions classiques en envisageant également la morphologie et la morphophysiologie de la plante, dont on s'est peut-être trop écarté, à mon sens, en allant trop loin dans la physique de l'atmosphère sans considérer suffisamment la physiologie de la plante.

I believe that this problem is in fact very interesting and important. I have schematisized it here in an approximate way. First of all, I believe we must make sure that we have here a general relation with the water consumed but under the form of the ratio [real/potential evapotranspiration] which takes into account the variations of the climatic conditions. But I believe that this is an idea coming from physicists of the biospere, an interesting relation, of course, but it seems to me — as to you, I daresay — that the limites may clearly to be seen. In fact, if the transpiration were only a function of the energy received, the fat plants ought to transpire like maize or wheat. In any case, the ratio mineral consumption/hydrique consumption is quite different. It appears to me that for these problems one should perhaps a little more recur to the classical conceptions regarding likewise the morphology and morphophysiology of the plant from which we have deviated perhaps too much, according to me, by going too far in the physics of the atmosphere without considering sufficiently the physiology of the plant.

COLWELL

This effect of water on nitrogen is something which I think interests many of us. We in Australia have been looking at this too. We find response to nitrogen is determined not only by the total available water but also very much by the distribution of rain throughout the year. If rain falls at certain times it can make all the difference between getting a response to nitrogen or a depression from nitrogen. If we get rain at the wrong time of the year nitrogen will depress yield, if we get it at another time it will actually stimulate yield. It seems to be a matter of forecasting rain, and we are not much good at that.

HAUSER

When we compare a big amount of data material from wheat in the arid zone where we sometimes have a very serious water shortage and sometimes a normal rainfall we find that phosphorus effects are very insensitive to the water situation compared with the influence of the water on the nitrogen effects. If there is not enough water we do not find nitrogen effects. If there is enough water we can go very much higher with our nitrogen applications and get much better results in yield. But this contradicts what Mr. BLANCHET showed in the diagram; water is not, in our experience, to be replaced by nitrogen. The other way around might be possible; you can maybe replace nitrogen by giving more water, if the water is in short supply, but you can surely not replace water by nitrogen, in our experience.

BLANCHET

Oui, je pense que les possibilités de substitution sont effectivement très limitées. Shimshi a donné un exemple assez caractéristique sur le maïs: la compensation partielle atteint tout de même dans ses essais, si mes souvenirs sont exacts, une dizaine de quintaux/hectare, ce qui n'est tout de même pas négligeable. Enfin, l'un ne compense naturellement pas l'autre dans une grande ampleur.

Yes, I believe that the possibilities of substitution are really very limited. SHIMSHI has given quite a characteristic example on maize: the partial compensation yet obtained in his trials, some ten hundredweights/hectare, if I remember exactly, which is not at all negligeable. Naturally the one does not compensate the other in a great amplitude.

RUSSELL

I would like to make two comments on what Dr. COLWELL has said. We find in Great Britain that during dry periods in summer, short-term pastures will be using water at their full potential rate and yet growth will be restricted because the available nitrogen is in the dry top soil and the water is being taken from the subsoil. So initially we are irrigating the pastures to increase the uptake of nitrate rather than to supply water to the crop.

We also find, in agreement with Dr. HAUSER, that in semi-arid regions nitrogen applied to a cereal crop early on in the season may be very harmful since the additional leaf it produces will increase the transpiration rate from the land. On the other hand, nitrate in the subsoil can be beneficial for the crop cannot use this nitrate until most of the leaf growth has taken place, so nitrate taken up at this time will all go to help the yield of grain.

BLANCHET

Je ne voudrais pas, à propos de cette disgression sur les interactions eau et azote, faire entendre ce que je n'ai pas voulu dire. Justement, comme disait le docteur RUSSELL, j'ai essayé de montrer dans ce rapport qu'à mon avis, le degré d'enrichissement du sol en éléments fertilisants, et l'importance de la fumure minérale à apporter, doivent précisément être considérés comme une fonction de la potentialité de production du milieu, c'est-à-dire du rendement permis par les facteurs limitants dont l'eau est généralement l'un des principaux. On peut peut-être avoir quelques possibilités d'interaction positive en diminuant les effets de la sécheresse par un meilleur emploi des engrais, mais moins, à mon sens, qu'à l'égard des propriétés physiques dont nous avons beaucoup parlé au cours des dernières séances. Je pense en effet qu'une bonne fertilisation peut contribuer notablement à lutter contre ces défauts physiques, en permettant d'une part une plus grande vigueur du système radiculaire, et d'autre part en permettant que les flux d'ions susceptibles d'arriver au voisinage des racines soient beaucoup plus importants lorsque le milieu est suffisamment riche. Donc, je crois que la plante peut avoir besoin de moins de racines dans un milieu riche que dans un milieu pauvre, et c'est peut-être là une des voies de lutte, si elle est économiquement valable, contre certains défauts physiques.

As concerns this disgression on the interactions water and nitrogen, I would not want you to understand what I did not mean to say. As Dr. RUSSELL said, I have tried to show in this paper that in my opinion the grade of enrichment of the soil in fertilizing elements and the importance of mineral fertilizer to apply, must precisely be considered as a function of the production potentiality of the milieu, that is to say of the yield permitted by the limiting factors of which the water is generally one of the main ones. One may perhaps have some positive interaction possibilities by diminishing the effects of the dryness with a better use of fertilizers, but less, according to me, with regard to the physical properties of which we have much spoken in the course of the last sessions. I really believe that a good fertilization may remarkably contribute to fight against these physical lacks, permitting on one side a greater vigour of the radicular system and on the other that the flow of ions susceptible to arrive in the vicinity of the roots is much more important since the milieu is sufficiently rich. Therefore, I believe that the plant may want less roots in a rich milieu than in a poor milieu, and there may perhaps be one of the ways to fight against certain physical lacks if it pays economically.

PRIMAVESI

I place great importance on the ecological factors and the interrelation between the many factors of soil productivity and plant production. For this I like your excellent exposition. I agree also that a good fertilizer policy is one of the most important points.

If mineral absorption improves much more rapidly than crop growth, there must be a point where crop improvement will become uneconomical. This point we reach very rapidly in our soils. Have you any experiences about the action of humus and micronutrients in a good fertilizer programme?

Do you believe we may advance the uneconomical fertilizer dressing point, if we emphasize the mineral equilibrium between macro and micronutrients and, if we emphasize better nutrient absorption by improving soil structure and the humus level?

BLANCHET

Je pense que le raisonnement que l'on peut faire d'après les besoins des cultures pour les macro-éléments peut aussi en général s'appliquer, au moins dans les grandes lignes, au cas des micro-éléments. En ce qui concerne les relations avec l'humus et la matière organique, je crois que la question est complexe; (elle a été déjà débattu ce matin sous un autre aspect). Simplement, je pense que la type de résultat qui a été largement montré par Flaig, Chaminade, etc. reste valable; en fonction de la fertilisation minérale, on observe généralement une élévation du plafond de productivité en présence de matière organique, due notamment, me semble-t-il, à une plus grande vitesse d'absorption des éléments minéraux, probablement en partie par une accélération du développement du système radiculaire. Je pense que c'est la principale conclusion que l'on peut retenir de l'ensemble des travaux des écoles de Flaig, de Chaminade, de Christewa. En outre, l'importance de la matière organique sur la structure et les propriétés physiques qui sont des facteurs essentiels du développement des racines, doit être soulignée, en dehors de l'effet physiologique, car il conditionne les possibilités d'exploration du sol par les racines.

I think that the reasoning that can be made according to the needs of cultures for the macro-elements can generally also be applied, at least in large outlines, in the case of micro-elements. As concerns the relations between humus and organic matter, I daresay that the question is complex (it was already discussed this morning under a different aspect). Simply, I think that the type of result which has largly been demonstrated by Flaig, Chaminade, etc. remains valid; in function of the mineral fertilizer one observes generally an elevation of the productivity in the presence of organic matter, mainly due, it appears to me, to a higher absorption rate of the mineral elements, partly probably because of an accelerated development of the radicular system. I think this is the main conclusion that can be drawn from the whole of the works of the schools of Flaig, Chaminade, Christewa. Besides, the importance of the organic matter on the structure and the physical properties which are essential factors of the roots' development, must be emphasized beyond the physiological effect, because it conditions the exploration possibilities of the soil through the roots.

Hernando

I would like to ask you about a surprising result in table 4 — surprising at least for our country. You say that the yield of wheat is higher than the barley one. In our country we always get the contrary: higher yields with barley than with wheat in the same field. Is this a special result or is it usual in your country?

Blanchet

L'orge, dans cette région du sud-ouest de la France, en général ne donne pas de très bons rendements; c'est assez habituel dans cette région. Je sais que c'est un peu exceptionel, certainement.

In this region of soustwestern France barley generally does not give very good yields. This is quite usual for this region. I certainly know that this is somewhat exceptional.

HERNANDO

Another point I would like to ask you is in relation to the graph you show here between yield and organic matter. In the last Study Week on Soil Fertility and Organic Matter I presented a paper about this and we found that the yield will be related to the humic acid applied in a way like that. Without humic acid — with fertiliser — we get an increasing yield, like that, but if we apply humic acid we get increases like that. This means there are some concentrations of humic acid that increase the yield but if you increase the amount of humic acid you decrease the yield, and later increase again, and later decrease again. And that is maybe the explanation why sometimes we apply organic matter and get less yield than without applying organic matter. The farmers in some areas are not keen on using the organic matter because they sometimes get this bad result, but I think it is because they do not use the right amount to produce increasing yield. Another point is that in your paper you talk about the relationship between yields and content of the element in figure 2, but in the last part of the curve increase the content and decrease the yield. You say that is possibly toxicity. I think we must not say toxicity; we must say maybe the yield does not depend on this element, there may be another one.

BORNEMISZA

I would like to make addition to this want of nitrogen business, as it is quite important. We have observed in Central

America, where there is an extended dry season on the Pacific side, that a late nitrogen application conserves the pastures in good shape for a considerable period, in addition to increasing appreciably their protein content. I really do not know the mechanism involved but it has a large practical effect as pastures in a five-month dry season become very scarce. Would you mind commenting, Dr. BLANCHET, on this? You might probably have some explanation for it.

BLANCHET

Je connais évidemment trés mal les problèmes de l'Amérique latine, mais je pense que justement cette fertilisation azotés, notamment sur les prairies, permet à la plante de rester dans un état physiologique très correcte, et il me semble que c'est peut-être une des raisons essentielles de la meilleure longévité, aussi d'une meilleure implantation, je suppose — une meilleure colonisation du sol, je crois, et cette impression déborde un peu ce sujet précis, que nous avons trop tendance à raisonner trop simplement sur les relations entre la croissance des plantes et la teneur du sol en éléments fertilisants. Ce n'est qu'un des aspects, il y a aussi l'autre, aussi essentiel et qui est l'importance du système radiculaire. Or, l'importance du système radiculaire est assez directement liée à l'état nutritif de l'ensemble de la plante et, au moins dans une certaine mesure, il faut suffisamment de vigueur de la plante et des parties aériennes pour avoir un système radiculaire suffisamment développé. Je sais bien que la relation entre azote et système radiculaire est très controversée: souvent en culture en milieu liquide on a plutôt une restriction du développement radiculaire par l'azote, mais je crois que dans le sol cela peut éventuellement être un peu différent, et en particulier dans la constitution des réserves racinaires qui sont un facteur essentiel pour la repousse et le redemarrage de ces prairies.

Evidently I am rather badly acquainted with the problems of

Latin America, but I believe that it is exactly this nitrogen fertilization, especially on grassland, that enables the plant to maintain a very correct physiological state, and it appears to me that this may be one of the essential reasons of the better longevity, also of a better implantation I suppose, a better colonization of the soil, I daresay, and this impression goes a little beyond this specific subject which we are inclined to discuss too simply with regard to the relations between the plant growth and the soil content of fertilizing elements. This is only one of the aspects, the other one is also essential, namely the importance of the radicular system. Now the importance of the radicular system is rather directly connected with the nutritional state of the whole of the plant, and the plant and the aerial parts need, to a certain extent at least, sufficient vigour in order to have a sufficiently developped radicular system. I know very well that the relation between nitrogen and radicular system is very much disputed: on cultures in liquid milieu the nitrogen exerts rather a restrictive action on the radicular development, but I believe that this may probably be somewhat different in the soil and particularly in the constitution of the root reserves which are an essential factor for the re-shooting the re-growing of these meadows.

PROFITABILITY AND OPTIMAL USE OF MINERAL FERTILIZERS IN FARMS OF DIFFERENT CROPPING POTENTIAL

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The fight for the daily need of food has determined the historical development of human settlements in their regional distribution and structure as much as in their expansion and growth. Up to now hunger is spread all over the world and is the reason for much misery, especially in the Third World where the expanding population, as a result of a rapid medical progress, is increasing in depressing manner and on the other hand the necessary surplus production of food does not keep pace.

The large Christian organizations « Miserior » and « Bread for the World » in connection with other national and international organizations make great efforts to soften the misery in many developing countries.

The insufficient food production in the developing countries is in strong contrast to the over-production of food in the highly industrialized countries, which is typical for their technical development.

The essential causes for this discrepancy are based on the fact, that the technical progress in food production in the

For this paper in German language see Appendix Nr. 2.

developing countries does not go ahead to such a degree as will be necessary to satisfy the increasing demand.

The idea to balance the under-production of the developing regions with the agricultural surplus of the high industrialized countries will be theoretically possible, but as a general and definite solution it cannot be realized practically. Transport, storage, and distribution of this surplus production leads to new financial and social problems which do not contribute at all to the peace in the world.

The major objective of all efforts should primiraly be to improve the production of food in the developing countries in order to enable the people afflicted by any form of hunger or malnutrition to cover the demand of food on their own.

This assumes that the causes of the low agricultural production will be completely recognized and steps should be taken in the most effectful and economical way. Just these principles in many cases will not be respected because ideological thinking is against the realization of these targets and also political interests of many states are not adjusted to the economical possibilities.

Many foreign aid projects have been started in both last decades with much eagerness and élan by industrialized countries for the Third World, but very often came to a standstill half way, because either the assumptions were not fulfilled or ideas were taken as a basis in which the solvable problem of increasing agricultural production was oriented by standards of the industrialized countries.

Starting point for a satisfying solution of nutrition problems in the Third World must be first of all an analysis of the agricultural-biological situation, which gives information of whatever degree the soil can be brought to by using modern knowledge and methods. Rural-social, and economical points of view are important but not decisive in this phase of development.

A great number of experiments exist — especially in connection with the FAO Fertilizer Program — which show efficient ways of obtaining a higher production level in land use, without any change in the existing main agricultral pattern, size of farms, or social structure of agriculture, if a good planning program for the soil-plant system goes ahead with an efficient extension service giving the farmer the correct information.

The Fertilizer Program mainly succeeded because the solution of practical problems was more important than fighting for ideological ideas.

In the highly populated developing countries most of the soils have been heavily stressed since centuries and therefore largely robbed of their natural nutrient supply. Only where the soil was restored periodically by natural flooding in the deltas or by ash-rain of vulcanic origin (Java), relatively high yields could be expected. If this natural manuring or the rain failed to appear, crop failures followed and often became a heavy disaster for the people.

The main objective of agricultural activities should be concentrated first of all on the supply of soils with the necessary plant nutrients. The nutrient status of most soils in the developing countries is extremely bad and a sufficient release — especially with respect to nitrogen and phosphate — by weathering and mineralization will not be sufficient to gain a higher yield level.

All efforts to attain the target of increasing yields by cultivating the soil with tractors and modern technical implements, as compared with the ancient hook-plough, did not generally succeed. Rather the contrary became true. Intensifying methods of cultivation mean accelerated aeration of the soil and by this a rather quick oxidation of organic matter, with the consequence, that at the cost of humus the nutrient-flow will be improved — but only for a short period — if the humus will not be replaced. Higher yields in the beginning will be followed by worse ones in the long run, which are below the initial yield level.

Humus decomposition often is accompanied by chemical processes which lead to nutrient fixation by formation of heavy-soluble inorganic compounds. Especially the phosphate compounds of sesquioxidhydrates are dominant in tropical and subtropical regions, because most of the soils dispose of high amounts in P_2O_5-fixing cations (Fe, Mn, Al).

Besides this the effect of humus as a colloidal material in protecting some plant nutrients from fixation will be reduced as decomposition goes on.

Moreover, the decrease in storage capacity of nutrients will be accompanied by a reduction of the nutrient mobility with the consequence, that ion-uptake by the plant will become more difficult. Intensified cultivation methods and the use of tractors instead of animal power in many developing countries has also led to a progressing damage of soil structure and soil fertility.

Even the soils rich in nutrients but suffering from need of water — making irrigation necessary — cannot be improved only by the use of modern agricultural equipment. Very often a lack of knowledge about the most effective use of technical implements is responsible for declining fertility. Since in this paper plant nutrient problems should primarily be discussed, irrigation problems will not be treated.

In every case, in connection with increasing yields the soil will play the most important role. Its nutrient status and its dynamical features will be a decisive criteria for the possible yield and to what extent the soil can be utilized. On this base — according to Mitscherlich's law — a sufficient information about the profitability and optimal use of fertilizers can be reached. The importance of commercial fertilizers for increasing yields as compared with other sources of changes in crop production may be shown in figure 1.

As may be seen fertilizer takes the first position with 58% of total then followed at a wide distance by weather and others.

Commercial fertilizers which mainly are applied as mineral compounds enable the farmer to supply the soil with sufficient

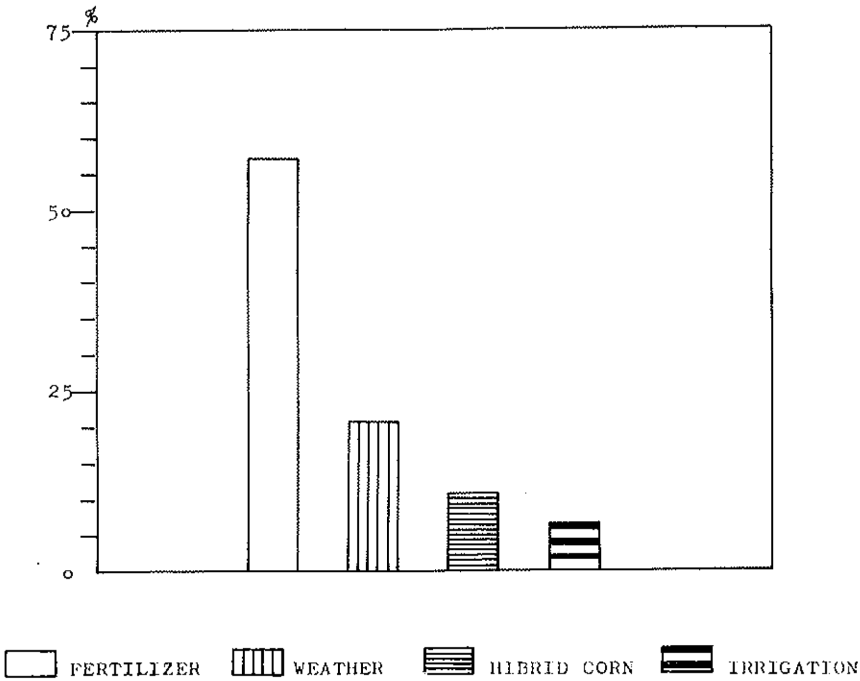


FIG. 1 — Sources of Changes in Crop Production per Acre United States, 1940-41 to 1955.

amounts of plant nutrients and also to equilibrate ratios between various nutrients and last not least to satisfy every plant's demand. In farming systems without fertilizer use this will not be possible. Under these conditions it will be necessary that the choice of crops and cultivating methods must be adjusted to the available nutrients in the soil. The yield level will be higher the more favorable the release of nutrients from the soil reserves will be.

The crop potential of farming systems operating without the use of commercial fertilizers as is the case in most of the developing countries of to-day will be described by the following equation:

$$(N_N - N_V) = (N_E - N_W)$$

N_N = nutrient release of the soil by weathering and mineralizing processes (storage of nutrients included).

N_V = nutrient losses in the soil by leaching, volatilization and fixation.

N_E = gross nutrient removal by the yield.

N_W = nutrient return by farmyard manure, urine, straw and other residues from animals or plants.

In the state of equilibrium the net removal of nutrients by the yield ($N_E - N_W$) will be compensated by the amount of available nutrients in the soil which is the difference between release of nutrients and their losses in the soil ($N_N - N_V$).

The factor N_N is not an independent variable. It is limited by weathering processes and their intensity, that means that ($N_E - N_W$) as an indicator for the yield level will be limited mostly by N_N (stage of subsistence in agriculture).

As far as plant nutrients in organic compounds are concerned, the quantity of N_W has to be considered in direct relation to N_N. The return of nutrients by farmyard manure and other farm-born residues will favor the release intensity of N_N. Moreover the nutrient losses by leaching will be reduced because of the improved storage capacity of the soil.

An increase in N_W will diminish the net removal as expressed by ($N_E - N_W$) with the consequence that crop management practices should be adjusted to a minimum of nutrient export from the soil to keep the fertility level. On the other hand the demand for food and plant material at this stage of agricultural development in areas with a high density of population is so tremendous that the yield in total will be utilized as far as possible, that is to say not only as a human food but also as feeding stuffs or for fibres, housing and heating purposes.

Parts of the yield, going to animal production, mostly will not return to the soil because solid excreta are well estimated as heating material.

The quantity of N_W therefore keeps a very important key position within the nutrient equilibrium of this kind of farming systems. As far as the demand for plant products is concerned, there is a tendency for a maximum net yield; on the other hand it is absolutely necessary to stabilize the level of soil fertility without any risk for decreasing yields by reduced amounts of N_W. This contrast of interests will lead to an equilibrium, which will be characterized by a yield level of about 6-10 dz CU(*)/ha normally.

The height of this level will be increased by a more favorable release of soil nutrients. This depends on the mineral constituents, amount and quality of humus, duration of cropping and of the kind of crop management practices. In every case the upper limit will be given by the maximum nutrient flow from the soil as far as normal water supply conditions are concerned. Where this natural limit will be exceeded, exceptional conditions are the cause, so that those results cannot be generalized.

An increasing yield beyond this natural limitation can be attained only by an additional factor into the nutrient equilibrium equation, that is the use of commercial fertilizers symbolized by N_Z. For this new farming system we have to write:

$$(N_E - N_W) = N_N + N_Z - N_V$$

The addition of nutrients to the soil from outside (commercial fertilizers) is of fundamental importance for modern agriculture. By the introduction of N_Z the system of subsistence farming, which approximately can be compared to a nearly closed nutrient cycle, will be opened and the more, the higher amounts of fertilizers will be applied. By this change

(*) CU = cereal units.

of production pattern the subsistence phase will be left in favor of a system producing for the market in order to supply parts of the population working outside of agriculture.

In this state of development, farm management practice is going to be adjusted to the need of the market. With the introduction of N_Z an input-output-model of land-use has been realized with the consequence that the plant demand for nutrients will not depend on soil-born nutrients. All that the plant needs can be added by fertilizers. The principal outline of this model may be demonstrated by the following diagram (Fig. 2).

With increasing fertilizer dressings the role of native nutrients will decrease more and more. In a farming system of a high production level therefore N_Z will be much greater than N_N. The function of the soil has changed from an originally releasing system to a transformer with the task of supplying the plant with fertilizer nutrients at maximum efficiency.

The farming system of the subsistence model needs a fallow as a regenerating period to restore the soil with available nutrients of native origin. This is not necessary in the input-output-model because nutrient removal by cropping and losses will be compensated by fertilizer use.

Furthermore, the adjusting procedure with respect to choice and rotation of crops in relation to the natural resources of available nutrients can be neglected. All plant needs can be fulfilled by fertilizers, if the correct methods and amounts are applied. The use of fertilizers has made it possible, for the first time in history, to utilize the genetic cropping potential of the plant. The factor N_N thus may be considered as a milestone in the development of the modern industrial society and will be characterized by the following facts:

1. The possibility of supplying the soil with plant nutrients by fertilizers (N_Z); that means yields will not be limited by the amount of native nutrients on the soil. There remains

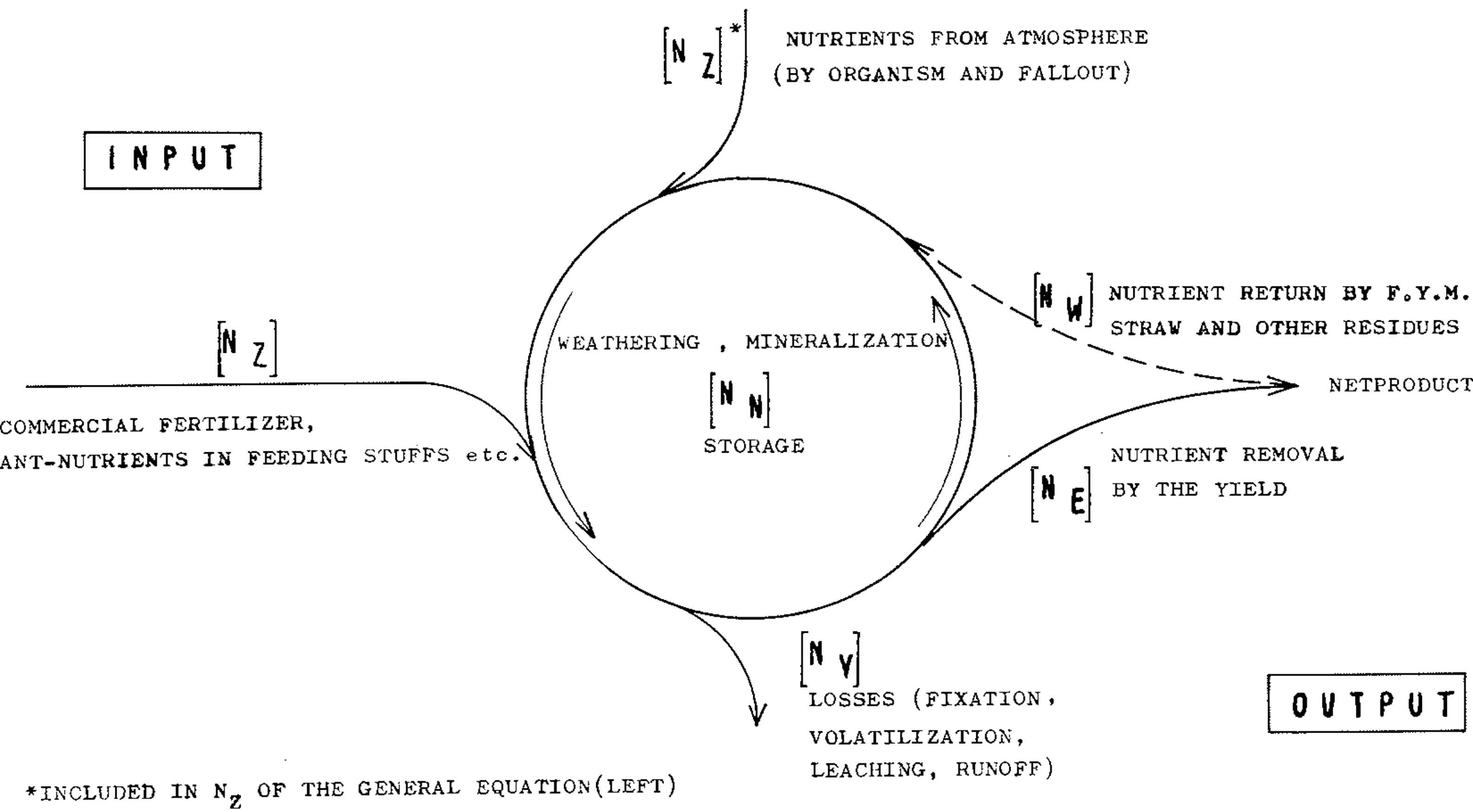


FIG. 2 — The soil as a nutrient transforming system of the input-output-model of intensive land-use.

only a limitation by those growth factors which cannot be influenced by man as insolation, temperature, and weathering.

2. The chance to increase the yield according to Mitscherlich's Law with more profitability and without a noticeable expenditure in labour. People, employed in agriculture, thus will get more and better food, surplus of farm products can be sent to the market, so that people outside of agriculture can buy products of domestic origin.

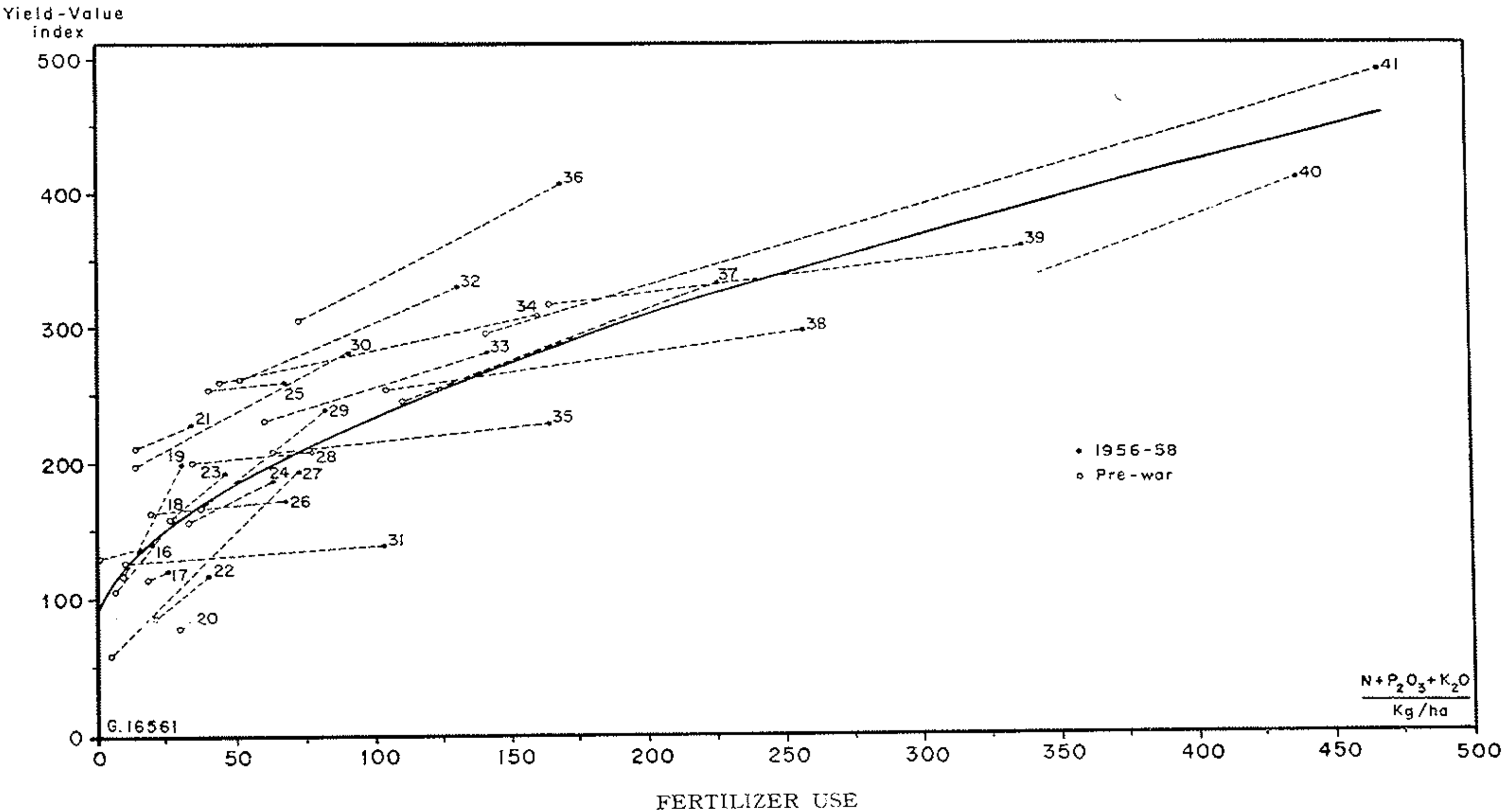
3. Production for the market will raise the farmer's income. By this he can make use of modern equipment and techniques. Manpower will be substituted by machinery and will be set free for employment outside of agriculture. This process is a basic function for industrial development.

The production of fertilizers on an industrial scale is therefore of tremendous economical value and the intensity of fertilizer use a signpost for the achieved level of crop production.

The range of the values primarily depends on different climatic conditions, farming systems, crop rotation, and the nature of the soils. By these factors, profitability of fertilizer use will be more or less determined. The intensity of commercial fertilizer use depends on the price, the farmer has to pay for N_Z, and what could be the profitable return from extra yield of crop. For calculating purposes therefore it is necessary to compare the curve of fertilizer costs with the yield curve, expressed in monetary values, as it is the use in all countries with a high agricultural standard. The optimal range will be indicated by a maximum of net return (value/cost = ratio $>$ 1).

Further increase in fertilizer use up to the point of intersection of both curves (gross return = fertilizer costs) is only of importance in those countries where planned economic programs will be preferred instead of the optimal economic criteria of the individual farmer.

In the beginning of fertilizer use various economic difficulties mostly happen. In the developing countries usually fertilizers must be imported. For that reason prices are very high



1. Burma	8. Indonesia	15. South Africa	22. Australia	29. France	36. Switzerland
2. Argentina	9. Philippines	16. Yugoslavia	23. Italy	30. Austria	37. West Germany
3. Thailand	10. Canada	17. Spain	24. Peru	31. South Korea	38. Japan
4. Pakistan	11. Colombia	18. Greece	25. Egypt	32. Denmark	39. Belgium Luxembourg
5. Turkey	12. Mexico	19. U.S.A.	26. Finland	33. United Kingdom	40. Netherlands
6. India	13. Brazil	20. Portugal	27. Israel	34. Norway	41. New Zealand
7. Syria	14. Chile	21. Ceylon	28. Sweden	35. Taiwan	

FIG. 3 — Curve of average relationship between fertilizer use and value index of crop production. (per arable hectare 41 countries, 1956-58)

and transport charges from the port of arrival to the farms are very expensive. On the other hand, the gross income on the base of considerable increase in yield is often so low, that it is not possible for the farmer to get a net return.

Typical examples to demonstrate these difficulties in the beginning of fertilizer use may be taken from the extensive and longtermed Fertilizer Program of FAO (Table 1).

TABLE 1 — *Results of some field experiments of the 1st five-year-period of the FAO Fertilizer Program* (1961/62 - 1965/66).

Region and Plant	Fertilizer kg/ha N - P_2O_5 - K_2O	Increase % of control	Value/ Cost ratio
Ecuador, peanuts Highland	45 - 0 - 0	33	4.1
	45 - 45 - 0	11	0.9
	45 - 45 - 45	9	0.5
Coast	45 - 0 - 0	25	6.4
	45 - 45 - 0	38	5.8
	45 - 45 - 45	30	3.8
Ecuador, corn Highland	45 - 0 - 0	30	2.4
	45 - 90 - 0	63	2.3
	45 - 90 - 45	78	2.6
Coast	45 - 0 - 0	—	—
	45 - 90 - 0	7	0.3
	45 - 90 - 45	14	0.5
West-Nigeria, Yams Forest	22.4 - 0 - 0	4	2.0
	22.4 - 22.4 - 0	6	1.5
	22.4 - 22.4 - 22.4	6	1.4
Savannah	22.4 - 0 - 0	18	9.9
	22.4 - 22.4 - 0	28	7.4
	22.4 - 22.4 - 22.4	30	6.7

The results show remarkable variations of value/cost-ratios. This is caused mainly by the amount of available nutrients in the soil, the different plant needs, the local climatic conditions, and the different costs for purchasing and transportation of fertilizers.

Very often a strong increase in yield by relatively low amounts of fertilizers will be reached — but without any economical result on this stage of agricultural development, due to the beforementioned reasons.

In the developing countries therefore it will generally be necessary that the costs for fertilizers and fertilizer transportation should not be too expensive and because of this, should be fixed by government. Also the increased yield must be supported by fixed prices, if the farmer shall be encouraged to use more commercial fertilizers.

In countries where industry is still in initial stages of development and thus labour costs relatively low, agricultural subsidies or other supporting systems can be reduced more and more with the development of a free market. Working people outside of agriculture take an increased influence on the demand of food which in most cases cannot be covered by the national agriculture. Compared with the prices for the farmer's products, the expenses for fertilizers are generally low, therefore it is very attractive for the farmer to favour the factor N_z in order to get a higher income (phase of intensity I, increase of soil productivity and cropping potential).

In the high industrialized countries where farmers have to make high capital investments for technical processes and machinery due to a shortage in labour, a high level of wages as well as high costs for energy, agricultural buildings and machines, are outstanding characteristics and go together with a surplus in agricultural produce.

To avoid a complete breakdown of prices and by this a risk for small holdings, fixed prices as well as subsidies are necessary in order to fill the gap between industrial wages and farmer's income. Also, regulations hy law for a limitation of agricultural production will be essential. The consequence of this policy will be that farmers with small holdings drift away into industry to obtain a higher income, and farms of medium size will be interested to acquire more agricultural land.

Due to this change of structure in the size of holding, soils with low fertility will no longer be used for agricultural purposes, so that the percentage of « Grenzböden » are steadily increasing. On the other hand, agricultural land of high cropping potential will be managed more intensively, that means, that higher amounts of commercial fertilizers will be applied.

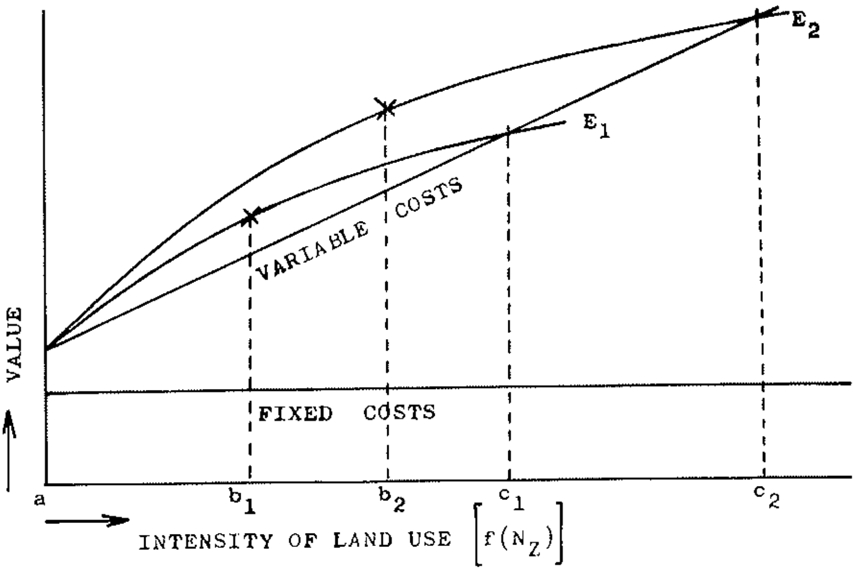
This general situation may be found in various countries of the Common Market and shows a typical feature of highly developed agriculture in industrialized countries (phase of intensity II, continuation of I together with an increase of labour productivity).

The general tendency to concentrate the crop production on soils of high fertility and in good growth conditions is the consequence of the price/cost-ratio because the gross return from extra yield of crops will be higher than the expenses for fertilizer purchase and management (Fig. 4).

The optimum and maximum dressings shift in favour of higher amounts of fertilizer with increasing A-valnes.

This characteristic tendency in the structure of agriculture in highly industrialized countries has an additional effect on the ratio of N_W/N_Z in favour of N_Z.

Due to high labour costs and irregular working time, most of the farms in the last years have reduced animal production. Animal industry outside of the farmer's holding is being preferred more and more. The consequence is, that the amount of farmyard manure, liquid manure, etc. within the farm will be diminished continually. Most of the straw remains on the field. The wide C/N-ratio of this organic material needs additional N-dressings for securing a normal decomposition by soil-organism. N usually will be applied as a commercial fertilizer because N-autotrophic legumes for intercropping are



E_1 = monetary yield curve with low A-value.
E_2 = monetary yield curve with high A-value.
a = minimum dressings in the state of equivalence between monetary yields and costs.
b_1 resp. b_2 = optimum dressings for E_1 resp. E_2 (maximum profit).
c_1 resp. c_2 = maximum dressings for E_1 resp. E_2 in the state of equivalence between monetary yields and costs.

FIG. 4 — Optimum and maximum dressings of fertilizer application in relation to different yield curves.

mostly not economical. Very often it is cheaper to grow plants like rape, sennep, rye, etc. as green manure to stabilize or improve soil fertility.

The reduction of F.Y.M., liquid manure, etc., makes it necessary to apply additional amounts of commercial fertilizers. Therefore, the ratio between N_Z and N_W will increase in favour of N_Z, as shown in the following graph (Fig. 5).

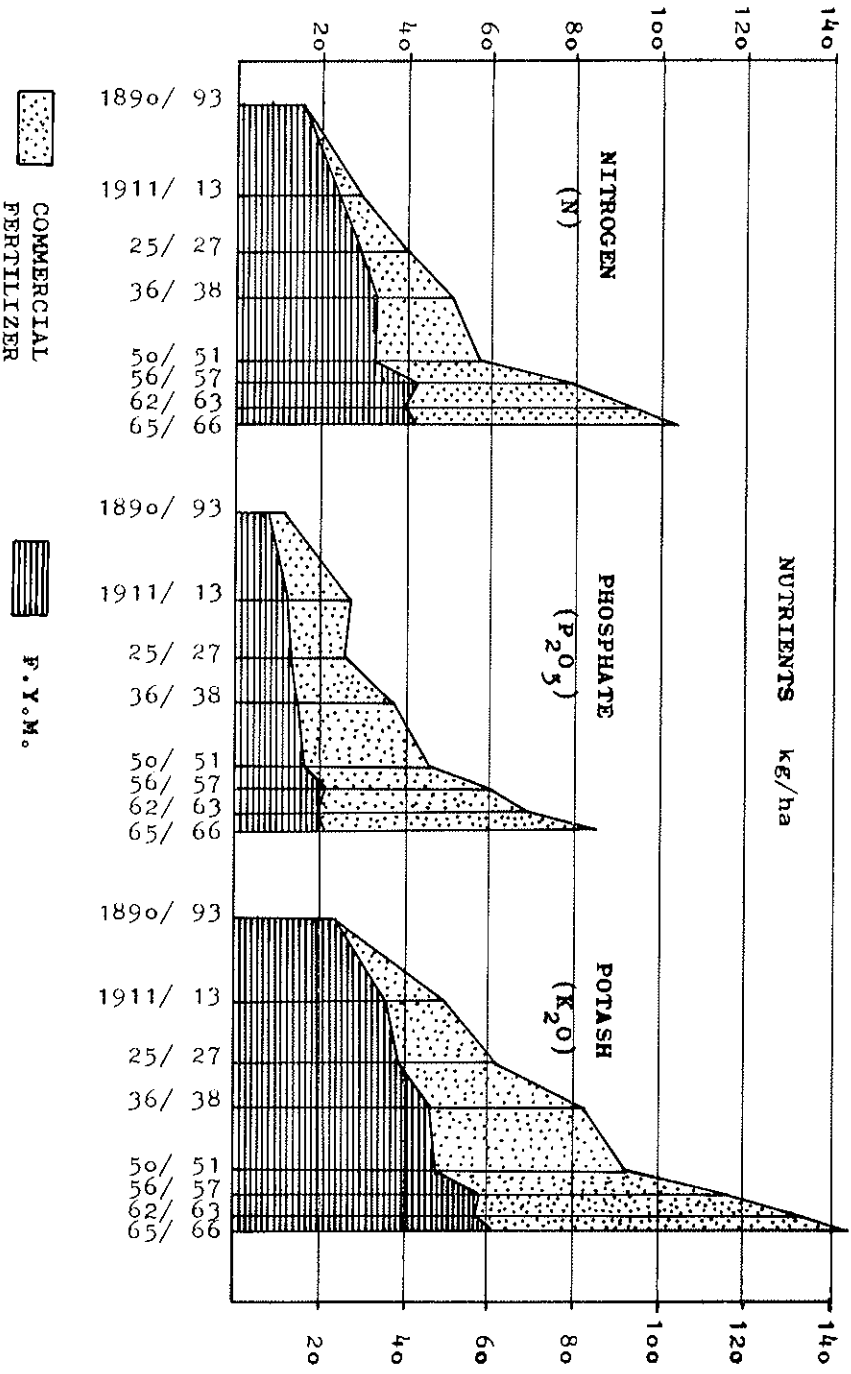


FIG. 5 — Nutrient supply of German soils (1890/93 - 1965/66).

On the high level of today's agriculture in the developed countries like BRD of about 45 dz CU/ha as an average, nearly 70-80% of the nutrients removed by the yield have their origin in commercial fertilizers.

The strong increase in the amount of fertilizer (N_Z) leads to new problems. To make the most profitable use of it, the choice of the right composition and right amount of fertilizers, as well as applying these dressings in the right place and at the right time in accordance with the requirements of the plant, is becoming more and more important. Increasing needs for trace elements should not be overlooked. Timing is also a real problem with respect to nutrification of surface waters. Manuring has to include all nutrients, necessary for good and high qualified crops, and has to be adjusted to the physiological need of the cultivated plant during the growth period by maintaining a sufficient nutrient status in the soil.

To guarantee a profitable use of fertilizer at a high level of agricultural production, the modern farmer should keep a high standard of education and experience and the extension-service must be well developed and organized.

DISCUSSION

Chairman: J. D. Colwell

Pesek

Your graph implies that N_N (the quantity of N in storage in a cycle) would be a constant; do you really mean that the N_N amount would represent the same quantity at the steady state reached initially as it does later after the soil has been improved, i.e., fertilizer has been added, and a higher production level is reached?

Welte

No, I did not say anything about velocity with respect to the cycle. The transformation function depends on a lot of factors and it should be very clear that with increased amount of fertilizers the soil will be improved due to the fact, I have mentioned here, that we are able to get a higher A-value. That means that a certain amount of added fertilizer will be utilized more efficiently

Blanchet

Dans ce graphique, où je suis tout à fait d'accord sur les différentes pentes que peuvent avoir les courbes de Mitscherlich, ne pensez-vous pas que la pente de ces courbes peut être en partie prévue d'après la connaissance des propriétés du sol? En effet, je pense que si ces pentes sont différentes, c'est surtout parce que les capacités du sol pour la fixation des éléments, que ce soit capacité d'absorption ou de rétrogradation, varient; est-ce que vous ne pensez pas qu'on peut prévoir en partie ce comportement d'après l'étude de la capacité d'échange, la courbe d'absorption du phosphore, par exemple, ou les possibilités de rétrogradation, et l'ensemble de l'étude des argiles et des colloïdes?

In this graph in which I quite agree with the different inclinations which may have the Mitscherlich curves, do you not think that the inclination of these curves may in part be provided according to the knowledge of the soil properties? In fact, I think that if these inclinations are different, this is chiefly so because the soil capacities of fixing elements, be it the capacity of adsorption or retrogradation, vary. Do you not think that one can partly provide for this behaviour according to the study of the exchange capacity, the absorption curve of phosphorus, for instance, or the possibilities of retrogradation, and the whole of the study of clays and colloids?

WELTE

The difference between this low curve and the maximum yield curve may be explained by a lot of factors which influence the soil. That is not only the exchange capacity. All limiting factors of the soil and culture practices such as clay mineral content, type of the clay minerals, pH-value, acidity, salinity, soil structure and texture, water regime etc. must be considered. Also the quality and quantity of humus microbiological activity, the educational level of the farmer, his skill — all this comes together here. Therefore I expressed this in the mentioned equation by concerning fertlization and cultural practices as one factor-complex. From this point of view we are able to say something about the productivity of the soil comparing the attained A-value with the maximum yield A-value. To find out this A-value of the maximum yield curve, you start the experiment without soil (hydroponic) under field conditions, using the method of Homès. Parallel to this procedure you work on series with increasing amounts of soil, for instance — 10 percent, 20 percent, and so on, and you see what happens in relation to yield and mineral uptake. For instance, with respect to exchange capacity, we have found in rye grass soil-free medium a certain amount of potassium calcium and magnesium and from that the expression Ca/Mg. in the plant. This ratio is very important in connection with grass tetany. With added soil this ratio was distinctly lower due to the exchange capacity. The effect varies with the quantity and quality of the soil, with the character of the exchange capacity and other influencing factors. We have to see the soil *and* the plant if we apply fertilizers, because both fight for nutrients.

BUSSLER

I just want to remark on the words of Prof. WELTE. I think one of the worst words we have in the papers on plant nutrition is the word « normal ». We find normal fertilization, normal content of sugar, and so on, but I am sure that nobody has ever seen a normal plant so I think that the new experiment made by Prof. WELTE to look for the plant that has exhausted fully the genetic potential is a very important experiment and should be repeated in different places under similar conditions.

CAPÓ

I understood the speaker to say that the objective in this connection would be to find out how much the plant needs in order to apply it to the growth medium and maintain the equilibrium. From the approach I presented in my paper I believe the objective should not be that; the objective should be to find out the optimum amount which should be added, that is, the one that would provide the maximum benefit to the farmer, and then, of course, apply in the future whatever may be needed to keep that new equilibrium.

WELTE

I think that is not contradictory to what I have outlined. Your remark is especially related to the process at the beginning of fertilizer use, or where the conditions are very bad. Of course, we have to look at the economical problem. But each system has its own optimal economical value. Nevertheless we have to know what the maximum yield under given conditions will be in order to compare it with the real attained yield and to see how far away we are from the possible maximum. If we have such a great difference like this shown on the blackboard then it is clear that the soil is in a very bad condition. May be that the physical conditions are bad, may be that the chemical or biological conditions are insufficient or may it be an other sore factor — in every case this result is caused by very bad conditions in the soil.

CAPÓ

The speaker spoke about soil-less material, and he was suggesting that experiments should be made in a medium in which there is no soil. I would like to say that we have done this kind of work about 30 years ago, in which we planted in sand culture and we found out that we could get a maximum yield with considerably less concentration of nutrients than are necessary in the soil, that is, in sand there will be no fixation of potash nor the locking up of nitrogen and you can get maximum yields with considerably smaller quantities of nutrients than you have to apply in the soil to get the same yield.

WELTE

With the same amount of fertilizer you can get various yields in dependance of the A-value or as you may express it as a function of soil fertility. The soil is a complex of physical, chemical and biological characteristics. They belong together. To find out the most important limiting factors is to find a mental goal for research work in the future. Was that your question?

CAPÓ

No, I was just referring to the procedures to obtain the information required to obtain the optimal production.

WELTE

As already pointed out in my paper you will find the optimal production on the base of this curve (A_1-value) if you have the lines for the fixed and variable costs. Then this point on the curve, indicated by a maximum of net return, is also the point of optimal production. But if you have a curve with a higher A-value (A_2-value) and the same lines for the fixed and variable costs as before, then the optimal point is here (showing on the blackboard). The economical use of fertilizers is on the curve before the A-value. You cannot speak about optimal production and optimal use of fertilizers without any connection with the system in which you work that means in relation to the A-value.

HERNANDO

You talk about maintaining the soil fertility, and what you recommend is very interesting but it does not increase the cultivation, on the contrary, it reduces it. I agree completely with you that reducing the cultivation normally increases the soil fertility. But anyway in the South of Spain, near to Madrid (Toledo Province), many farmers working the soil one meter deep with new implements, get a high increase in yield the following year but gradual decreases afterwards. With this method they are increasing the yield, but is is difficult to teach them that they are spoiling the soil for the future. It is a problem of education and knowledge. What do you think of this?

WELTE

This cultivation technique has not been considered in my paper because the costs are very high for the farmer. It is more, what we call in Germany, a melioration, and if you grow tomatoes, vegetables and get a high price, or the government will give you some subsidies, of course you can do that. By deepening the soil, the roots will utilise the subsoil more intensively. Therefore more nutrients become available at least for a certain time. It is very difficult to tell the farmer that within a few years this resource will decline.

ADJUSTING FERTILIZER RATES TO SOIL FERTILITY LEVEL ON THE BASIS OF SOIL TESTING

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Introduction

Soil testing as a basis for dressing of fertilizers has probably in no other country taken such a flight as in the Netherlands. It seems worth while to bring into general discussion the reasons why this has happened, the results and their importance on circumstances not quite similar to those in Holland.

The density of the population, and also the restricted size of the farms, have necessitated a highly intensified form of agriculture. Furthermore, fertilizer consumption is high and represents an appreciable part of the costs (approx. 10%). For these reasons a careful dosing of fertilizers is needed. This must be adapted to the differences in soil fertility found in practical farming.

The application of soil testing is especially relevant if the level of soil fertility in agricultural regions is very diverse. Such a diversity was especially brought about by a continuous cultivation with individual variations or by a varying state of degradation on different plots of originally fertile soils. This tendency was intensified by a completely uncontrolled use of fertilizers in the first part of this century. These differences have to be taken into consideration if a most effective use of fertilizers at each separate site is wanted.

The necessity to meet the difficulties in practical farming was early recognized by workers of the State Agricultural Experiment Station at Groningen [1]. This station was situated in a region especially confronted with the problem. It became clear that the application of artificial fertilizers had to be guided scientifically, and those early investigators expected that soil testing would be the way. The development has strongly been stimulated by the establishment of a Soil Testing Laboratory, owned by the Farmers Associations but closely tied to the Experiment Station — as early as 1927 —. Reliable tests for mass investigation had to be developed. It was realized, however, that especially these tests would need calibration under the very conditions of practical farming. That the most careful attention is paid to this point is probably the most characteristic feature of soil testing in the Netherlands. For tens of years research has been directed to the elaboration of a system of fertilizer recommendations based on field trials and spread over all soil types of the country.

Essentials of the soil testing method

A method like soil testing has to meet at least some principal requirements. One of these is that the magnitude of the soil factor, as estimated by the test, must be representative for the amount of fertilizer needed. This means that the relating factor should not be disturbed by interactions of the widely varying factors of soil and climate. In an absolute sense this will never be realized, but for practical purpose it may be sufficient if this demand is fulfilled to a considerable extent. Interactions are less disturbing if they are determi-

[1] Precursor of the present Institute of Soil Fertility at Haren-Groningen.

nable. In that case their effects can be taken into account. An example of this is the antagonism of potassium and magnesium. When including the level of the second factor into the calculation the diagnosis of the effectivity of the former may be refined and vice versa.

Another requirement to make efficient use of soil testing is that an essential aspect of a factor, through which it actually works, must be characterized. In some cases the whole quantity of a nutrient in the soil may be relevant to the plant, but it may only be a restricted portion of the latter in others. In such cases this portion must be represented by the test. It may be questioned whether it will be best represented by the concentration of the soil solution, or by the rate at which the level of the latter is supplied. Certainly, a true localization of the working agent is largely responsible for the effectivity of a soil test index. In some cases the inapplicability of soil testing may be due to the fact that too little of the said requirements is fulfilled. The apparent lack of success with methods used to assess the nitrogen status of the soil, for instance, might be ascribed to such an imperfectness.

Though it may sometimes be justified to claim the superiority of a certain method to another on merely theoretical grounds, it is nevertheless certain that the final decision as to its efficiency has to be made in the field. In a similar way the recommendations of rates of fertilizers must be learned from field trials conducted under conditions similar to those of practical farming. The reason is that the actual field conditions are decisive for interactions which cannot be deduced from general rules.

Application of soil testing data

In general soil testing is not restricted to the assessment of isolated single factors. The goal in the Netherlands is a complete recommendation of fertilization. Factors are evaluated in relation to each other; the amounts of potassium and magnesium fertilizer and of lime, for instance, are recommended in mutual relation. Characteristic soil factors, such as pH, contents of humus and clay particles are taken into account.

At a higher pH, but an equal content of exchangeable potassium, the availability of potassium to the plant is lower. It seems plausible that this decrease of availability results from a physiological antagonism between K on the one hand, and Ca + Mg on the other. In the case of P, an increase of pH causes a lower solubility of phosphorus in the soil solution which declines the absorption by the plant.

With the incorporation of pH in the diagnosis of available K and P two different lines have been followed. In the case of K the interaction has been determined purely empirically in field trials as well as in pot experiments. The research was conducted with different soil types and crops. The object in view is still a more satisfactory solution by which the changes in availability effected by pH, or some other soil factor, are incorporated in the test. It could, however, be realized with phosphorus. When a method of a high standard was used the phosphorus absorption by the plant corresponded to the P-indices determined. It follows that the P index concerned makes it possible to diagnose the availability to the plant exactly. Possible interactions need not be corrected.

A full discussion of soil testing as applied in the Netherlands would include the assessment of the lime status and magnesium and trace elements (copper, cobalt, boron). The lime status, determined as pH-KCl, gives a general information about the nutritional, physical and biological status of the soil. Graduated amendments of lime can be recommended on the basis of extensive field research, considering factors like the extent of the exchange complex and its quality, depth of arable layer and the needs of crops grown in the rotation.

Magnesium may limit crop production, especially on sandy soils. Its economical importance is still higher on grassland, as the magnesium content in the blood of cattle is a controlling factor in health of cattle (grass tetany) and milk production. Studies made on the interaction of Mg and K, the N content of grass and the botanical composition of the meadow, are exemplary for the treatment of such problems (SLUIJSMANS, KEMP).

A likewise extensive project dealing with the assessment of physical soil factors has an optimum state of soil structure as its ultimate goal. It is recognized that especially the distribution of clay and sand particles, content of organic matter, lime status and drainage are important factors. Recent research made possible an evaluation of these interacting factors with respect to the different aspects of soil structure, such as the resistance to mechanical forces, soil slaking, resulting in surface crusting of the soil (especially important for seedbeds), the suitability for plant growth (actual structure) and the importance for crop yield (BOEKEL).

Finally, mention should be made of recent attempts to ohtain valid estimates of available nitrogen in the rooting zone.

Thorough discussion of all these factors is beyond the scope of this paper. The purpose of the present discussion is to demonstrate the principal lines of research (see also FERRARI). By confining myself to the solutions found with respect to the fertilization with potassium and phosphorus, I shall attempt to elucidate the objectives of soil testing in the Netherlands.

Potassium

Experience gained in Holland and elsewhere has shown that the exchangeable form of potassium is an acceptahle index of the availability of this nutrient. As has been said, its value is affected by the magnitude of the exchange complex. In a similar way the availability of K depends on a physiological antagonism with Ca and Mg. It is realistic to account for these factors. To include the exact determination of each of these factors would exceed the requirement that soil testing has to be simple and cheap. The content or organic matter on sandy soils and that of mineral particles $< 16\ \mu$ on clay soils are used for the approximate measures of the magnitude of the exchange complex. For a similar reason pH is taken as a measure of adsorbed bivalent cations. The interrelations between the three factors, namely content of exchangeable potassium, content of organic matter and mineral particles, and pH have to be investigated in the field. Series of field trials were conducted which meet these requirements. In such a case, plots were preselected which widely ranged between low and high for each of these factors. Mutual correlations must also be kept as low as possible.

The same crop was grown, by preference potatoes of the same variety and origin.

Crop responses were measured as yield differences, but additional information was obtained from chemical crop analysis, visually assessed scores of deficiency symptoms, etc. The results of such an experiment are demonstrated (fig. 1).

Though the effect of K-content was the most pronounced, clear relations to pH especially at low values, and also to the content of clay particles, were found. The same K content appeared to be most effective to the plant when the pH was low. In this case the antagonistic effect of other cations was lowest. The same was found at a weak magnitude of the exchange complex.

From similar series of field trials, performed in different regions and years, a K index was deduced which incorporates the relation of the three factors with the potassium response of the crop. The equation from which the K index is computed reads like this:

$$\text{K value} = \frac{\text{K-exchangeable} \times b}{0.15\ \text{pH} - 0.05}$$

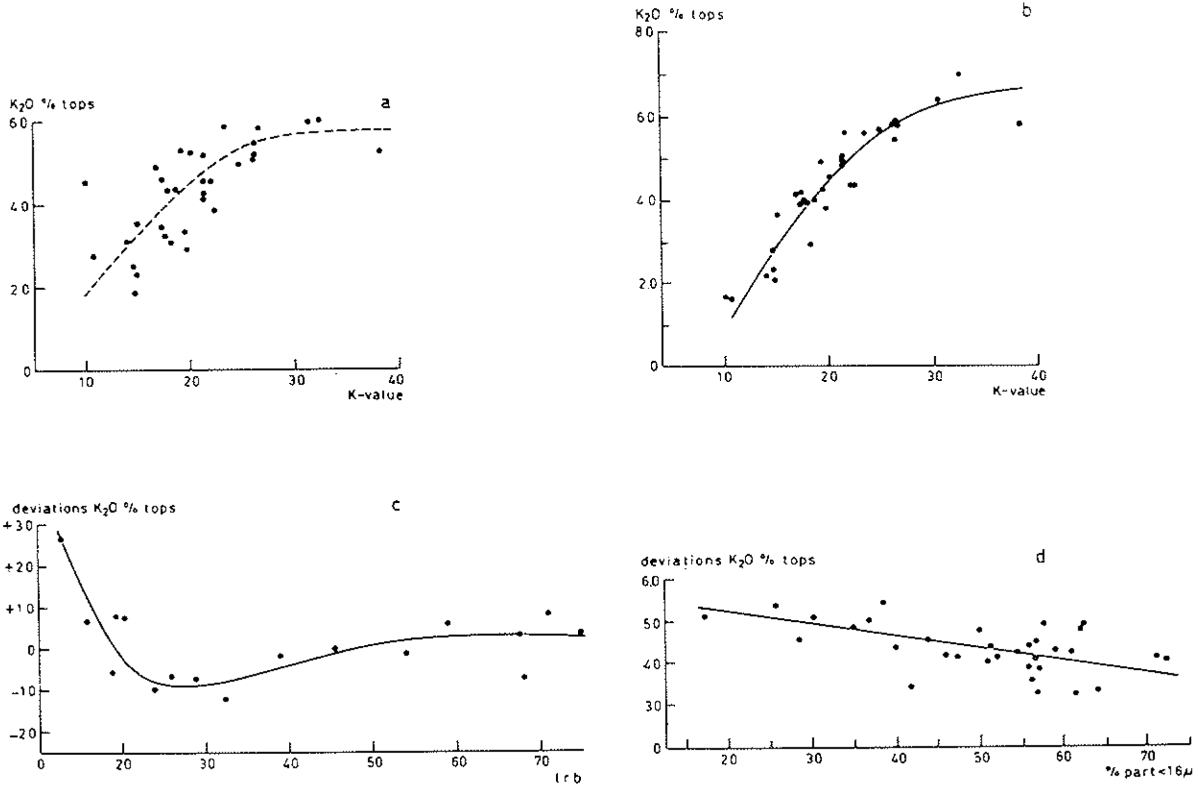


FIG. 1 — Analysis of relation between soil factors and K_2O content of potato tops grown on zero-K plots of series field trials conducted on alluvial marine soils.

a) Relation between content of exchangeable K and K_2O content of tops.
b) Same after elimination of effects of lime status (c) and clay content (d) on K_2O content.
c) Relation between lime status (indicated as factor lrb) and deviations from curve of K_2O content (a).
d) Relation between clay content (particles $< 16\ \mu$) and deviations from curve of K_2O content.

The influence of the clay content is expressed by the value b which decreases at increasing clay content.

The factor pH is only considered if lower than 7. In case it surpasses 7 it is arbitrarily reduced to this value. In these cases the denominator equals unity.

River clay soils are often characterized by a high capacity of potassium fixation. The question has arisen whether the latter has also to be taken into account. The answer is negative as this factor is also expressed by the intensity of the K-value (which represents the combined effects of K, pH and particle size), taking the response of the crop as a criterion.

Similar empirical equations have been drafted for other soil types. Arable land and pastures had to be distinguished. A reliable diagnosis of K-availability was made possible in this way. It must be observed, however, that research of this kind is laborious. It was therefore hardly possible to repeat the investigation with other crops. Besides, difficulties have arisen with soils of a transitional type.

The next step is the estimation of the rates of fertilizer to be recommended at any K value of the soil. The way in which this is done will be discussed in the next paragraph.

As a rule, soils are tested when the main crops will be grown. For this crop a rather exact recommendation can be given; but the exactness is less for following crops, due to the relatively rapid change of the K content under cropping conditions. This is especially true for light soils where the stock of available potassium is small.

Phosphorus

In the past a considerable number of methods for the assessment of plant available phosphorus were developed. In so far as extraction methods were involved, the extractants used varied between pure water and very strong solvents.

The background of this uncertainty was the lack of insight into the process of phosphorus assimilation. Though the latter has increased, uncertainty still remains up to the point whether the same aspect of phosphorus supply is a controlling factor under different conditions. In field trials a remarkable difference was indicated between arable crops and pasture.

In the first case, water appeared to be the most efficient solvent under Dutch climatic conditions. This conclusion was underlined by more fundamental research which indicated that values of isotopically exchangeable soil phosphate, determined under laboratory conditions in a soil-water system (E-value) and in pot experiments (L-value) appear to be of the same order of magnitude (SISSINGH). The conclusion was that water mobilizes the same components of soil phosphate as those which are in a mobile state in the soil in contact with the soil solution.

However, on permanent grassland better results have been obtained with stronger solvents, like 1% citric acid or a mixture of ammonium lactate-acetic acid, which is used with the so-called PAL method (EGNÉR, RIEHM and DOMINGO). This may indicate a higher phosphorus absorption from a densely rooted superficial layer under permanent grass. Evidence was obtained from a pot experiment with grass which was grown in a restricted volume of soil and frequently cut. It appeared that the correlation between Pw value and P response of the successive cuts was steadily declining, whereas the correlation with P-AL value grew higher. The result seems to indicate that, when P absorption is very intense, the phosphorus present in the labile pool may be a more strongly controlling factor than the level of mobile phosphate.

The clear indication that water is to be preferred to diagnose the phosphorus status on arable land does not include that the procedure of the extraction would be of less importance. On the contrary, very different correlations with crop response were obtained when factors like soil-water ratio, time of extraction and temperature were varied. Taking the response of potatoes, grown in a pot experiment conducted with widely different soils, as a criterion the most appropriate combination appeared to be an extraction with a wide ratio of water and soil, namely 60:1 on a volume basis, with intensive shaking during 1 hour at 20°C. Premoistening the soil sample during 22 hrs. gave a further improvement as the original properties of the most soil were probably restored. A high correlation of this value with crop response was found independently in a considerable number of trials conducted with a diversity of soils. Appreciable advantages of the method are its non-specificity for soil type and the fact that the regressions are not affected by such characteristic soil factors like the contents of humus, clay particles and carbonate, and phosphate fixing capacity. Its dependence on pH and the deviations found in soils extremely high in Fe content are almost negligible.

To prove the efficiency of the method for a wider range of soils a pot experiment with wheat was conducted with soils gathered from different parts of the world (Europe, America, Australia) (VAN DER PAAUW, 1971). The result was similar also under these conditions (fig. 2).

The results appear to indicate that the process of phosphorus supply to the plant is closely related to the dissolution process of soil phosphate in an excess of water. The fact that no equilibrium was obtained in the 1 hour extraction implies that a rate process is involved. Higher values obtained with a longer duration of the extraction proved to he less correlated with crop response.

The merits of the method were also checked under farming conditions. Series of one-year field trials (197) were conducted in 6 different years. A comparison was made with the P-AL method used formerly. Using the visual response of the rather young crop, assessed and scored in a scale 0 to 10, or the P_2O_5 contents of the shoots as a measure of the response, the correlation with P-water values appeared to be satisfactory and appreciably better than with the P-AL values

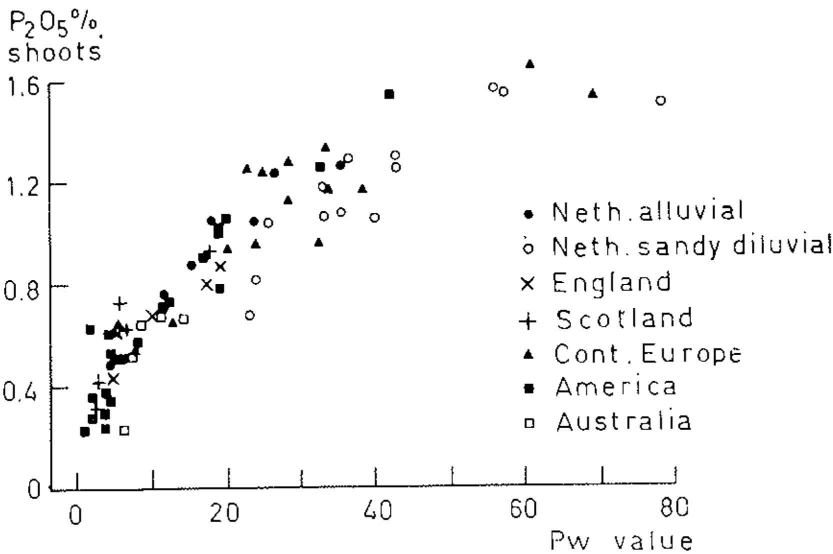
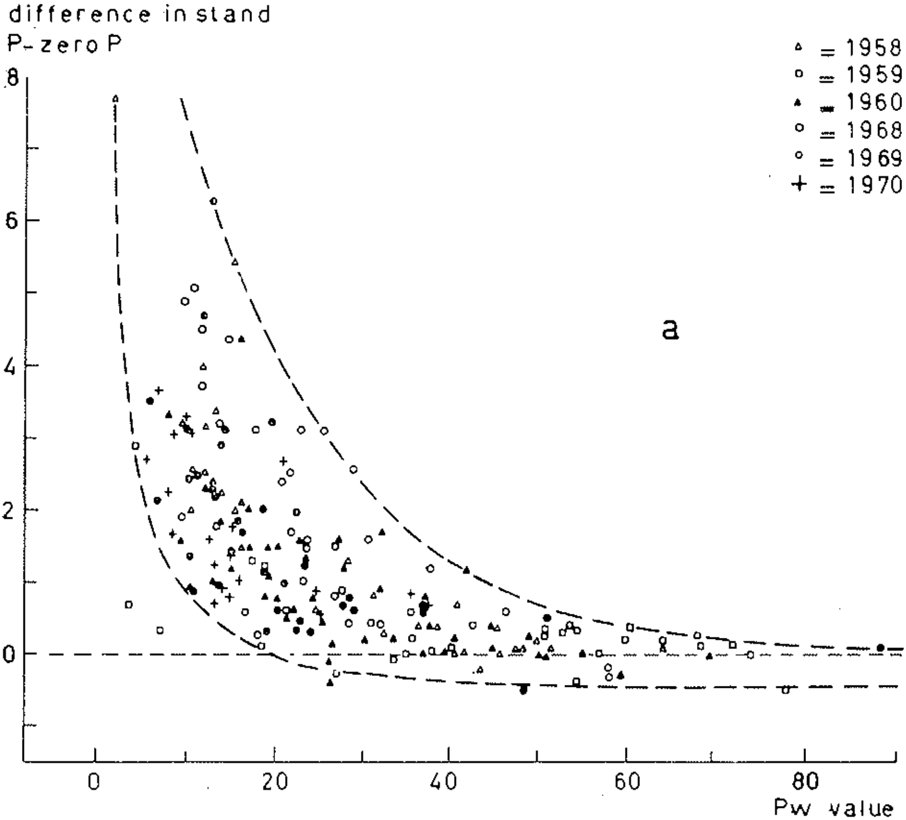


FIG. 2 — Pot experiment with wheat. Relation between Pw value of soils collected from different parts of the world and percentage phosphate in shoots.

(fig. 3). However, clear indications were found that the responses were higher under moist weather conditions. If allowance was made for the differences between years, the correlation with Pw value was much improved (fig. 4).

Using yield differences between crops amply dressed and the controls as a measure of the response, the correlations are generally lower (fig. 5). The lower correlation can be largely attributed to the variable weather conditions during the growing season and to the different climatic conditions occurring during the test years. As the P-water method has proved to be superior, it has replaced the P-AL method as a basis for fertilizing recommendation. An exception is still made for pastures.

The scheme used to recommend fertilizer rates has been


difference in stand
P-zero P
8
6
4
2
0
▵ = 1958
▫ = 1959
▴ = 1960
○ = 1968
◦ = 1969
+ = 1970
a
0
20
40
60
80
Pw value

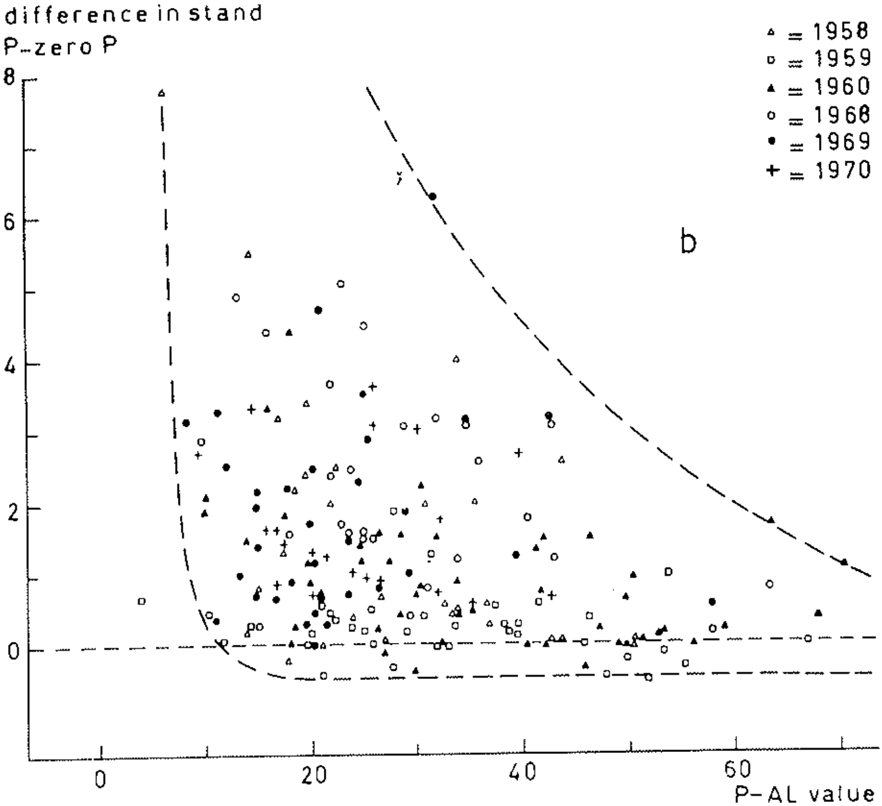


FIG. 3 — Field trials with potato in six separate years. Relation of Pw value (a) and P-AL value (b) with difference in visual score (scale 1 to 10) of potato plants dressed with approx. 300 kg P_2O_5 per ha compared with control plots, differentiated into years.

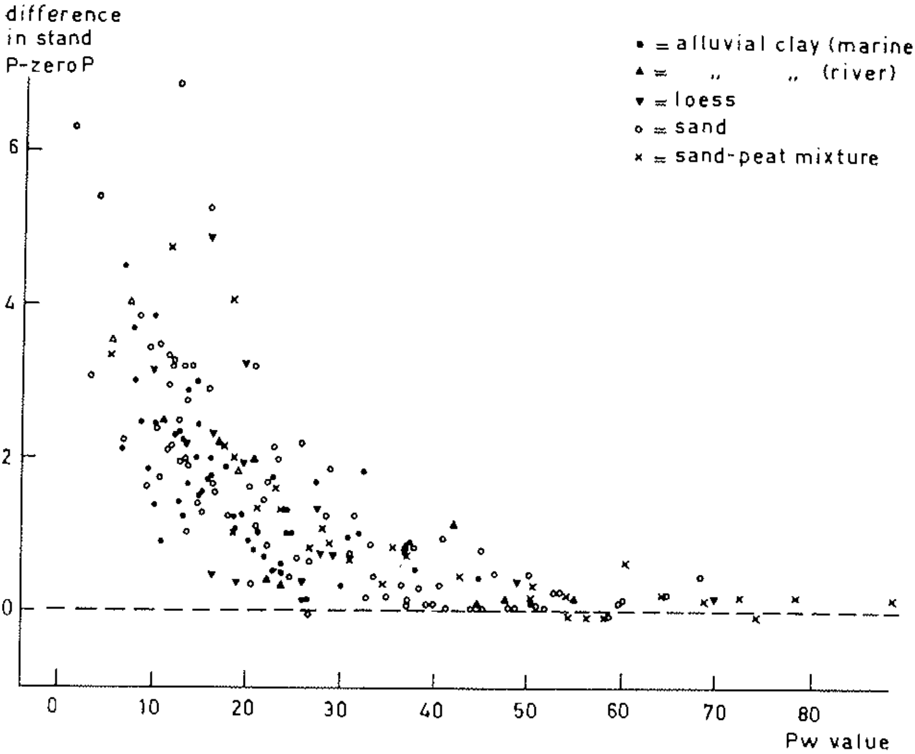


FIG. 4 — Same as fig. 3 (a) after correction for year differences.

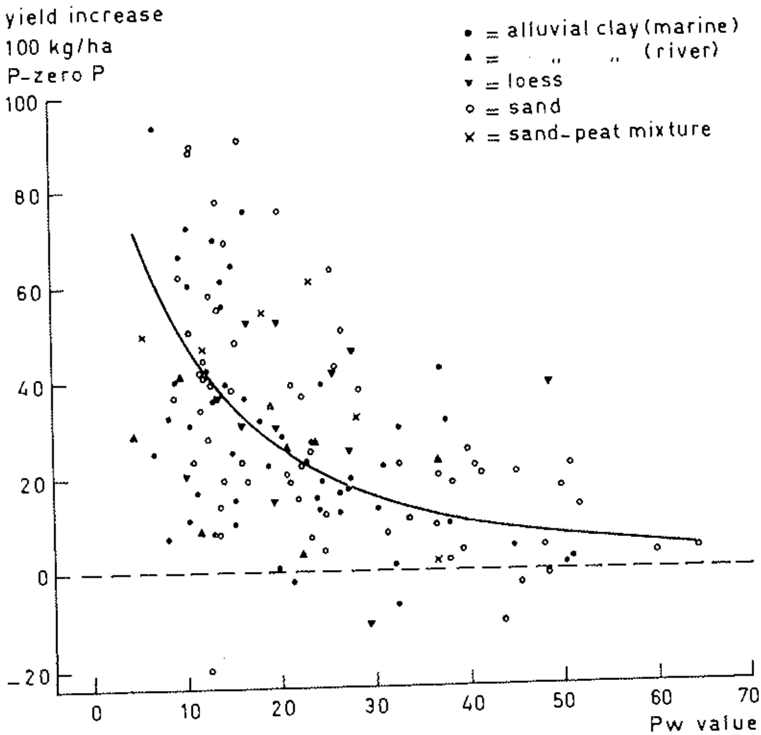


FIG. 5 — Same field trials as in fig. 3. Relation between Pw value and yield differences caused by ample P dressing (approx. 300 kg P_2O_5 per ha).

deduced from the results of the 197 potato field trials already mentioned. Rates recommended for other crops were deduced from a comparison between their responses and those of potatoes grown in the same rotation on longterm field trials. In all cases the rates of dressings widely varied. It must be remarked that potassium recommendations have been deduced in a similar way.

For each trial plot of the first group already mentioned, the rate of P dressing was plotted against the value of the yield and the costs of the fertilizer, both expressed in guilders (BAKKER and RIS). An increase of the rate of dressing is economical as long as the yield curve is rising more steeply than the line representing the costs. The optimum rate is indicated by the point of contact (fig. 6). Next, the Pw values of all trial plots were confronted with the optimum rates. With the exception of one extremely dry year (1959), the responses in the other years corresponded fairly well. The average is represented by fig. 7. It also appeared that the differences between soils are negligible. The important conclusion can be drawn that at all soil types of Holland the same phosphorus dressing can be recommended if the Pw value is equal.

In general P levels are more constant under cropping

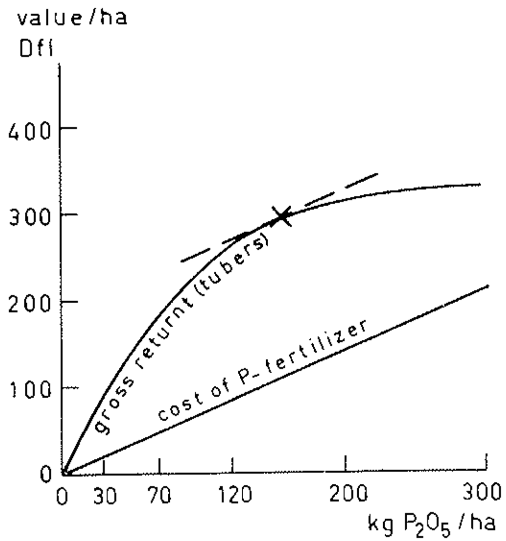


FIG. 6 — Assessment of optimum P dressing on a field trial. The optimum is represented by the contact point of yield curve and cost line (in the case represented = 160 kg/ha P_2O_5) (BAKKER and RIS, 1971).

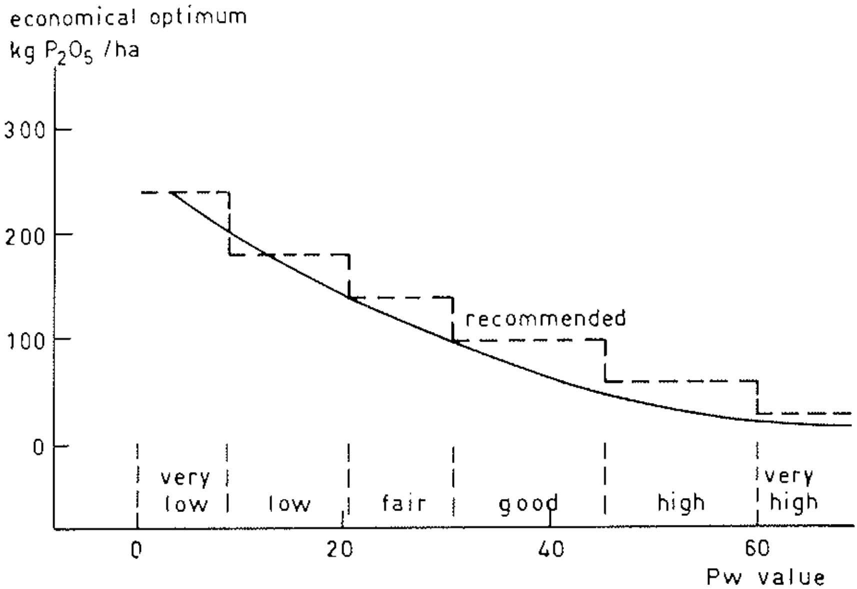


FIG. 7 — Scheme of recommendation for P dressing. Relation between Pw value and economically optimum yields. The dotted line represents the recommendations given (BAKKER and RIS, 1971).

conditions than K levels. Pw values are therefore also tolerably acceptable for fertilizer recommendation of the next crops grown in the rotation.

Schemes for fertilizer recommendation

Two schemes will be given for the recommendation of P and K dressing now being used. The second only relates to alluvial soils covering a wide range in particle size distribution. Crops are classified iu groups of different need.

TABLE 1 — *Scheme for P dressing (kg. P_2O_5 per ha).*

indication	Pw-value	potato maize vegetables	beets flax	leguminous crops, lays barley	cereals except barley seed-crops
very low	< 11	240	220	180	140
low	11-20	180	160	130	90
fair	21-30	140	120	90	60
good	31-45	100	80	60	30
rather high	46-60	60	50	30	0
high	> 60	30	20	0	0

TABLE 2 — *Scheme for K-dressing on alluvial clay-soils (kg. K_2O per ha).*

indication	K-value	potato onions vegetables	leguminous crops, lays other vegetables	sugar beets flax	cereals maize seed-crops
very low	< 11	380	280	160	110
low	11-12	330	220	140	80
fair	13-15	280	170	120	50
good	16-20	230	120	80	20
rather high	21-26	170	70	40	0
high	27-34	110	20	0	0
very high	> 34	60	0	0	0

The desirable level is indicated as "good". The rates recommended at this level are economically warranted and also meant to suffice for maintaining the K status of the soil at this level in the long run.

Especially for potassium it has recently been doubted whether the last requirement is fulfilled for all types of alluvial soils and for all crop rotations (PRUMMEL). Especially the low rates supplied to cereals, although being sufficient in itself, may result in a fall of K content below the level desired. It is now being studied how these changes are related to such factors as origin and nature of the soil (particle size, profile) and yields of the crops grown.

In case of phosphorus, the quantities of fertilizer required to increase the phosphorus level are connected with the fixing capacity of the soil and the leaching of phosphorus which occurs in some cases. It is to be hoped that a method which has recently been developed (by SISSINGH) to estimate the fixing capacity, on the basis of the water extraction method, may supply the additional information.

Since 1961 the advisory work has been completely mechanized. Recommendations are delivered by the computer. Loss of the desirable connections between farmer and Advisory Service has been avoided by sending duplicate reports to the Advisor, so that regional or individual factors can be considered.

Discussion and concluding remarks

Dutch experience with the method of soil testing over a considerable period of time (half a century) appears to indicate that the efficiency of fertilizing can be appreciably increased by adapting the fertilizer rates to the individually varying nutritional level of the sites. The profit will be highest when the latter is very diverse. If, on the contrary, this variation is small, the necessity of soil testing is less. In that case its use may remain restricted to the diagnosis of possibly occurring exceptional cases.

The question arises whether a comparable intensive use of soil testing must be advocated elsewhere. It must also be borne in mind that the creation of an effective system of fertilizer recommendation on this basis will be a very laborious task. If this is not fully understood, the output may be disappointing.

However, in those cases in which such a development is seriously aimed at, the Dutch example may be very helpful. As already said in the Introduction soil testing is undoubtedly applicable wherever agricultural conditions are more or less similiar to those in Holland. Soil test methods that proved to be effective here, might also be considered for application elsewhere. Under the conditions concerned it will, as a matter of fact, not be advisable to adopt those methods without a renewed evaluation of the method.

When, however, climatic and soil conditions are more deviating from the Dutch, it may be less probable that the methods developed here will be of great use, though the basic principles underlying the methods may still be of interest.

The Dutch approach may arouse the greatest interest among workers involved in a similar development. It specially concerns the general validity of the methods applied for the development of soil tests, the way to evaluate methods and the drawing up of fertilizer recommendation schemes on this basis.

In view of the serious shortage on the one hand and the enormous wasting of fertilizers and the injurious effect this may have on soil fertility on the other and their effects on the economy of crop production, it might still be attractive to start similar approaches as in Holland. In so far as much larger agricultural areas may be concerned, the prospects will even be more favourable than in Holland where the profits of this work will remain rather restricted due to the limited size of the agrarian area of this country.

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DISCUSSION

Chairman: J. D. Colwell

Primavesi

We are perfectly in accordance with you regarding soil testing methods, i.e. that the final decision as to its efficiency has to be made in the field, that in a similar way the recommendations of fertiliser rates must be learned from field trials conducted under conditions similar to those of practical farming.

And we also agree with what you said in page 4, and here we consider especially important what you said in paragraph 3 about soil structure.

You gave a very good explanation about the situation in the Netherlands. I aspire to organise a similar approach in Brazil but this is only possible in a future programme for lack of sufficient experts and the area being enormous.

Hauser

I have a small question here with regard to the phosphorus determination. You said that the best correlations and the most suitable methods were found with a very wide relation between water and soil, and it was a water extraction. In this case I feel that in the developing countries when we want to use this method there will not be sufficient phosphorus in the soil to make the determination.

VAN DER PAAUW

That is right. The method can be used in our country but I am not certain that it can be used on very poor soils, unless the accuracy of the analysis is improved.

HERNANDO

I should like to ask you about the results you present. You speak of a relation with the content in the stem and in the leaf, but not of the relation of the underground content in potato tubers. Do you know if there is some relationship between this potential value you give us and the potato yield?

VAN DER PAAUW

If there is a correlation?

HERNANDO

A correlation. Yes.

VAN DER PAAUW

We are using P contents of plant parts or colour of the leaves or anything else only to get an indication of the availability of the phosphorus. It is the same for potassium. Now in general my experience was that the correlation between soil K and potassium content of the leaves was usually slightly better than the correlation with potassium content of the tubers, and therefore we used it. We want a usable index and the correlation between potato yields and the potassium content of the leaves was found to be highest. Therefore the K content was the most appropriate index to distinguish between the effects of the three different factors, (exchangeable K, clay content and lime status). We can do the same with the yields but the variation of yields is generally larger than that of potassium contents of the leaf; for this reason the latter were used. But the results have always been controlled by yield determinations. However, it has not always been possible to establish similar influences of the three factors with the same evidence.

HERNANDO

I do not know whether you noticed it already. I believe van Diest of Wageningen published a paper, making a comparison between several techniques for the evaluation of phosphate in relation to the yield by studying different types of salinity soils, especially soils from the new-irrigated areas in north-eastern Spain. They get the best results with your technique and with the technique we are actually using in Spain, quite better results than with other wellknown techniques: the Olsen technique, the Bray technique etc.

VAN DER PAAUW

Of course there may be different correlations. I have told you that we have found the best correlation with a water extraction method. However not every water extraction method is as good. Large differences are due to the way in which the extraction is performed. If, for instance, the small ratio 3 is used instead of 60 (water-soil) then the correlations for each soil type apart are also high. But when different soil types are compared the results are different. An advantage of the present method is that the method is non-specific to soil type which is a very important point.

Hernando

I quite agree with you and say this paper presents very good results with salty soils obtained with your technique.

Van der Paauw

I do not claim that it is generaly applicable to the whole world, I only say that it may be applicable in those countries where conditions are approximately similar to those in Holland.

Saalbach

I am of the same opinion as Dr. Van der Paauw, that the soil analysis is a good method for controlling the phosphate and potash level of the soil. In Western Germany we also used these methods with success. But this is my question, why do you not respect the extent of the yield difference in your recommendations for the fertiliser dressing, we do so in Germany?

Van der Paauw

The last figure was showing the relation between the water method and yield differences, and the recommendation is based on this figure, not on the relation with P content of leaves. Those related to pot experiments. So we are doing the same in Germany and Holland.

Welte

The graphs shown on the relationship between exchangeable potassium and yield are also valid for many soils in Germany.

But there is one exception and that I would like to mention here, that are soils derived from loess material. Here the exchangeable potassium does not mean anything if there has been reached a level of about 6 to 8 mgs K per 100 gms soil exchangeable potassium. This level cannot be easily corrected by potash dressings because all potash goes to some clay minerals (Illite-type). These 2:1 clay minerals with expanding interlayers show the phenomenon of potassium fixation. If we take these soils, then the non-exchangeable potassium is also in relation to the yield. It comes out from these interlayers and fixation capacity will increase. It is very interesting that the critical level of exchangeable potassium will not change. The potassium going to the plant comes only from the non-exchangeable form.

VAN DER PAAUW

I do not completely understand you but I do not claim that the exchangeable potassium is really used by the plants. I only claim that exchangeable potassium content can be used as an index for this purpose, and what the reason for this is, is quite another question. I did not say that we can use this potassium index for all soils. We make a distinction in Holland for different soils. The formula shown is used on the alluvial dry soils but the recommendation basis is different for sandy soils, in this case it is based on the relation between potassium and humus content. For grassland again different formulae are used. I know this is not ideal but in this way we can work. Certainly the solution found for potassium is less ideal than that for phosphorus because the effects of interacting factors are also expressed by the method.

COLWELL

From this discussion, it seems to me that we might record agreement on the need for studies on factors affecting the interpretation of soil tests, and I think I am fair to say that Dr. VAN DER PAAUW has pioneered this idea. I remember reading a paper of his presented in 1952 in Dublin, which startled me, and a lot of other people thinking along these lines.

BLANCHET

Comme le docteur WELTE, et comme l'a indiqué aussi le docteur VAN DER PAAUW, je pense que ce problème de rétrogradation et de libération d'ions potassium par les argiles (ou même par les fractions granulométriques de taille supérieure à celle de l'argile, c'est-à-dire des fractions limoneuses ou même sableuses, en particulier dans des sols d'origine granitique ou schisteuse), est extrèmement important. J'ai également observé souvent ces phénomènes de fixation et de libération d'ions potassium, dont la teneur en potassium échangeable du sol rend très mal compte, et je crois que dans les cas de sols comportant soit des argiles illitiques, soit des minéraux micacès en cours d'altération, ces phénòmenes présentent une très grande importance. Malheureusement, les méthodes susceptibles de tester ces problèmes sont assez délicates; il y a bien sur le tetra phénylborate de sodium ou des réactifs de ce genre, mais il me semble qu'on doit surtout raisonner en tant que possibilité pour les ions potassium d'atteindre les racines. La aussi, les phénomènes d'échange et la capacité d'échange jouent également un grand rôle, ce qui fait qu'on n'a pas toujours de très bonnes correlations entre les tests de potassium libérable et l'alimentation des plantes. Je crois que le docteur VAN DER PAAUW est d'accord sur cette conception.

As Dr. WELTE and also Dr. VAN DER PAAUW have indicated, I think that this problem of retrogradation and liberation of potassium ions by clays (or even by granulometric fractions of larger size than that of clay, i.e. of silt or even sandy fractions, particularly in soils of granitic or schistous origin) is extremely important. I, too have often observed these phenomena of fixation and liberation of potassium ions whose exchangeable potassium content of the soil gives a very bad account, and I believe that in cases of soils bearing both illitic clays and micaceous minerals in the course of alteration, these phenomena are of greatest importance. Unfortunately the methods susceptible of testing these problems are quite delicate; there is certainly the tetra sodium phenylborate or the reactives of this kind, but it seems to me that one ought to argue especially about the possibility for the potassium ions to reach the roots. There the phenomena of exchange and the capacity of exchange likewise play a big role so that there will not always be very good relations between the tests of liberable potassium and the plant nourishment. I daresay that Dr. VAN DER PAAUW agrees with this conception.

PESEK

I have a comment and a question. The comment is: it is my feeling, and I hope one that I share with most people here, that a good method for assessing soil nutrient availability is a critical condition to moving toward a scientific agriculture in any country, especially if it relates to the application of fertilizers. The question is this: in case of potassium we have found that its fixation and/or release is an important factor in assessing the value, especially of the contribution of the subsoil, to the potassium nutrition of crop. To get around this problem we have adopted the procedure of keeping the soil field moist prior to analysis and this has the effect of causing the subsoil potassium supplies to remain low as they really are when they are correlated or calibrated in pot culture experiments. It was not clear from your paper whether your procedure does or does not leave the soil in field moist condition or whether the soil is dried before extraction for potassium, and what is your extraction solution?

VAN DER PAAUW

The extractant is hydrochloric acid (HCl.sn). We do not use premoistening with potassium, we have introduced this in the determination of phosphorus recently. It might be that we must try this also with other methods. It has clearly improved the determination of phosphorus. Without premoistening correlation with crop responses differ at different soil types, but the slopes of response curves are equal when the sample is premoistened for 22 hours before the extraction.

PESEK

Our experience indicates that the effect of air drying is greater on the availability of potassium than its effect on the availability of phosphorus. We find that long storage and warming effects are greater for phosphorus than long term storage and dry warming for potassium, in other words heating affects the phosphorus availability index more than it does for potassium.

COLWELL

I might add in connection with this pre-treatment of samples whether they should be dried or kept moist, we ran into a problem recently in Australia. We were studying phosphate in the glasshouse and one soil behaved in quite an extraordinary manner, and eventually we tracked it down, we had got an enormous release of manganese due to drying. We did not want to study manganese but it was manganese release that spoilt our pot experiment. So one has to be on guard after drying a soil.

VAN DER PAAUW

It might be of interest to Mr. PESEK that already rather slight differences in the humidity of the air in which dried samples were stored, considerably influenced the final result.

HERNANDO

Our experience in relation to this is that with potash we got even more different results than with phosphate when we dried the soil samples. With phosphate we have found not much difference but with potash a very large one.

PESEK

We have seen experiments in which there has been demonstrated a clear interaction of nitrogen applied as fertilizer and water supply or moisture supply, these have been demonstrated by Domingo and Laird with wheat in Mexico and published there, and in some of our experiments in the western corn belt we find that moisture supply and nitrogen also interact. This brings me to the point of saying that it is critical to keep in mind what moisture supply is, it is not necessarily equivalent to rainfall, keeping in mind the conditions in the corn belt where our rooting zone is approximately 5ft deep to 6ft almost 1½ to 2 meters and the available moisture if the root zone is filled to field capacity, is adequate to produce approximately one half of a good maize crop before the seed is planted. In one experiment which I recall clearly, we observed the effect of nitrogen as being one of « water sparing » so to speak, and after further probing of the soil we found that the fertilized corn exploited the moisture down to a depth of approximately 2 meters while the corn without fertilizer exploited the soil moisture down to only one meter. The following year, when the subsoils were not recharged with moisture before maize planting, there was approximately the same amount of precipitation, but there was no effect of nitrogen while in the previous year the effect of nitrogen was tremendous.

COLWELL

This question of water-nitrogen interaction seems to be something we have all been thinking about. Perhaps this is something we might agree needs quite a lot more research.

HERNANDO

This is a comment in relation to the paper of Dr. WELTE. In regard to the organic matter, it would be interesting to maintain the organic matter following the method I indicated yesterday. In tropical conditions Dahr showed that it is not necessary to increase the quantity of nitrogen when you leave the straw in the soil. His theory is that nitrogen is not needed for decomposing the straw because some nitrogen is fixed by a photochemical process. I do not exactly know that but my experience in Spain, not in tropical conditions, is that we need not increase the nitrogen in the soils when we leave the straw on the surface during the whole summer, not completely down in the soil, and at fall mix it with the soil on the top. This material will be decomposed during the growing season of the crop, and we did not deem it necessary to increase the nitrate of the ammonium sulphate during the last 15 years, and this is quite good. I remember, when I was in Brazil with Professor PRIMAVESI that there they had good results also without increasing the nitrogen applied to the soil. This is very important because the fertilizers with nitrogen are more expensive than other fertilizing material, and in underdeveloped countries it is very interesting to use such a technique. No wonder the theoretical aspects are not very clear.

WELTE

It is very complicated indeed but what is the principle? If you put straw into the soil, from the chemical point of view that is a material of very wide carbon-nitrogen ratio, let us say about 80:100:1. By micro-organisms attack the carbon decreases and nitrogen will be fixed. (Biological and biochemical fixation). The micro-organisms themselves have a very narrow carbon nitrogen ratio, bacteria about 5:1, and fungi nearly 8-10:1 and you see the ratio becomes more in favour of nitrogen. During this process the available nitrogen in the soil will be incorporated in the metabolic reactions. The atmospheric nitrogen only can be brought into this process by microorganisms in lower plants which are able to fix atmospheric N_2. It may be that some inorganic N-compounds come out of the atmosphere by precipitation (N-oxides, Ammonia). But nevertheless, if we consider all these processes the yield will be limited by the amount of nitrogen available in the soil during the growing season. You cannot take more out of the system than there is in the system.

HERNANDO

Our experiences are surprisingly different. I don't know where the nitrogen is coming from, but we do not have to apply more nitrogen than normal. The only difference I try to explain here is: we leave the straw like that, we do not put it in completely, and with this method it is not necessary to apply higher amounts of ammonium sulphate, which is only needed when we put the straw approx. 5 cm deep into the soil. In this case the straw remains near the surface and you can see the straw when going to the field. We saw that this material had decomposed during the whole growing season until spring-time, and with this method there is no need to apply a higher amount of nitrate or ammonium sulphate to the wheat than usually. I do not know if this is because there is a photo-chemical process or a microbiological one. I have no real explanation, but I think it is a very important point for practical purposes in developing countries.

BRAMAO

A propos of the method of increasing nitrogen in the soil proposed by Professor DAHR from India. He claims that his method is very successful if basic slag is applied. I believe he says that if you do apply basic slag after burying the straw, then there is no need to apply nitrogen. Am I not right?

HERNANDO

I try to explain something in relation, to that. Our soils are very high in calcium carbonate. You see the soil with which we made our experiments contains from 30 to 40% of calcium carbonate, therefore we apply only superphosphate and we get the same results as DAHR using natural rock phosphate or slags.

In tropical areas where conditions are such, that there is a low level of calcium, they ought to apply calcium phosphate liberally, but we found that it was not necessary in our conditions because we have a very high level of calcium carbonate. Thank you, but I did not present the whole story and this is a very important point.

WELTE

I think both aspects of the story are true. At first I repeat once more, you cannot take out more than there is in the system. Secondly I did not mention the velocity of the decomposition rate. This is very important. If the process of straw decomposition is not finished before the vegetation period begins, a strong competition comes into existence between the microbes and the higher plant nitrogen. On the other hand if the ecological conditions are in favour of a high decomposition rate so that the straw has been transformed into humus of high quality (N/C = ratio about 10-12 : 1) before the growing season starts, the mineralization comes into being as a benefit for the growing plant. Mineralization means that now the nitrogen comes out from the changed organic material. The amount depends on the quantity and quality of humus and mainly on the rate of the mineralization. If you apply basic slag or liming material to the straw on the surface of the soil the activity of micro-organisms will be strongly accelerated — supposing humidity is sufficient, especially the bacterial will find the best conditions for their work. Basic slag with its high content of lime (about 35-40% C or O), besides phosphorus and minor elements, is an excellent fertilizer to increase bacterial activity, the activity of atmospheric N-fixing bacteria included. We have to study this problem very carefully because it is strongly influenced by the local climatic conditions, the culture practices included.

HERNANDO

It is not that because after fifteen years we have a higher level of organic matter in the soil than before and the nitrogen content is also higher than before. This means that the nitrogen must come from another place because the yield is higher than the control plot. This is a surprising result, but I think it is true because results are results.

LATKOVICS

Much has been said about the environmental factors which considerably influence the efficiency of fertilization. Now, let me point out on the basis of our results that in some instances, so in Hungary the well-known low fertility of salt affected soils could markedly be increased by irrigation and fertilization, and we obtained good hay yields on them.

The experiments were carried out on heavy-textured solodized solonetz, well provided with organic matter and plant nutrients. This soil had disadvantageous chemical, physical properties and water regime. In our experiment the effects of increasing nitrogen doses were studied on pastures and meadows with and without irrigation. The effect of the treatments manifested itself throughout the growing period of the plants. As a response to irrigation and fertilization, some changes took place in the composition of the plant associations. So, the percentage of the more valuable grasses, as meadow foxtail (Alopecurus pratensis), meadow grass (Poa pratensis) and perennial rye grass (Lolium perenne) has increased. At the same time, due to regular irrigation, the leguminous plants have recently become dominant on the untreated plots and on those receiving 54 kg N/ha.

When evaluating the data, the highly positive effect of irrigation was established. The hay yields increase in the first and subsequent years after the application of increasing calcium nitrate rates, under both irrigated and non-irrigated conditions. After the third year, a considerable yield increase could be observed on the irrigated control plots and on those treated with 54 kg N/ha. In the last years, these increases were nearing or sometimes even surpassing the yields reached as a response to heavy N-dressing. This phenomenon may be explained by the fact that, owing to regular agrotecniques and primarily to irrigation, the nutrients were mobilized in the soil and a considerable change has been brought about in the composition of plant associations of the grassland, the dominance of leguminous plants has increased and this resulted in higher yields of hay with valuable nutrient contents.

FRIED

Prof. BLANCHET and myself are chairman and secretary of the session on the final discussion, the general conclusion on Friday afternoon, and we would like to have some help in drafting something for discussion during that afternoon. We have suggested a committee consisting of BORNEMISZA, BRAMAO, PESEK, RUSSELL and WELTE. In addition to those people who I see are willing and available, we would like the help of any of the others of you who are willing. We would like you to hand over to us in writing any suggestions or remarks that you would like to see included in the conclusions of this meeting. I think people here are ready and willing to type anything at any moment that you hand it over, so if it is rather a long thing you may want to get it typed first, but in any event, if you give it to anybody on this committee they will take it from there. If there are any other suggestions as to what might be done I would certainly appreciate hearing from you.

ARATEN

I would suggest that the people who wrote down their talks they gave us, should hand over their extracts to Prof. FRIED and Prof. BLANCHET. This would be very helpful in getting the extracts of all the papers.

FRIED

Well, we have abstracts of all of the papers, but it would be helpful if authors would summarize some of the important things they think came up during the discussions on their own paper. That might be helpful for the committee to consider in relation to drafting the conclusions. Can I ask all of you to summarize, please, any of the important points that you think might want to be included in the conclusions that came out during the discussions of your individual papers.

COLWELL

Of course we have to be careful that we don't have everything: we want some highlights. Does someone have a specific point on this matter that Dr. FRIED has raised? If not, I think Prof. THERON had a comment to make.

THERON

I was just thinking of the problem that Dr. HERNANDO and Dr. WELTE were argueing about. Surely you have all the necessary conditions there for nitrogen fixation by azotobacter. You have the organic matter there to provide the needed energy to bind the nitrogen from the air and you have got the lime there to neutralise whatever acids they may produce.

PRIMAVESI

Referring to the paper of Prof. WELTE, I agree with what you mention in your paper, page 3, paragraphs 4 and 5 and paragraph 1 on page 4. You showed very well the situation in the tropics. In the last page you mentioned the importance of the education of the farmer for the success of the extension service. I think it is a very important point.

HERNANDO

My question is to Prof. VAN DER PAAUW. We found in the areas where we use a high level of fertilizer for intensive agriculture, great trouble in finding the method to get the correct interpretation of the soil analysis to give the right amount of fertilizer to apply to the next crop. Do you have problems like that in

Holland? After we had made the soil analysis in areas where the farmers use very high amounts of fertilizers, we found difficulties in getting the correct interpretation of the soil analysis to know the level we need to apply next year for the next crop. The only thing I would like to know is if you have the same problem or if you can give me a suggestion or some method to resolve this problem. The problem is in areas with very intensive agriculture in the east of Spain where we apply a high level of fertilizer, like you do in Holland, but I said we found that for us it is very difficult to get a good correlation between the soil analysis in one year and the need of fertilizer for the next crop. Have you a problem like that in your country and how do you resolve it? That is my question.

VAN DER PAAUW

In this respect very often none or only weak correlations between soil tests and crop responses were found. It has been a very long way from bad to more efficient methods. Therefore, it is very normal that no correlations between soil tests and crop responses are present. You have to find the improved methods yourself, though this is not so easy.

PESEK

I think that there are many countries in which intensive agriculture has gone on for some time, where test levels for fertilizer elements in the soil are so high that nothing is needed and the simple answer is: do not add anything. I suppose that this is most likely to occur on soils growing potatoes, tomatoes or other high value crops. I believe that the place of tissue analysis in all of its various forms becomes important as a refinement of agricultural practice after the use of the soil test has been exhausted in terms of predicting needs. At this time, a base level or an optimum level of fertility has been established and if an imbalance in the nutrient status of your crop remains, you do analyse the tissue and use the results of the analyses for the following year.

HAUSER

I just want to make a final point. I think there are some ideas which are not quite correct about soil testing calibration. The soil analysis is not difficult but the calibration is, and that is what Mr. HERNANDO has said. In any one country where a good soil calibration is done it has taken 40 years or more for that. Let us keep that in mind. Unless we find a quick method which would then be new, we have to think in terms of 20, 30 or 40 years. It is easy in countries where this has been worked out but in countries where no correlations are worked out you cannot do it with the present methods in a shorter time, as Mr. VAN DER PAAUW said. The Netherlands started in the 1930's. I say that only to prevent a misunderstanding among us regarding the calibration of soil tests.

IV

EFFETS DES FERTILISANTS SUR LA QUALITE DU RENDEMENT

EFFECT OF COMPLETELY EQUILIBRATED FERTILIZER ON THE PRODUCTION OF PLANTS CULTIVATED ON LARGE SCALE

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The mineral fertilizer, by influencing strongly the plant productivity, represents together with the irrigation certainly the most powerful means at the disposal of man for improving the production. But perhaps it is not useless to recall that the agronomical tests with mineral fertilizer are more often restricted to taking into consideration the classical fertilizing elements: nitrogen, phosphorus and potassium. It is also useful to emphasize that most of the agronomical tests are limited to establishing an eventual relation between the quantity of these fertilizing elements and the *quantitative production of that part of the plant which interests the agriculturist.*

These considerations are very useful when the ambition of the experimentalist does not go beyond the intention to draw from his tests a conclusion of empiric character applicable to the particular local situation in which he conducted his experiments. In fact, any generalization remains dangerous and nevertheless in the majority of these experiments, one desires to give greater importance to the results. Let us take up our first observation.

For this paper in French language see Appendix Nr. 3.

Nature and number of the fertilizing elements taken into consideration.

Nobody denies that major elements different from N, P and K as well as minor elements influence the plant production. To abide by the former, we begin to speak of the influence of Sulphur, Calcium and Magnesium. There arises the question why so many recent trials, sometimes on very large scale, are only based on fertilizers, sometimes called "essential": nitrogen phosphorus, potassium.

Undoubtedly this is partly due to the idea deeply rooted in many minds, that these three elements are indeed essential. This conviction rests partly on the fact that the factorial method mostly used to put in evidence any interactions, often leads to minimizing those where other elements intervene which seems to justify that these latter are neglected in many trials. Besides, this same factorial method, for being reasonably applied to a larger number of fertilizing elements, without prejudice as to their interest and their importance, requires an experimental extension beyond the real possibilities. There is also that other methods, like the MITSCHERLICH method, permit to study the effect of the fertilizing elements one by one, and that in these conditions the elements different from N, P and K seem to exert indeed a much lesser effect than these.

It may be that in the presence of the material difficulties one forgets rather that the extrapolation with the factorial method is particularly dangerous, and that the negative conclusions where it leads to (such as the negligible character of certain interactions), are only valid in the situation explored, and within the limits (of the dose, for example) of the experimentation. Any conclusion — especially negative — drawn in different conditions or from fertilizer doses not experimented requests confirmation.

Therefore a method that does not offer an exaggerated experimental extension and that is not susceptible of certain extrapolations would be particularly valuable. We return to this later after having taken up the subject of our second observation.

Quantitative production and qualitative production.

In the first place it must be repeated that the production normally envisaged is the production of a part of the plant, namely the one that interests the agriculturist. Now if the quantitative relations expressed or shown by the experimental methods, have a biological sense, there must indeed be admitted that the nutrient factors, more than others, must affect the whole plant, and within it, they may affect the relation of weights between parts of the plant which finally leads to the quantitative production of one of these parts. But if such is the process, the simple observation of the final result transforms the result of a hidden process which the method is unable to show.

Furthermore, within this production of weights it must be considered that the physiological action of the nutrient substances, which commands the final result, does it through their intervention in the metabolism or other processes which, not only lead to a global production of weight but also to an infinity of morphological situations, to an infinity of chemical compositions, in short to characters which, besides the weight of the crop, define *its quality*.

Indeed there are already certain indications, such as the richness in sugar of the sugar-beet, according to which the nitrogen dominates or not in the fertilizer etc... These, however, are stricktly limited indications and which, once more, are never connected with the complete composition of the nutritional environments. It is the same with the extreme aspect which transforms the morphological action; it is the symptom of deficient alimentation, always attributed to the action or to the deficiency of only one nutrient substance.

Experimental possibilities for studying the effect of a complete alimentary environment.

We have elaborated an experimental method permitting to determine the composition of a compound fertilizer including the six major elements in the best possible proportions (optimum fertilizer). In order to know the test dose of this fertilizer, there are sufficient six or seven experimental treatments and one control. To infer from them the composition of an optinum fertilizer different from the test dose (either higher or lower), six more treatments will be enough. With twelve or fourteen treatments, one solves a problem that no other method permits to solve with this insignificant experimental extension.

This method is in detail explained in HOMÈS and VAN SCHOOR [4, 6, 7] and perfected by HOMÈS and VAN SCHOOR [8 and 10]. We cannot repeat it here entirely. We recall, however, that the experimental treatments are all *complete* treatments as concerns the major elements (N, S, P, K, Ca, Mg), which all correspond with the same total dose expressed in chemical equivalents and which differ among one another in that each one is characterized by the dominant proportion of an element, all other elements being present in a different proportion, called "weak". Moreover this method is adaptable, if one wants to limit it, in case of a fertilizer where only the elements N, P and K are in agronomically justified proportion.

We have called this method "Method of Systematic Variants". It is amply controlled by experience. We are giving here a succinct explanation of it and an example of calculation.

Succinct explanation of the method.

If we call V the dominant proportion and v the weak proportion, there is once V and as many times v as the total of elements taken into consideration.

For example, if one wants to prepare a fertilizer containing two nutrient substances, there will be $V+v$ in the constant sum. If we give to this sum the value of 100%, we shall have $V+v=100$ (in per cent). There is thus occasion for utilizing two experimental treatments, one in which the first substance is in proportion V and the other in proportion v within the total of $V+v$.

Likewise, if three substances are taken into consideration, there will be three treatments. In the first one, one of the substances is in proportion V and each one of the others in proportion v within the total of $V+v+v=100\%$. In the two other treatments, each one of the two other substances is respectively present in proportion V.

In the method chosen on the agronomic plan,

v_2 presents the value of 20% and V 80% if two substances are taken into consideration

v_3 presents the value of 13% (there is twice v_3) and V 74% (the sum being $74+13+13=100\%$)

Likewise, one has successively:

$v_4 = 10\%$ and $V=70\%$ (sum $70+(10\times 3)=100\%$).

$v_5 = 8\%$ and $V=68\%$ (sum $68+(8\times 4)=100\%$).

$v_6 = 7\%$ and $V=65\%$ (sum $65+(7\times 5)=100\%$).

This is the most complex case which permits to solve the problem of the most equilibrated fertilizer for six major elements at a time. A certain latitude is possible around each of these values, whereby the agronomical result does not present the precision of a physiological result.

In these conditions if y_1, y_2, etc... are the yields obtained with the different treatments, y_1 the control yield, one obtains the proportions to be respected in the equilibrated fertilizer with the following calculations:

a) Two nutrient substances taken into consideration

proportion of the first $$\frac{y_1}{y_1 + y_2}$$

proportion of the second $$\frac{y_2}{y_1 + y_2}$$

b) Three nutrient substances taken into consideration

proportion of the first $$\frac{y_1}{y_1 + y_2 + y_3}$$

proportion of the second $$\frac{y_2}{y_1 + y_2 + y_3}$$

proportion of the third $$\frac{y_3}{y_1 + y_2 + y_3}$$

P.S. If one excludes the values indicated above for v and V, there must be put in a correctif term as follows:

$$\text{particular proportion} = \frac{y - \mathrm{T}}{\Sigma ny - n\mathrm{T}}$$

c) The value of T is indicated in the tables, but with an excellent proportion there may be written:

$$\mathrm{T} = 0{,}65\ ym \qquad \text{with } ym = \frac{\Sigma y}{n}$$

Only one calculating example will be given in order to enable the uninformed reader to realize the simplicity of the calculations.

Experiment with the Sugar-beet.

Subject:

One tries to find the best Nitrogen-Phosphorus ratio in the compound fertilizer at the rate of 25.000 equivalents per hectare (experiment in open field).

Treatments:

1) the control without fertilizer (yield y_t)

2) the parcels receiving the mineral fertilizer at the rate of 25.000 chemical equivalents per hectare, suppose 2,5 equivalents per square meter. The two treatments, similar as regards this dose, include also both 1,34 equivalent of the "invariant" elements divided as follows:

$$\left.\begin{array}{l} 0.17\ S \\ 0.53\ K \\ 0.47\ Ca \\ 0.17\ Mg \end{array}\right\} = 1.34 \text{ (and } 1{,}16 \text{ of } N+P)$$

The two treatments differ from each other as follows:

— treatment 1 (N dominant) (yield y_1)

v_2 = 15% of the sum N+P (the ideal percentage was not realized; the corrective term will be used)

V_2 = 85% of this sum.

This gives

$0{,}15 \times 1{,}16 = 0{,}17$ equiv. P

$0{,}85 \times 1{,}16 = 0{,}99$ equiv. N

— treatment 2: symmetric to the foregoing

0,99 equiv. P

0,17 equiv. N

The following table summarizes the composition of the fertilizer applied in the two treatments.

Dominance		Treatment 1 N		Treatment 2 P	
Total sum		2,5		2,5	
Part of the invariant		1,34		1,34	
In this invariant	S		0,17		0,17
	K		0,53		0,53
	Ca		0,47		0,47
	Mg		0,17		0,17
Part of N + P		1,16		1,16	
In this part	N		0,99		0,17
	P		0,17		0,99

(P.S.: The choisen dose corresponds approximately with a quantity of a ton per hectare).

In these conditions, for the production of roots are obtained:

$$y_i = 29{,}6 \text{ (tons/hectare)}$$
$$y_1 = 51{,}8$$
$$y_2 = 34{,}1$$

The calculations are limited to the following:

$$y_m = \frac{51{,}8 + 34{,}1}{2} = 42{,}95$$

$$T = 0{,}65 \times 42{,}95 = 27{,}9$$

This gives:

Optimum proportion of N/N + P:

$$\frac{51{,}8 - 27{,}9}{51{,}8 + 34{,}1 - (2 \times 27{,}9)} = \frac{23{,}88}{30{,}06} = \cdot 79 \ (79\%)$$

Optimum proportion of P/N + P:

$$100 - 79 = 21\%$$

Conclusion:

On the whole N + P present in optimum fertilizer, this one must contain:

79% N
21% P

This conclusion is valid with the experimented dose.

If there had been experimented *two doses* (for instance 1.250 and 2.500 equivalents per square meter), there would have been an optimum N/P proportion no matter what other dose.

Thanks to its simplicity the method permits easily to study many other manifestations of the plant than the one regarding the weight, i.e. the qualitative and phytosanitary manifestations.

As concerns the results, we shall limit ourselves in the present paper to interesting cases of plants cultivated at large scale but it may also be pointed out that the method was successfully applied to a case as different from the former as the culture of Penicillium with regard to the production of penicillin.

Experimental data of the effect of fertilizers on the plant production.

The results quoted in this paper were obtained by different collaborators and researchers in the Laboratory of Plant Physiology of the Brussels University and by some of them on mission in foreign countries. These data are far from representing the totality of those in our possession and which are actually under study. However, they seem to us sufficient to show that the method which we recommend permits to obtain precise and many data, that it achieves particularly a *qualitative aspect* of the plant production and that it is possible as from now on to draw indications from it useful for the practice.

The "optima" of the fertilizer composition are always intended in *percentages* of the total N + S + P on one side; K + Ca + Mg on the other. They are also intended for concentrations or quantities expressed in chemical equivalents and not in weights of the different elements, neither in radicals such as P_2O_5, K_2O. An equivalent is counted per atom for N and K; two equivalents per atom for S, Ca and Mg; three equivalents per atom for P.

Having specified this, the points which we try to touch are the following:

1) Effect of the chemical fertilizers on the weight production of the plants.

2) Effect of the chemical fertilizers on certain qualitative characters of the plant production.

I. Effet of the fertilizer on the weight production of the plant.

Our works permitted us to come across with the important question which consists in knowing whether the differences in exigencies revealed by experimentation are mainly due to the species cultivated or to other factors.

1. *Specific character of the alimentary exigencies of plants cultivated in the same environment.*

In order to avoid the interference due to the fact that the apparent exigencies may be different according as the parts of the plants are different themselves, we consider here the case of the production of the *total green vegetative material,* be it that this material is normally the subject of a crop (forage), be it that, on the contrary, it is abandoned (foliage). The environment is the whole of the conditions maintained uniform and constant and includes also the duration of the experiment; the alimentary exigencies might vary with the duration of the culture.

We are giving here a few results.

Environment	Plant	Anionic optimum			Cationic optimum		
		N	S	P	K	Ca	Mg
I	Maize forage	70	25	5	39	32	29
(quartz or	Tobacco	77	19	4	36	32	32
crushed glass)	Lettuce	80	17	3	41	37	32
II	Maize forage	62	15	23	37	33	30
(sand + soil C)	Tobacco	64	17	19	38	30	33
III	Maize forage	66	19	15	37	34	29
(sand + soil A)	Tobacco	64	24	12	36	29	35
IV	Valerian	54	24	23	37	36	27
(crushed glass)	Tobacco	55	24	21	32	35	33
	Lettuce	53	28	20	33	34	33

Although it can here only be a question of a few examples and that the generalization may be dangerous, one cannot fail to observe that in equal environment the specific differences (for crops that are all foliage) are very small. It might be then that the alimentary exigencies, in equal environment, be the same for very different species whose harvested part is of the same nature.

This suggests the following comparison.

2. *Alimentary exigencies of identical crops in different environments.*

a) *Potatoes.* Each of the "situations" corresponds to a different field designed by letters permitting the reference to our data. All these fields are situated in Belgium. The symbol E refers to the experiences with artificial substrate.

	Optimum			Optimum		
Situation	N	S	P	K	Ca	Mg
1 (C)	38	31	31	48	21	31
2 (C.F)	45	24	31	46	24	30
3 (C.C)	40	28	32	33	37	30
4 (O.P)	49	31	20	100	0	0
5 (O.R.C)	30	32	38	27	31	42
6 (O.R.C)				29	32	39
7 (A.C)	49	28	23	41	28	31
8 (S)	44	31	25	33	30	37
9 (V.O)	37	30	33	34	33	33
10 (U.E)	59	20	21			
11 (U.E)	62	25	13	28	38	34

One states that the diversity for one and the same plant, and according to the situations, exceeds the diversity manifesting for different plants in one and the same situation.

b) *Maize* (grain) in central Africa (field situated in Zaire, Ruanda and Burundi). Situations indicated by references [5].

	Optimum			Optimum		
Situation	N	S	P	K	Ca	Mg
1 (V)	43	29	28	25	39	36
2 (B)	32	30	38	39	27	34
3 (K)	61	25	14	29	36	35
4 (L)	35	35	30	34	33	33
5 (Ky)	48	28	24	32	36	32
6 (Ka)	47	26	27	35	26	39
7 (N)	31	33	36	30	34	36
8 (H)	30	30	40	28	39	33
9 (R)	22	30	48	38	30	32
10 (Ki)	23	35	42	26	40	34
11 (Li)	42	24	34	38	33	29
12 (Bo)	34	29	47	39	29	32
13 (D)	37	28	35	34	36	30
14 (G1)	21	43	36	32	36	32
15 (G2)	53	28	19	21	31	48
16 (G)	27	36	37	35	28	37
17 (M)	33	33	34	35	33	32

From these examples it appears evident that the differential effect of the situations (soil and climate) is important: the optimum of nitrogen varies from 21 to 61% for example.

3. *Variations of the alimentary exigencies according to the organs harvested.*

A few examples will illustrate this problem. The optima of the exigencies are all expressed in the order N-S-P then

K-Ca-Mg, the data expressing percentages within the two partial totals.

	N	S	P	K	Ca	Mg	
a) *Valerian*							
leaves	53	24	23	37	36	27	
roots	27	38	35	37	23	40	
b) *Sugar beets*							
leaves	65	18	17	32	31	37	
roots	41	32	27	31	31	38	
c) *Tomatoes*							
leaves	50	24	26	20	42	38	
fruits	40	30	30	24	38	38	
d) *Cotton tree*							
leaves + stems	62	20	18	28	46	26	
grains (+ cotton)	80	15	5	11	77	12	
(Zaire) field in Bambesi	63	15	22	33	47	20	A/C = 1,3

4. *Importance of the effects put in evidence by the method used.*

If one refers the effect observed with the best variant experimented — effect which is for the most inferior and never superior to the one of the optimum — to the control yield or to the general average for the culture with artificial substrate, counted for 100%, we observe the following results.

On artificial environment

Valerian	129%	of the general average
Oat	123%	
Tobacco	152%	
Potatoes	179%	

In real soil (field)

Potatoes	124 to 194% of the control
Cotton tree [3]	159 to 194%
Sugar beet	116 to 125%

5. *Effect of the applied fertilizer dose.*

Two groups of results are obtained from the application of the methods indicated:

a) Effect of the optimum fertilizer dose used in percentage of the control without fertilizer

Potatoes	135 to 194%
Cotton tree [3]	194%

b) Possibility offered by our method [10] to calculate the optimum compound of the fertilizer with any dose starting from the results obtained with two experimental doses (Maize, soil).

Experimental doses	Optimum compound		
	N	S	P
1 (500 meq/vase)	42	32	26
2 (1000 meq/vase)	35	35	30
Optimum compound with untested doses			
2000 meq	31	37	32
250	56	26	18
125	84	14	2
100	92	8	0
75	100	0	0

The interest of this calculation is to show that the optima proportions vary with the dose, but chiefly that under a certain dose (starting from 115 meq of the quoted example), the optimum proportion of one of the elements becoming null, this element P, becomes superfluous, and the optimum fertilizer contains, in the case of anions, only N and S. Lower still, at the level of 75 meq, two of the elements (S and P) become superfluous and only the nitrogen remains useful. One understands thus that in certain practical trials, the response is obtained only with one fertilizing element: this is a limite case often expressed by the principle of the law of the minimum.

This possibility offered by our method is so important that we believe it useful to give a second example (Tobacco), where the optimum results of the calculation for the untested dose of 2000 meq could be controlled by the experiment.

Tested doses (in meq/vase)	Optima N	S	P	K	Ca	Mg
500	64	17	19	38	29	33
1000	49	21	30	34	31	35
Untested doses						
a) with control 2000 calculated	42	23	35	32	33	35
experimental control	46	24	30	32	33	35
b) calculated						
400	71	15	14	40	28	32
300	84	12	4	43	26	30
270	90	10	0	45	26	30
200	95	5	0	50	23	27
160	100	0	0	55	20	25
100				70	13	17
60				96	0	4
55				100	0	0

One states in fact that the experimental control confirms the calculation, the greatest deviation, in percentage, being 4 which falls within the usual margin of error.

On the other hand, starting from the dose of 160 meq, the only anion necessary being N, there is a mixture of three nitrates which alone will produce an effect.

Starting from the dose of 60 meq, only a mixture of the nitrates K and Mg will produce an effect. Finally, starting from 55 meq, only the potassium nitrate will be useful.

II. Effect of the fertilizer on the qualitative characters of the plant production.

1. *Effect of the relative production of different parts of a plant.*

a) *The Cotton tree*

We cite as example the optimum of the relative proportions of K and Mg in the alimentation of the plant, determining either the highest plant production:

K	Mg
60%	40%

or the highest production of cotton grain

K	Mg
28%	72%

It is therefore important to respect between these two nutrients the precise proportions.

b) *Fodder beet* (field in Waterloo, Belgium)

Influence of the relative N and P proportions on the root and foliage productions:

Optimum for the production	N	P
of roots	76%	24%
of leaves	82%	18%

The results illustrate here the well known fact of the influence of nitrogen on the leaf production but they indicate it through the *optimum proportions* in the manuring, besides making it evident that the optimum nitrogen production is far from being deficient for the root production.

2. *Effect of the fertilizer on the plant content of useful substances.*

a) *Sugar in sugar beets*

Besides the action on the relative production of the root and of the leaves, the ratio nitrogen-phosphorus of the latter acts, as is known, on the sugar content. As on the other hand it acts on the weight production, it determines finally the sugar production per hectare. The method of the systematic variants lends itself particularly well for determining the best proportions with regard to the different productions.

Optimum of the proportions for the production of	N	P
weight per hectare	68	32
sugar per hectare	63	37

There is a small difference here but always in the same sense and it is perfectly susceptible of practical application.

b) *Production of active substance in valerian.*

It should be emphasized that the contents of an active product are more influenced by the relative proportions of cations than by those of the anions. The latter do not produce any significant difference. As concerns the cations, the treatment with dominant Calcium produces the highest content of ethereal extract (3.9%) and of alcoholique extract (31.8%). Compared with the less favorable treatment, the increases in content are of 20 and 11% respectively.

It must be noted that the less favourable treatment from the point of view of the content of active substance, is the less favourable from the point of view of the weight production of the roots. This correlation, however, is not a general one, and the production of drug per plant is therefore differently affected by the mineral treatments. Thus, in an experiment where three anionic variants (marked by T.N - T.S - T.P) and three cationic variants (T.K - T.Ca - T.Mg) are applied, the productions in percentage of the average are:

Treatments	for the weight yield	for the ethereal extract	for the alcoholic extract
T.N	78	72	80
T.S	95	102	95
T.P	101	108	99
T.K	108	97	106
T.Ca	84	95	93
T.Mg	133	127	128

The composition of the mineral alimentation therefore influences clearly the production of active substance extracted from valerian.

c) *Production of alkaloids.*

c.1. *Nicotiana tabacum*

The optima of the anionic and cationic compositions presented here, are extracted from a thesis of SEE RYUN CHUNG, debated but not yet published (Laboratoire de Physiologie végétale) [1].

	Optima					
	N	S	P	K	Ca	Mg
Weight production (leaves)	56	29	15	42	34	24
Alkaloid content	43	17	40	28	21	51

c.2. *Lycopersicum esculentum*

The data are taken from the same work

	Optima					
	N	S	P	K	Ca	Mg
Weight production (leaves)	39	31	30	32	34	34
Alkaloid content	41	19	40	30	25	45

It is evident that the mineral alimentation influences the alkaloid content and that it does it differently from its action on the simple weight production, with a resultant still different on the production of alkaloids per plant.

d) *Production of cotton oil.*

The mineral environment influences also the oil content of an oleaginous grain, and this mainly through intervention of the ions in the enzymatic reactions of the lipogenesis. The data we are citing are taken from the graphs represented in T. VANDENDRIESSCHE [9] whose work contains many other precisions.

The alimentary optimum assuring the highest oil content in the Cotton tree grain is the following:

(in per cent in each ionic group)

N	S	P	K	Ca	Mg
30	40	30	30	50	20

It may be useful to point out that the alimentary optimum assuring the highest weight production of grains in the same experiments is as follows:

N	S	P	K	Ca	Mg
80	10	10	10	75	15

The alimentary exigencies are therefore very different according as one wishes the highest grain weights or the highest oil content.

e) *Amino acid content in potato tubers*

The following data are extracted from a work of D. COUTREZ-GEERINCK [2], where three alimentary treatments with a respective dominance of N, S or P were applied to the culture of the plant. From the tubers yields, the following results are obtained:

Amino Acid	A.A. content (micromoles/gr.m.s.			Proportion of A.A. in the total of each column		
	Treatments			Treatments		
	N	S	P	N	S	P
Glycine	2.66	1.69	2.07	1.20	0.99	1.03
Alanine	5.81	4.61	4.49	2.62	2.69	2.24
Valine	27.46	20.37	24.54	12.36	11.88	12.27
Leucine	5.75	4.69	6.30	2.59	2.74	3.15
Isoleucine	9.57	7.47	11.81	4.31	4.36	5.90
Serine	17.00	8.95	11.71	7.65	5.22	5.85
Thrionine	9.86	6.67	8.66	4.44	3.89	4.33
Tyrosine	14.30	12.07	14.55	6.44	7.04	7.27
Phenylalanine	12.62	8.86	11.46	5.68	5.17	5.73
Aspartic A.	26.28	17.96	23.40	11.83	10.47	11.70
Glutamic A.	28.84	27.98	25.15	12.99	16.32	12.57
Lysine	14.39	13.45	15.29	6.48	7.84	7.64
Arginine	20.60	16.15	16.86	9.28	9.42	8.43
Histidine	5.43	4.27	4.96	2.44	2.49	2.48
Methionine	5.54	3.92	5.78	2.49	2.29	2.89
Proline	15.98	12.36	12.99	7.20	7.21	6.49
Total	222.09	171.47	200.02	100	100	100

It will be observed that the amino acid spectra are different according to the alimentation received from the plant. The contents are all inferior to the others in the treatment with S dominance. The global richness in amino acids is naturally sensibly diminished.

3. *Effect on certain qualitative characters of the crop.*

The examples refer to the cotton tree and concern both the quality of the oil and of the fiber.

a) *Oil*: The anionic proportions influence hardly the acidity of the oil. On the contrary, the cationic proportions have a marked influence, the acidity may vary under the effect of the alimentary treatments from 1.2 to 6.4%.

The optimum of this action, i.e. the cationic proportions assuring the lowest acidity is as follows:

	K	Ca	Mg
%	30	30	40

b) *Fibers*

This case is all the more interesting since we have indeed to deal with purely cellulosic hair. It is the quality of these hair (or fibers) that are influenced by the alimentation received from the plant.

The index of dispersion of the fibers' length varies, according to the treatment, from 21.9% to 24.6%. The most favourable treatment is the one where nitrogen dominates among the anions and magnesium among the cations.

On the other hand, the index "importance of the short fibers" varies from 10.1% to 16.8%. The most favourable treatment is the same as concerns the index of dispersion.

Conclusions.

1. In the composition of fertilizer whose estimated effect is the best possible, it is not possible to neglect a priory any of the major components. For each of them exists an optimum proportion which depends on the dose of fertilizer applied. If there is a small dose, certain of these proportions may reach the zero value, and it is then not necessary to give a compound fertilizer.

2. If necessary to determine the optima proportions of *all* of the nutrients in a fertilizer, the opportunity of an adequate method is justified. The method of the systematic variants corresponds to this necessity. It constitutes an excellent exploratory method of the alimentary exigences of the plants.

3. The proportions of the compounds of the alimentary environment seem to differ very little from one species to another if the same type of organ harvested is taken into consideration. They depend, however, strongly on this type of organ, on the general conditions of the culture and particularly on the soil.

4. The composition of the fertilizer influences the qualitative characters of the crop. It may be useful to deviate from the optimum of the weight production when the qualitative character is rather important.

5. The paper contains several examples susceptible of immediate practical application.

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DISCUSSION

Chairman: J. T. PESEK

PESEK

I would like to make two points: one is that the optimum which Prof. HOMÈS speaks of, in my understanding, is a physiological optimum for a maximum yield or of quality rather than of an economic optimum, and second, the optimum for quality and yield may be at two different points.

HOMÈS

Quite so. May I answer about the economic point of view. Of course the physiologist is not himself competent from an economic point of view. But from the last development of our theory, we can reach the economic point of view. The total amount of fertilizer, from the economic point of view, is usually defined by reasons which have nothing to do with the physiological conditions. But since we can compute the full composition of the fertilizers at any level, once the economic level is fixed, we can indeed decide the best composition of the fertilizer to apply, economically speaking.

PRIMAVESI

Nous avons étudié votre travail avec très grand intérêt. Les résultats publiés sont intéressants. Par exemple, les tableaux des feuilles 12 et 13 montrent la grande influence du sol et du climat qui souvent apparaît plus importante que la propre culture (feuille 13), résultats que nous avons obtenus aussi an Brésil, même qu'avec d'autres expériences.

Nous sommes d'accord avec vous parfaitement que la généralisation est très dangereuse.

Nous avons aussi obtenu, en Brésil, les mêmes résultats de vos expériences, c'est-à-dire que, dans certains essais pratiques, on n'ait de réponse qu'à un seul élément fertilisant. Avec intérêt nous avons constaté, que vous avez démontré dans votre tableau (feuille 22) que les spectres d'acides aminés sont différents selon l'alimentation reçue par la plante.

Nos expériences aussi montrent parfaitement que c'est de la plus grande importance l'alimentation minérale équilibrée des végétaux.

We have studied your work with very great attention. The published results are interesting. For instance, the tables of the leaves 12 and 13 show the great influence of soil and climate which often appears to be more important than the proper culture (leaf 13). The same results we have also obtained in Brazil even though with other experiments.

We agree perfectly with you that the generalization is very dangerous. In Brazil we have obtained the same results as you, that is to say that in certain practical trials one gets a response only from one fertilizing element.

We stated with interest that in your table (leaf 22) you showed that the spectra of amini acids are different according to the nutrients received by the plant.

Also our experiments demonstrate that the equilibrated mineral nutrition of the plants is of utmost importance.

HERNANDO

I am delighted to hear you and to have you here because I remember we are in close relations for more than 20 years, and we use your experience in Spain for many field trials and with very good results. I like to show that for myself your line of work was — if I have got the whole idea of the literature — closer to the real idea of Liebig in the respect of using more elements than NPK to solve the problem of fertilization for good crops. Later on, there are more people here — Prof. BUSSLER — who will present another paper to us on the same lines and further, I think it is very interesting to have here the man who first tried to put in action the original idea of Liebig. In relation to your work, because I read it in advance, I find several question to ask you. I try to ask only one, because I think it will be better. On page 12 of your paper you have the optimum condition for NSP and the K Ca Mg, but there are cases without soil. The question is, what is the reason for the change in the relation in the last two situations without soils?

HOMÈS

The answer is that on this table on page 12 of the French text, the optima are expressed in percent of the anionic or cationic group, because, physiologically speaking, they have a different importance. In the anionic group — nitrogen, sulphur and phosphorus, you have the nutrients which are building pieces in organic molecules. In the cationic group you have chiefly those which are intervening in the enzymatic process and thus help to build the other molecules. And so indeed there is an interaction between the total amount of cations and the total amount of anions. In this table I only gave the percentage in the total amount of anions and cations; it was because I wanted to have a comparison from that point of view. And moreover those optima are the optima in fertilizers and not in the total nutrition and they are obtained for various ratios of anions to cations, there can thus exist a different optimum from one case to the other. My purpose was to show that inside the ions total there was a variation but i could not give the complete results because it is too much.

FITTS

I am much interested in the presentation of Dr. HOMÈS and his technique of evaluating plant needs. Of course a plant root has little choice in its assimilation of ions, but takes up those which are put in front of it. When there are ions present in the soil solution which are not essential for plant growth such as aluminum, how do you fit these into your concept or how do they affect the assimilation of the essential elements?

HOMÈS

I have written three or four books about the question. And I really think it is impossible to explain now how I came to all the results in such a short time. It is quite a new concept you see. It is also a new theory and the method is deduced from the theory on a principle which is not usual, the principle of optimizing a function and defining the conditions for this optimisation. It usually takes 30 or 40 lessons to present the whole subject and I am afraid I could not answer you now — I am quite ready to do it outside this room any time you please, in the hotel for instance.

VAN DER PAAUW

Mr. CHAIRMAN, from the early beginning of agricultural research, attempts have been made to formulate the fundamental relations between nutrients and plant growth or crop yields. The first one was the well-known law of the minimum of Liebig, later there were other ones, the law of Mitscherlich, for instance. Mr. HOMÈS has added another theory, emphasizing that not only the concentration of a nutrient is important but also the mutual relations. When increasing the concentration of one nutrient, the ratio between this factor and all other factors are changed simultaneously. I do not disagree with this conception. There are examples that it really holds. However, I disagree on the point that a generalization could be based on such observations. I may remember that the same holds for the Mitscherlich equation. On the basis of 27,000 fertilizer experiments he came to the conclusion that he had completely proved the validity of his law. I have recomputed the same data from a different point of view and was able to show clearly that the Mitscherlich law is invalid. This does not mean that it has not been of great use for many purposes. In my opinion this is the same in the case of the theory of Mr. HOMÈS. I am convinced that his fundamental idea of optimum ratios is not true. I shall try to demonstrate this by showing two graphs taken from the first book of Mr. HOMÈS (1961). As you know Mr. HOMÈS increased the concentration of one nutrient, decreasing that of another nutrient simultaneously. In the example taken from left to right, there is an increase of calcium concentration, from right to left an increase of potassium concentration. The yield curve calculated by Mr. HOMÈS deviates considerably from the yield data actually obtained. The experimental results can be represented by a horizontal line which is very much in contrast to the presentation given by Mr. HOMÈS. Going from left to right, we see that an increase of calcium does not affect the yield, or only slightly, going from right to left no influence of potassium is found. Similarly in the case of phosphorus and sulphur, the effect is represented by a straight horizontal line. In this respect. Prof. BUSSLER has spoken in one of his publications of a very flat optimum, but I can hardly see any difference between a flat optimum curve and a straight line. From this it becomes clear that ratios are not always important, over rather broad ranges (at least varying from 1:4). It follows that Homès' theory is generalising too much and that ratios between nutrients are providing no sound basis to formulate the relations between nutrients and yields.

HOMÈS

So what you have on the graph is this, which can be the expression of a general curve, and I like very much myself the expression of Dr. BUSSLER, a flat curve, because indeed you can have a very sharp one or a very flat one. I could not go into the details of the expressions, but I simply write the expression of the yield versus various ratios, which is

$$y = \left(S - u + 1 \frac{\alpha^a \cdot \beta^b (1 - \alpha - \beta \ldots)^n}{K_1 \alpha^a + K_2 \beta^a + \ldots K_n (1 - \alpha - \beta)^a} e^{-mc} \right)$$

Where C is the total amount of nutrients and α, β etc. the various individual ratios of those nutrients inside the total. The last factor (e^{-mc}) introduces a second inflection point like it was described in one of the first papers nere at the meeting. Well, if α, β, are small the curve will be flat: if a and b are very close together, the optimum will be near 50:50 and for any curves where the optimum is near 50:50 the experimental points on the graph place themselves in the same way approximately. When, of course, a and b are much higher than zero and different from each other, the optimum will be asymmetrically placed and sharp. But you refer of course to a regression calculus which was made 20 years ago when there was in no book of statistics a way to compute the curvilinear relation in another way than with the quadratic equation. Well, the quadratic relation cannot be applied here because both zero are two points of certainty. The curve must pass through zero, it is not an approximate value. The other values are approximate values. So we have to find a special way of calculating by regression the probable curve. This was the first attempt and we now have much better possibilities. The curve in that way, of course, will be what I call a flat curve compared to a curve which is not a flat one and which can be symmetrical or asymmetrical. I want simply to say that I am conscious of your criticism and thank you for it, but that things have progressed since that time.

CAPÓ

On page 5 of your English version you present a calculation of the proportions of these elements. Now it seems that you have used a number 40 there as basis for this calculation. There must be some kind of experimental evidence showing that this 40 is the proper one. That is you divide 40 by 3 and you get a 13. When you divide 40 by 4 you get a 10 to get those proportions. Now, is there any experimental evidence showing that the 40 is the proper number?

HOMÈS

Yes, the design is this one: When you have a general interaction curve between two nutrients, (I shall take an asymmetrical curve), the optimum is the X value for the maximum yield. The approximation we use, (because of course it is an approximation; for the practical purpose, we cannot afford to define a fertilizer with too complicated calculus) is a geometrical approximation. The tangent to the curve at the origin or the approximation of the curve on the small part of it to a straight line at both ends will give an intersection with it nearly, but not completely, in coincidence with the optimum. Well, to find those straight lines you have to use two experimental treatments, placed symmetrically in the graphs. And so you obtain two straight lines and one intersection. It can be shown that when you take progressively different couples of experimental treatments starting from the origin towards the center, you will have various couples of lines and so on, and progressively the errors of one sign become an error of the other sign. There is one place where the error is nil. It is computed of course by a regression calculus, on numerous individual experiments, and the proportions are as you find on page 6.

THE IMPORTANCE OF « BALANCED FERTILIZERS » WITH 12 MINERAL NUTRIENTS FOR HIGHER YIELDS OF ADEQUATE QUALITY

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1. *The development of fertilization.*

It has been known by peasants for centuries that the digestive products of animals, such as dung, certain green plants and mud from the river can improve cultivated soil. With the addition of these substances the productivity of the soil was increased. It was known that, the less these substances were applied, the smaller was the productivity and it was also known that an excess of, e.g. dung from pigeons, can harm plants. (Cato, 200 b.C. S. THIELSCHER). Today we would record this process as an optimum response curve of plant growth.

While, till the construction of the Assuan Dam, the mud of the river Nile fertilized the Delta again and again, and while in Chinese agriculture the cycling of nutrients by using faeces for fertilization was almost complete (LIEBIG 1859), the already low standard of fertility of Central European soils could not be maintained even by means of manuring. The

For this paper in German language see Appendix Nr. 4.

soil was not fertile enough any more to feed the increasing population. By means of barn manure only it was not possible to replenish the deprived soil. It was even more impossible to increase production. As a result famine was leading towards emigration to other parts of the world where soils were not exhausted. How to restore the fertility of deprived soils again by the methods then available, was not known. On the other hand it was possible, though for a short time only, to get better crops by intensively cultivating the soil giving it lime. But this method was only to result in wasteful exploitation and so diminished fertility more and more.

It was only in the last century that an important change in the history of agriculture was made by BOUSSINGAULT, LAWES, GILBERT and LIEBIG.

LIEBIG *demanded that the nutritive matter should be replaced fully in soils deprived of nutrients after producing crops, so that fertility might be conserved.*

Some of these nutrients were found in raw materials such as potassium in the waste of salt mines, or phosphorus in bones and in basic slag. In other words raw materials existed in industrial by-products, just as manure existed in the by-products of the dairy and the farmstead. Neither kind of nutrient-carriers was adapted for a manageable or dirigible plant nutrition. Now research in raw materials for the nutrition of plants began. Potassium salts were now systematically won. With the winning of ammonium sulphate started the development of manuring with nitrogen in a very pure form. A trend to develop more and more nutritive materials free of by-products began to be evident.

New types of fertilizers appeared on the market, containing more concentrated nutrients with fewer by-products. A new technology was leading towards urea and calcium cyanamide, and also towards fertilizers with a high content of N, P and K.

The fertilizers lost, with the increasing N, P and K content, more and more the contents of calcium, magnesium sulphate and the trace elements. Today a great number of fertilizers are known, containing one or more nutrients and no by-products. (SEE e.g. SLACK 1967).

Today one has reached the point where fertilizers are composed to contain the necessary nutrients according to need and growth of plants. (WANEK, ONDRÁČEK and HAMPL, 1971). The release of nutrients from the fertilizers is guided by using coated fertilizers (see SAALBACH et al. 1971) of fritted fertilizers (APPIAGYEI-DANKA and BUSSLER) or by combining mineral nutrients with organic compounds, which are destroyed by the soil by and by, as for instance different aldehydes with urea.

These new types of fertilizers prove that in modern industry it is possible to produce materials which permit a preplanned nutrition of plants. At the same time, in densely populated industrial areas new products appear: waste, industrial muck, city garbage, which have to be cleared away and therefore are offered to be used in agriculture. These waste products contain nutrients (and plenty of other matter) and consequently can contribute to the improvement of soils, as regards structure and fertility.

Compared to the possibilities of modern plant nutrition and fertilization, the use of these waste products means a relapse into the beginning of agriculture.

In the great variety of fertilizers available which permit the combination of old and new nutritive substances and nutrients, three especially are represented: nitrogen, phosphorus and potassium. These three are significant in the practical use of nutrients in industrialised areas.

2. *Present stage of the use of fertilizers in industrialised areas.*

Looking back, we know that around 1872 seven essential nutrients were known. Today we know of twelve nutrients which are of practical importance. In fact only three are deliberately added to the soil in considerable quantities. LIEBIG demanded the replacement of all nutrients removed by crops.

Is this deviation from the demand by LIEBIG justified? The success of farmers on the whole supports this limitation to only three nutrients.

Crops have increased in a way that a hundred years ago would not have been believed to be possible. Even more, one is convinced that it is possible to double crops of a productive soil (BUSSLER 1966, FINCK 1963, MENGEL and FORSTER 1971) because the genetically fixed potential of growth and development of productive plants has not yet been realised. Not only has fertility of soils been conserved by modern agricultural methods, but it has also been increased and even improved. We know of examples where already sterile soil has actually been converted into fertile soil, (THORMAN and GOLISCH 1970).

For other reasons also the preference of three nutrients seems to be justified. We know that not all nutrients are needed in equal quantities to increase production. Certain nutrients in some soils prove to be non-effective, even harmful in some cases. There are soils which contain a great quantity of those nutrients which are not present in the common fertilizers.

Taking the average results of crops in all countries, we need not be alarmed over the simplification of the demand by LIEBIG, were it not that discrepancies and the trend of diminishing crops are evident in an increasing way.

Even by adding high amounts of N, P and K, crops are not everywhere increasing, although new types of seeds and the most effective methods of cultivation have been applied.

In the past the soil was fed unconsciously with by-products in fertilizers. Some of these by-products are no longer present in quantities high enough to replace the removed and leached nutrients in the soil. These substances too have to be added deliberately to the soil again. And so fertilizing has become more complicated at the present day.

In Figure 1 the development of fertilizer usage is shown together with a schematic representation of yield performance — not to scale.

The — • — line indicates the increasing use of N, P and K. (See "Die Westdeutsche Landwirtschaft"). The — o — line indicates the increase of production in consequence of this development. The • • • line indicates the more frequently occuring diminution in harvest, which does not correspond to the increasing use of fertilizers but runs contrary to it. The — — • — line indicates the reserve of non-given nutrients (in process of being exhausted, chemically fixed, or washed out) becoming less. The ratio between "given nutrients" and "non-given nutrients" is increasing steadily. This ratio will increase according to the quantity of nutrients given and according to the lesser release of non-given nutrients from the reserve in the soil.

As long as deprivation was not high and relatively small amounts of nutrients were given to the soil, the deprivation of non-given nutrients remained low and partly they were even replaced by by-products in the manuring matter. With tbe increase of using N, P and K, and with the increasing grade of chemical purity of these fertilizers, higher crops were the results, but at the same time the non-deliberately given « other nutrients » decreased. More and more the balance of nutrients had changed. It led to inducement of mineral deficiencies, and even resulted in inducement of a deficiency of one nutrient through an overdose of another one. The diminution of crops in spite of using high concentration of N, P and K is related to an absolute or an induced deficiency of one or more of the other nine nutrients. The balance of nutrients is disturbed through one-side manuring methods. We know that in many cases this deficiency can be eliminated by applying a replacement of nutrients.

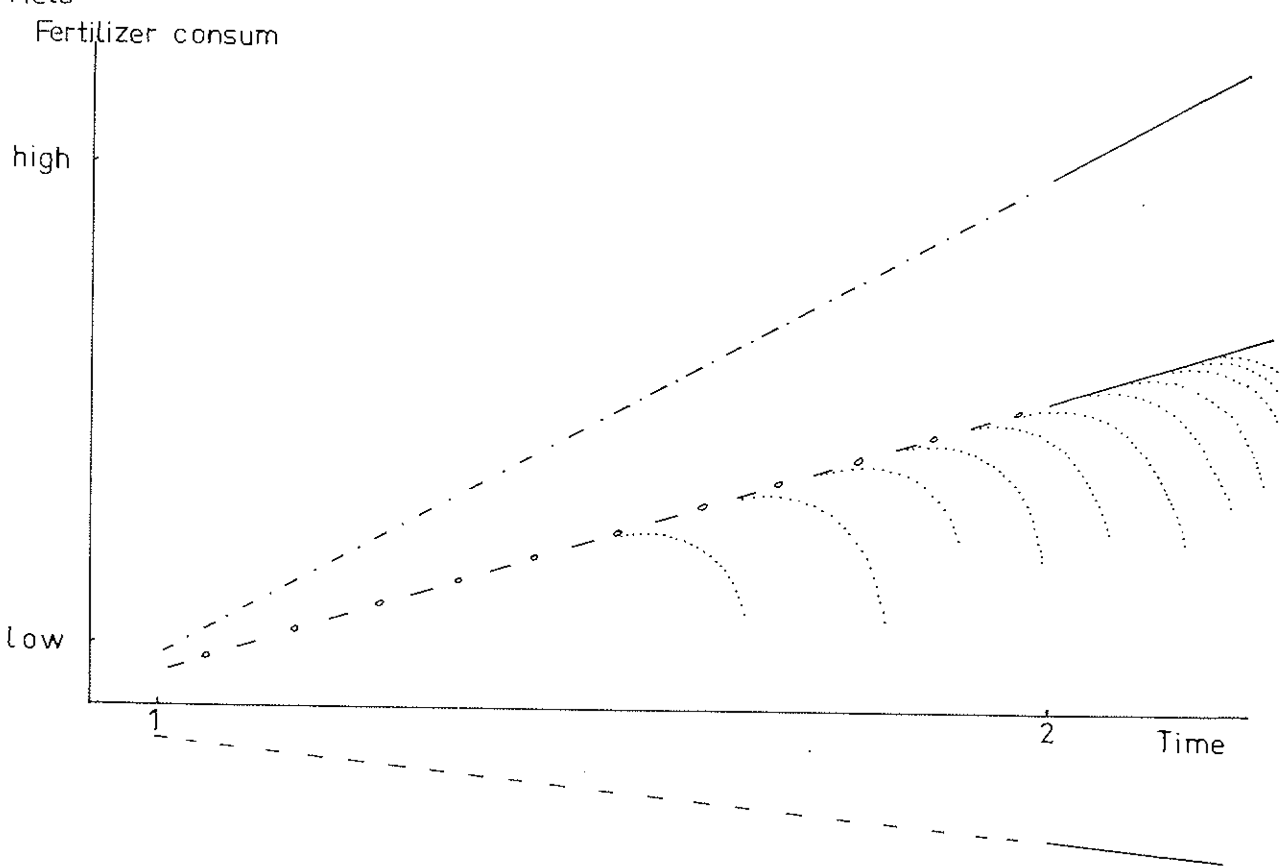

FIGURE 1 — The increasing expansion of the ratio between given and non-given nutrients.

1. Beginning of the application of commercial fertilizers.
2. Today.

— · — · N — P — K — fertilization
— o — o yields
· · · · · · · · depression in yields
— — — availability of non-given nutrients

Frequently the reason for a mineral deficiency is recognized only after a longish period of decreasing productivity.

It is already quite clear from LIEBIG's discovery that sooner (in sandy soil) or later (in heavy soil) a stagnation or decrease of yield must result if the manuring matter does not contain all the nutrients necessary to the particular soil. The question, by what nutrients the three mainly given ones are to be replaced, will only be solved by analysis of soil and plant species and by considering the utilization of the final product.

Generally this analysis is not being carried out. On the contrary, it is only carried out if a noticeable decline in production is evident or a plant shows visible symptoms of mineral deficiencies.

3. *The spreading of mineral deficiencies.*

Mineral deficiencies appear worldwide. They can occur as a result of degradation of the soil, e.g. the acid washed out lateritic soils of the tropics. They can occur as a result of salinization of the soil in an arid climate and also as a result of certain cultivating methods which lead to a fixation of nutrients, e.g. heathmoor soils, the organic substance of which is copper-binding. In intensively carried out agriculture, mineral deficiencies often appear as a result of the balance of nutrient substances being shifted. This shifting of the balance of nutrients is being promoted in the underdeveloped countries that mainly apply nitrogen to reach a higher yield of crops, and which often is even applied in a physiologically unfavourable form. The profitability is measured on the new crop.

Only a few examples are chosen to illustrate the spreading of mineral deficiencies:

— In the United States in 1967 18,7 million ha which were cultivated had mineral deficiencies. In most cases these soils had started to be cultivated as virgin soils only a hundred years ago. The aim to get highest possible yields has actually partly destroyed the basic conditions for production.

— 50% of all soils in the Federal Republic of Germany have need for a treatment with lime (HENZE 1971). In the season of 1968/69 up to 50% of the cabbage which was destined for the tinning process in food factories suffered from a necrosin of the inner leaf caused by insufficient Ca-supply. (See WEHRMANN 1971).

— About 40 to 58% of the soils in northern Germany (DDR) did not contain the necessary amount of copper needed; 30% of the soils had a manganese deficiency (SCHNORR and BERGMANN 1967).

— In the Weser-Ems District 60% of all crop-soils and pastures had a deficiency of magnesium (VETTER 1971).

— PRIMAVESI (1972) in his field experiments carried out at length shows that the presence of copper in certain species of rice can compensate the unfavourable effect of too high nitrogen dressing and so increase resistance against fungus deseases and consequently can lead towards a significantly higher yield. Here, through a very often neglected nutrient,

1. The balance in the available nutrients is restored,

2. The quality of the plants is improved by strengthening. their resistance, and,

3. The crop yield is higher.

4. *The development of mineral deficiencies in plants.*

Plants cannot grow properly if even one nutrient is deficient or if another one is overdosed. The re-supply and the availability of non-given nutrients must decrease and consequently lead to setbacks in production if

1. a deliberate replacement is not effected;

2. an unconscious supply of nutrient through dung, mud, secondary matters in manure, etc., is not taking place any more;

3. acidity of the soil promotes leaching or in another way diminishes the availability of, e.g., molybdenum;

4. through salinization the uptake of a nutrient is prevented, or the direct effect of a nutrient overdose prevents the uptake of another one through antagonisms of chemical fixation, e.g. NH_4: K, P: Zn;

5. continuous high crops are attained with similarly continuous high deprivation of nutrients which are not adjusted any more.

This adjustment is also necessary for trace elements. Even if the average deprivation amounts to only 5 - 500 g/year and ha, one has to realise that in old soils in the course of time a considerable amount of trace elements has been used up. These were not replaced; moreover, in one growing season it is not possible to replace them through soil-decay because of the high stability of soil minerals.

A plant does not show straight away the symptom of a mineral deficiency if there is a disturbance in mineral nutrition. Three successive phases are noted: A, B, C. Each successive phase includes the previous one, they are related to one another and each phase may be graded in itself.

A. Metabolic changes occur in the plants, which can only be detected analytically. The pattern of the mineral ions inside the plant cells is shifted. As a result changes in the pattern of the organic parts take place, e.g. an overdose of chloride lessens the amount of organic acids and K deficiency leads to accumulation of low-molecular N containing compounds. (Compare chapter 5).

B. In the plants the arrangement of the organelles, cells and tissues is changed. Long before the plant shows visible signs of damage, the changes can be seen either microscopically or under the electron microscope. Certain structures are not built up any more, or are changed in their organisation or destroyed. (See chapter 6).

C. Visible symptoms are to be seen in the plant. The organs can deviate from their original form or colour or development compared to the "standard plant" (chlorosis, necrosis, morphosis). The crop can be reduced to nil.

Phases A and B belong to the most common range of latent deficiencies. These are detected only seldom. What consequences the consumption of this sort of vegetable actually has, is known only in some cases, mostly in cases of stock nutrition. Example: the desire to lick when a deficiency of copper is present, Hinsch-disease when cobalt is deficient, tetanus when the relation of cations in the serum is disturbed through a too small amount of magnesium, Teart disease when Mo is present in an overdose.

Since all over the world in an intensive agriculture the same production methods are employed, an adjustment of human nutrition via optimally provided food is not guaranteed any more.

5. *Metabolic changes as a first stage of mineral deficiencies.*

Each morphological change in cells and tissues must be preceded by disorganisation of the metabolism. The pathways of metabolic changes leading to morphological disturbances are presently not known. Some of the easily proven changes are mentioned here to show how many possible deviations of metabolism exist. (Table 1). Faulty fertilization, because deficient or one-sided, will not only lead towards a change of

TABLE I — *Metabolic changes as a first stage of mineral disturbances.*

Cause	Metabolic change
N - Deficiency	Relative expansion of the carbohydrates, plants turning more woody.
S - Deficiency	Accumulation of low molecular N-containing compounds.
P - Deficiency	Accumulation of secondary plant substances, e.g. Anthocyanines (BUCHHOLZ 1962) and quinic and shikimic acids (COÏC 1961).
K - Deficiency	Accumulation of toxic substances, e.g. putrescine (COLEMAN and RICHARDS, 1956).
B - Deficiency	Accumulation of a substance which promotes the division of cells. (BUSSLER 1964, 1965).
Mo - Deficiency	Accumulation of nitrate.
Fe - Deficiency	Hindered protein synthesis, increase in soluble N-containing compounds, accumulation of organic acids.
Cu - Deficiency	Stopped activity of the phenoloxidases, diminished build-up of lignin (RAHIMI 1971).
NH_4 - Overdose	Diminished build-up of organic acids.

the plant's component substances, but also to a higher susceptibility of the plant towards harmful organisms; further it will lead towards a higher demand for pesticides and so will have also its effects on the pollution of the environment. (KRAUSS 1969, GROSSMANN 1970). The recognition of these relations is made difficult through the diverse effects of nutrients and also through the irregular behaviour of plant species.

6. *Histological changes as a result of mineral deficiencies.*

To be able to recognize the first histological signs of mineral deficiencies, a series of microscopical examinations is necessary. The tissue chosen for these examinations must be taken from the organs and regions which later show the visible symptoms. From sequences of cuts it was discovered that the very first changes appeared in single cells only. The development of the damage from the histological beginning to the death of the organ can only be followed when more cells have been damaged. Figures 2 to 6 show typical stages of the development of symptoms.

In the cortex a few cells have collapsed which have been squeezed together to yellow-brown strings by the growing neighbouring cells. At first the collapsed cells have little osmotic value and hardly any trace of potassium left. The neighbouring cells have grown to a size larger than normal and are divided irregularly. The structure of the tissue in the vascular-bundles, in the cambium and the pith is normal (BUSSLER 1962, 1964, 1970).

Parenchyma cells in the pith of the younger parts of the stem are completely dissolved. The pith becomes hollow, the stem bends. This symptom is preceded by a destruction of the membranes which is only visible under the electronic microscope. (MARINOS). Therefore the pectin of the middle lamellas is exposed to the attack of the pectinase which at first separates single cells from each other. Of the cells of the pith a non-

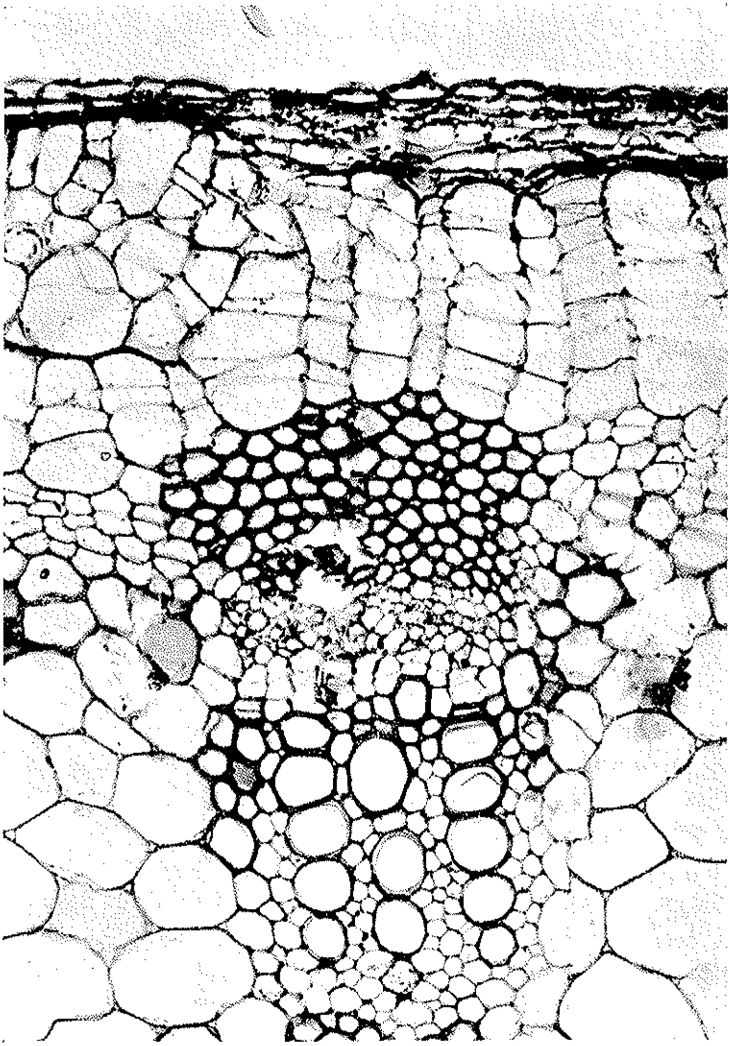

FIGURE 2 — Cosmos. Cross section of the lower part of the stem showing Potassium deficiency 250 ×.

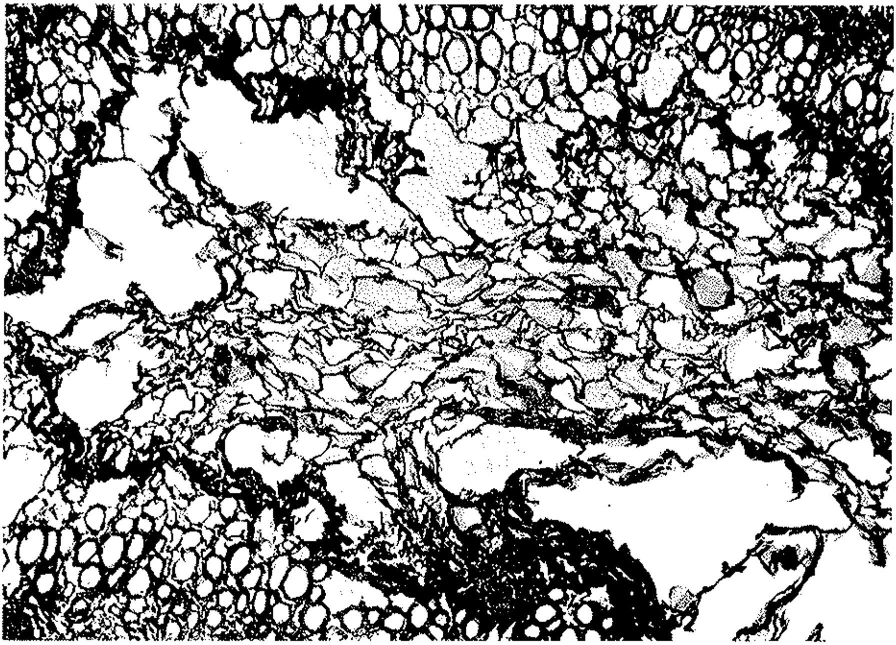

FIGURE 3 — Egg - Aubergine. Cross section of the upper stem showing calcium deficiency 100 ×.

structured brown substance remains. (BUSSLER 1962a, b. c 1963a, b).

The number of cells between phloem and xylem is growing. The cells of the cambium are continuously divided. The new cells are not any more differentiating. The tissue in this area can grow in a way that the stem bursts. In Cellery the homologue symptom is known as "cracked stem". The unlimited growth of cells is similar to that of animalic neoplasia (cancer). (BUSSLER 1956a, 1965a, b, 1960a, b, 1961, 1962a, b, 1964, 1965, 1966, 1968).

At the beginning of a Mo deficiency young parenchyma cells are filled with brown substances so that these cells will

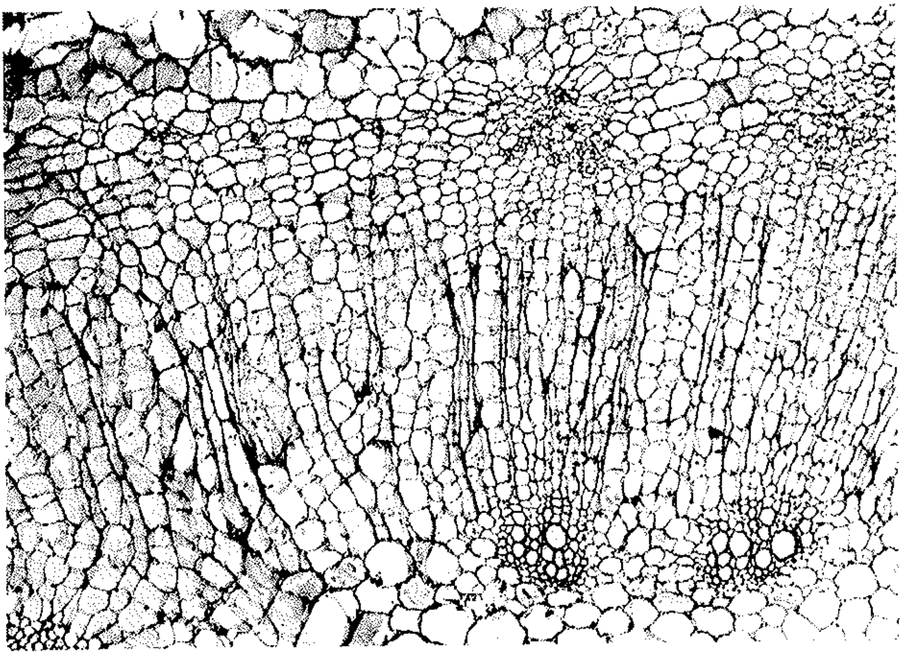

FIGURE 4 — Sunflower. Cross section through the stem below the terminal bud showing boron deficiency 100 ×.

die. If in this case cells of meristematic tissues are concerned, whole parts of the very young organs will be destroyed before they are able to develop. The rest of cells in this area has only the ability to form fragments. If Mo deficiency is present, a typical simpler form of the leaf can be noted, though completely irregular, which is known as "Whiptail". (BUSSLER 1969a, b, c, 1970).

In the case of manganese toxicity manganese is deposited in bigger accumulations in the epidermal cells, especially in the bottom cells of hair. Contrarily to the changes in the tissue caused through different kinds of deficiency, no disturbance with regard to the organisation of the tissues could be noted.

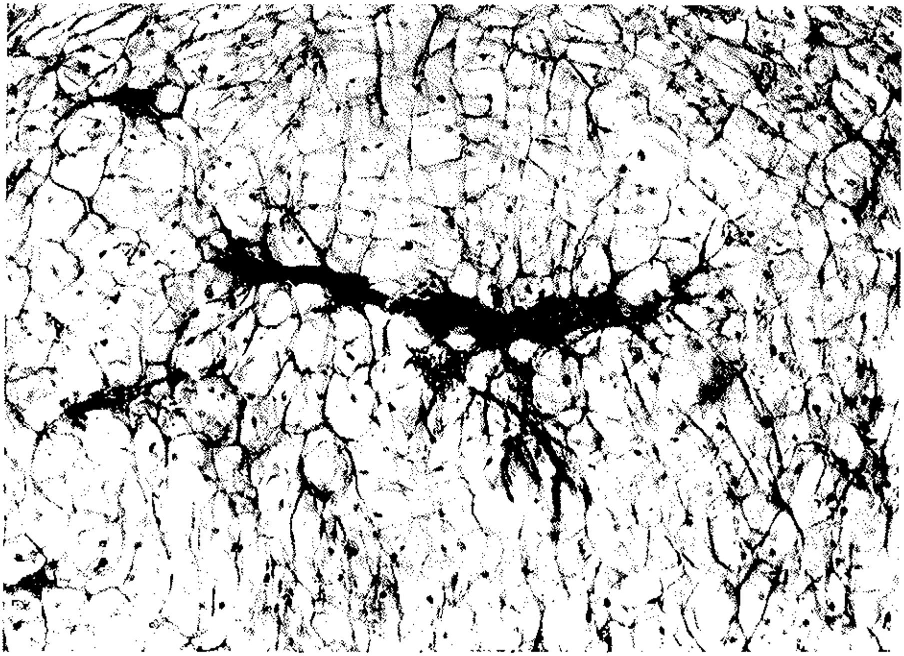

FIGURE 5 — Cauliflower. Cross section through the midrib of a young leaf showing molybdenum deficiency 250 ×.

After transfer of the plants into deficiency solution the manganese fixed in the accumulations can not be made effective again. Plants then show toxicity of manganese in the older organs and manganese deficiency in the younger organs. (BUSSLER 1958).

From figures 2 to 6 it can be seen how particular mineral deficiencies induce particular symptoms. These symptoms make it possible that, even when several different mineral deficiencies are noted and overlap one another, they can be distinguished from each other. These symptoms also show (and this is not new) that, if in the nutritive substance even one nutrient is missing, the plant is not sufficiently nourished

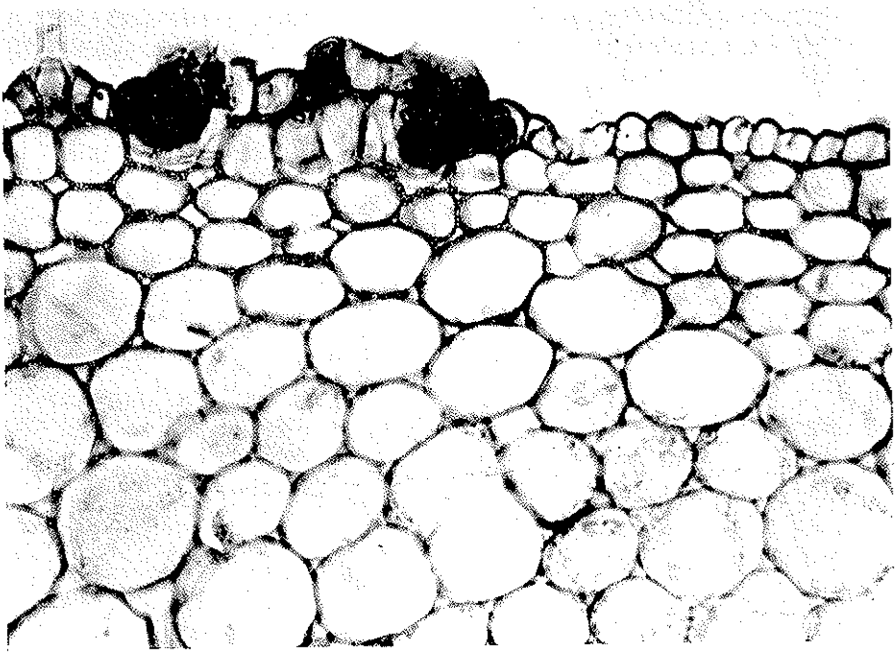

FIGURE 6 — Dwarf Bean. Cross Section of the older part of the stem showing manganese toxicity 250 ×.

for a normal development. Can fertilizers that contain virtually only 3 nutrients secure a proper growth if 12 nutrients have been removed?

7. *Directly visible symptoms of mineral deficiencies.*

A continuous nutritive disturbance will increase the changes in the plant and will lead to more and more damage to the cells, which finally is proof of an acute mineral deficiency. According to the mobility of the nutrients and their metabolic functions in the plant, the developing symptoms will vary. In the case of deficiency, the symptoms and their sequelae in the plant are typical for the kind of deficiency. (BUSSLER, 1968). By these symptoms the deficiency can be recognized. For a long time now these symptoms have been observed, described and shown, e.g. BROEDEL-KITCHEN 1948, BUSSLER 1962, 1964, DEL RIVERO 1964, ECKSTEIN, BRUNO, TURRENTINE 1937, HAMBIDGE 1951, JUNG & RIEHLE 1969, MALAVOLTA et al. 1962, MULDER 1956, PENNINGSFELD 1962, PRIMAVESI 1965, ROORDA VON EYSINGA & SMILDE 1968 & 1969, SPRAGUE 1964, STENUIT & PIOT 1960, WIMMER G. 1900.

Even though observations of the possible damage through mineral deficiencies are not as yet complete, the knowledge gained about the development of symptoms has greatly assisted in the struggle to eliminate mineral deficiencies. It is a disadvantage that the elimination of the damage can only be started at a later stage, because the right diagnosis of a symptom can only be made at a late stage, a stage preceded by latent deficiencies.

For many years already before the disturbance has been noted, a non-visible deficiency can be acute. In other words, the consumer in many cases received food for years which had a different chemical combination from food derived from plants nourished normally.

8. *Optimal ratios for nutrients.*

In the previous three chapters mineral deficiencies in plants have been described where the actual ratio of nutrients by way of combination or (and) concentration was not optimal. Since, owing to the kind of soil and the growth of plants a nutrient combination offered only once can change and this is not always clearly recognizable, we ought to ask ourselves what sort of optimal nutrient combination should be chosen for a water culture with flow-through and a constant offer (i.e. availability) of nutrients.

Table 2 summarises how to fulfil the necessary demand for an optimal nutrient offer. In words it could be expressed as follows:

An optimal nutrient offer is given, when, under favourable condition, it allows the plant to fully develop its genetical constitution. In the contribution of our colleague Mr. Coïc we find the following statement: "Les facteurs qui ont une action sur la Physiologie de la plante ne sont pas indépendants les uns des autres. Il faut donc amener chacun d'entre eux à une valeur correspondante à un équilibre entre tous".

The requisites in point 6 are the most difficult ones to be fulfilled. Only through the method of systematic variations as developed by HOMÈS, has it been possible at all to obtain almost optimal relations between nutrient anions and nutrient cations,

TABLE 2 — *Requisites for an optimal offer of nutrients.*

1. It must contain all nutrients.
2. It must contain all nutrients in a suitable form. (e.g. N. as NO_3 or NH_4-ion).
3. It should contain no by-products and no unwanted ions.
4. All nutrients should be given in amounts according to the type of offer. (See table 4).
5. The pH-value of the solution should neither be too high nor too low.
6. It should contain all nutrients in an optimal proportion to each other.

with a few experimental steps which technically can be carried out. (HOMÈS 1953, 1961, 1963, 1966, RAUTERBERG and BUSSLER 1963, 1966a, b). With this method developed by HOMÈS we have tried to find optimal ratios of trace elements too. (FOROUGHI and BUSSLER 1969). In a much varying offer of trace elements and major nutrients, we found nutrient combinations for the sunflower as they are represented in table 3 (culture in 40-ml-glasses, solution not aerated and not renewed, BUSSLER 1971a, b).

According to the type of offer of nutrients, these ratios must change more or less. The smaller the nutrient offer is on the whole, the more important becomes the possibility of the plant to select nutrients. The higher the offer of nutrients, the more will this offer influence the amount of nutrients the

TABLE 3 — *A "balanced offer of nutrients" for sunflowers in 40-ml glasses.*

Cations of major nutrients/plant : 2,4 meq
K : Ca : Mg = 26 - 44 : 29 - 42 : 20 - 37

Anions of major nutrients/plant : 2,4 meq
cations : anions = 28 - 46 : 33 - 45 : 17 - 31

Cations of trace elements/plant : 0,012 meq
Fe : Mn : Cu : Zn = 20 - 41 : 17 - 31 : 14 - 29 : 20 - 33

Anions of trace elements/plant : 0,012 meq
B : Mo = 42 - 72 : 28 - 58

Major elements : Trace elements = 200 : 1

Trace element cation : Trace element anions = not known given here 1 : 1, optimum not analysed.

(BUSSLER, 1971b).

plant will absorb. (See Table 4). Since for highest yields nutrients have to be offered in great amounts which have a great influence on the amount of nutrients taken up by the plant, an optimal relationship should already be present in the offer. The same rule is valid for trace elements.

TABLE 4 — *Types of nutrient offers.*

High concentration of nutrients > 50 meq/l ↑	1. in one offer sufficient for the growing season or the anticipated duration of the experiment.	The ability of the plant to select is increasing
	2. in several offers, according to development	
Low offer of nutrients < 5 meq/l	3. ± kept constant through frequent renewal	
	4. given constantly with lost flow-through ↓	

9. *The trace elements in the offer of an optimal ratio.*

In former times the smaller the offer of all essential nutrients was, the less was the plant capable of taking up a single nutrient in a considerable quantity. In older reports it is written that the trace elements are poisonous: today we know that they are essential. Consequently the use of trace elements was only applied in areas with an evident mineral deficiency. But as in the case of major nutrients, even before symptoms of deficiency appear the yield is influenced by unsuitable combinations of trace elements. (See Table 5).

The quantity of major nutrients offered is always the same. A change of the relationship, trace element anions : trace element cations, leads to a significant improvement of growth.

TABLE 5 — *Comparison between the yields from a Colwell-solution and from a solution composed according to systematic variations. (Sunflowers in 40-ml-glasses) with a varying offer of trace elements.*

Major Nutrients		Trace Elements	Anions of Trace Elements		Cations of Trace Elements	Yields s.V.	COLWELL (rel.)
200	:	1	1	:	1	63	100
200	:	2	1	:	1	80	100
200	:	4	1	:	1	41	100
200	:	2	2	:	1	98	100
200	:	2	10	:	1	180	100

This improvement of growth was measured by the yield of crops. The improved effect of the trace element anions was due to the added boron, whereas molybdenum in an already too high offer had no influence on the yield.

10. *How to evaluate the effect of nutrients on the development of plants.*

As a rule the effect of fertilization, or more generally of the offer of a nutrient, is measured by the yield. But this is only one way of the many which are being applied to examine whether, through a certain method full scope is given to the genetical development. Other possible ways of judging the effect of a nutrient are described in Table 6.

All points made in Table 6 are insufficient with regard to a scientifically based judgment. Because the yield of crops

TABLE 6 — *Criterions for a judgment of the effect of nutrients.*

1. Yield
   (insufficient, does not show negative metabolic compounds).
2. Appearance of the plant
   (insufficient, an overdose of N or a slight deficiency of P in the plant can make it appear "to be normal").
3. Quickness of development
   (insufficient, does not reveal anything about the final product).
4. According to recognizable physiological values, i.e. content of soluble nitrogen containing compounds.

represents the most simple way of finding a criterion, almost all fertilization methods in practice are orientated by that finding. We know very well that high yields do not mean high quality at the same time. In the field of human nutrition it is quite clear that the heaviest man is not necessarily the healthiest one.

If, nevertheless, we continue to judge the effect of nutrients by the yield it is because knowledge about the connections of growth factors which form the yield is incomplete and also because of the economic point of view. Profitability is taken much more into consideration than quality. To a great extent the quality of our food is judged by its outer appearance, insignificant regarding the metabolism, or else is judged by negative aspects. The crop is supposed to be free of residues, diseases and pests. In these circumstances it is evident that a production of high quality food will not come about.

11. *Dilemma between profitability and quality.*

If, considering quality and quantity, an optimal yield of crops is to be obtained, it is imperative that the whole of our knowledge be applied practically. To apply this knowlodge to the changeable and occasionally prosperous market economy only, is not sufficient. Acid soils, plants with deficiencies of organic and inorganic matter will be the result of concentrating too much on profit. As Coïc puts it (1972): "En agriculture, on se préoccupe plus de rendement que de la qualité, car pour beaucoup de produits agricoles, l'amélioration de la qualité est peu payée".

The producer would certainly be willing to apply optimal fertilization were he to be paid for it. Here is one example: For the producer of ornamental plants it is certainly profitable to apply the best of available methods since the public will pay for it. The food consumer is not yet prepared to spend in accordance with the nutritive value of his food as he is so readily for "flowers to present to a lady". The consumer is still of the opinion that the producer should produce cheaply a high-quality food by using, if possible, wastes and garbage. The words of VIRTANEN are not as yet treasured generally by men: "The new view with regard to the influence and importance of food can be supported if one realizes what an important factor food is for men and if we take into consideration how much his health, his activity and his ability to work will depend on it. A sufficiently and harmonically balanced nutrient, as required by men and animals, is vitally dependent on the chemical compounds of plants". These are influenced to a great extent by fertilization.

Today famine can be fought through application of fertilizers. Our alimentation will not be guaranteed if we do not include all nutrients. Our alimentation will not be guaranteed if it is only possible to examine the basic facts on a very limited scale. The trend shown on figure 1 will continue to develop.

Mineral deficiencies will appear even where today we cannot detect any deficiency.

12. *Summary*.

1. It has been proved that, if we continue with the present methods of fertilizing soils, deficiencies of nutrients in plants will increase. The increasing prevalence of mineral deficiencies is to be attributed to the fact that the demand by LIEBIG that all nutrients be replaced in soils after crops has not been followed. The replacement of only some mineral nutrients is not sufficient.

2. Lack of even one mineral nutrient in the plant will lead to metabolic as well as histological changes which, besides diminishing the quantity of the crops, will also induce a decline in quality.

3. The most favourable development of plants which will lead towards higher yields of the best quality is only possible when nutrients are offered in a well balanced combination. The possibility of doing so is given by applying HOMÈS's method of systematic variations.

4. In the field of nutrition and plant nutrition the basic scientific research should be emphasized. At the present stage of our scientific knowledge, judgment if a plant has optimally developed is not possible, nor is the recommendation of optimal offers of nutrients. We do not know the maximum return of a crop of one species. We know of no basically valid criterion to judge the quality of our food plants.

5. To produce optimal returns with regard to quality and quantity seems to be impossible, taking into consideration that farmers produce only with a view to profit. The aim to produce cheap by using wastes instead of nutrients which are adapted to render the desired production, excludes almost always an optimal nutritive quality.

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DISCUSSION

Chairman: J. T. Pesek

Primavesi

Prof. Bussler, I will congratulate you on the magnificent paper, which, from our point of view, is of great importance for the fight against hunger in the world. In other words, important to help improve the agricultural production, quantitatively and qualitatively, in the Tropics and Subtropics, zones with very low yields per hectare, in contrast with the countries of temperate climate with high to very high yields per hectare.

Based on our long experiences in the Tropics and Subtropics and our knowledge of the zones with temperate climates of different parts of the world, I will say to you that you have perfectly understood that one of the principal problems in agricultural improvement in these zones is *adequate* fertilizer use and *correct* application.

At the Federal University of Santa Maria, in the most important agricultural State of Brazil, we have installed the First Post-graduate Course on SOIL BIODYNAMICS AND SOIL PRODUCTIVITY on the level of Master of Science degree, which work in this direction.

HERNANDO

When reading your paper a question came to my mind which I had met with about 12 years ago in relation to the problem of many illnesses in man, especially the problem of cancer. We discussed the possibility of studying the problem of cancer in man with medical researchers and analyzed the composition of the nutrient elements in food. They said that it would be very difficult since the food came from many areas. I thought then it would not be possible to carry out the study. Later on I happen to read a paper from Japanese people; they used an ultra super centrifuge equipment. They succeeded in finding the difference between normal cells and cancerous cells. Thanks to this system they found that the material inside the normal cells did not leave the cells, the cells remained as before. With a virus or under cancerous conditions, however, the material left through the cell walls. This means that the cell walls are different in both cases, and that this difference is in relation to the permeability of the cells. The physiological effect of boron in relation to the constitution of the plant is known. The cell walls are stronger, thicker when there is enough boron in the nutritive solution. If there is not enough boron, the cell walls are less thick and permeability is easier. I showed in my paper that when working with boron on tomato plants we found a method to know when boron was not deficient in tomato plants, and there are certainly some changes in the composition of the plant. I showed then a slide in relation to glucides or the sugar composition. The final part of the paper was reduced because as I told you I have been ill for some time, and it was not possible to develop all the things we were doing with amino-acids. But now I can say that the amino acid contents vary most evidently, and something in this respect is found at the end of the paper though no details. There is a complete change in composition before there are boron deficiencies. Some time ago little or nothing was known about the limitative effect of boron in the literature. Well, maybe that now we have come nearer to the possibility to study the effects of the different microelements in food, on the quality of food with different composition. We have now better techniques than before to determine the real amount of one micro-element in plants; with the absorpciometer method, f.i. it was not possible to detect the molybdenum concentration in plants. I hope, however, that in future it will be possible to get better knowledge on boron first, because I think it is most important, and then also on other microelements. The reason that led us to study boron was its deficiencies in apple trees. There is much similitude with open cancer in man. Therefore we started on the boron problem several years ago, but maybe it is not the same in the human body. Anyhow, boron or no boron, maybe that the plant needs many microelements in a higher or lower concentration than they are actually getting; it may also be that in future we find still other microelements necessary for the composition of the plant, of which so far we do not know yet. For this reason, we are using new varieties and new hybrids which need high amounts of fertilizers in the soil. At the same time they are getting certain elements from the soil which we do not apply, and maybe that these new plants need higher amounts of minor elements than they find in the soil and we find thus another type of deficiency of which we did not know of before. This may also be the reason that one of the experiments made in Holland about ten years ago — you will remember the paper — showed that the yield cannot be increased by using fertilizers beyond a certain level, when at the same time we do not apply organic matter. I think one of the reasons is what we discussed here; another reason may also be that this organic matter gave the soil some elements that are actually needed by the plant.

BUSSLER

May I give only a short response to your detailed remarks and only for the point of boron. I have published a paper in which I compared the morphological, physiological and geographical effects of boron deficiency with cancer. You can take some morphological descriptions of cancer from the text book of Bauer about cancer which with the same words describe boron deficiency in the cells. You can find a lot of physiological similarities in the cancer and in the boron-deficient tissue and you can also find some connection between geographical points, where boron deficiency is common and where some kinds of cancer are common. Now, I think it is not only the boron but other trace elements may be included.

SAALBACH

You have said, Dr. BUSSLER, that the farmer would certainly be willing to apply an optimal fertilization if he could pay for it. This means that an optimal fertilization is more expensive than a non-optimal. This may be in some cases but not in all. For instance, in Germany the price for calcium ammonium nitrate and calcium ammonium nitrate sulphate is the same per unit of nitrogen. On a soil with sulphur deficiency the last fertilizer is better and I could also bring you an example for complex fertilizers. It is my opinion that in many cases the optimal fertilization is not a question of the price of the fertilizers but a question of education and advice given to farmers.

BUSSLER

Well thank you Dr. SAALBACH, I agree completely with you. The optimal fertilization could even be cheaper than the normal fertilization with N, P and K. There may be given too high amounts of nitrogen or too high amounts of a third nutrient. This is avoided by optimal fertilization. I thought the farmer will give an optimal fertilization, if he would be payed for this.

I thought in the first respect to calcium. In this case an optimum fertilization is more expensive, because of a transport problem. The price for trace elements is low because there is a need for only some kilograms.

RUSSELL

I would like to make two points. First of all I think it is very regrettable that we appear to have forgotten what our grandfathers knew, namely, that non-calcerous soils need regular additions of lime if they are to remain fertile. The second point is that much more work is required, from the medical point of view, on the quality of food. From the agricultural advisers point of view, it must be remembered that very few people in developed countries eat just what the farmer grows. Most of our food is processed between the time it leaves the farm and arrives on our table for consumption, and this processing can greatly alter its nutritives value, either by the addition or removal of substances that affect its nutritive value. Also people in developed countries eat a large variety of food, grown on a wide variety of soils each week, so it is of little nutritional significance if a few of the foods are unbalanced. But the problems of the correct trace element intakes by human beings on their health are of great importance, but they fall into the field of medical and not agricultural research We know that in certain regions, some diseases are much more common than in the country as a whole. Thus, dental caries in children appears to be increased by a trace element unbalance in certain regions, and some forms of cancer may be trace element induced; but the medical profession has been very lax in giving us so little information on the amount of different trace elements needed for human health. It is of little use us talking about adding boron or molybdenum to the soil to put up the content of these elements in the food when we don't know what contents are needed for human health.

I would like one of the conclusions of this meeting to be that the medical profession be urged to pay much more attention to the mineral content of foods as they affect human health.

BUSSLER

Thank you Dr. RUSSELL, it was a very good thing you said that we should work together with the physiologist and with the medicine faculties, and it was said also by PRIMAVESI some years ago when he tried to build up an institute of general life science — a combination of nutrition and other life sciences. To the other point, that it is a problem of medicine for instance to give more trace elements, or vitamins or enzymes in some cases. I think it is a problem of agriculture to give the right amounts of nutrients to the soil and to the plants. We know some of our civilization diseases as e.g. heart diseases which were cured by the medicine with magnesium-salts. This can be avoided by the fertilization of plants before it starts to develop in men.

WALSH

Dr. BUSSLER gave us some very interesting information. He did not speak about substitution factors. For instance once you look at potassium, calcium, magnesium interactions you must take into account other elements such as sodium and boron. Boron has an effect on the balance of that complex. Again take for instance the molybdenum - manganese - phosphorus interaction situation. Molybdenum reacts with manganese - a deficiency being accentuated by manganese excess. Phosphorus can affect the uptake of manganese. You have in effect then here a highly interacting complex. I was asking Dr. BUSSLER if in these situations you have in your work taken such substitution effects into account. Another substitution factor which Dr. HOMÈS reminded me of when he said you don't get any yield without calcium, was that of strontium replacing calcium for vegetative growth in cereals. I am very glad to see that people have once again been agitated about those balance effects and about nutrient interactions. In talking about balance we are in effect talking about complex nutrient interactions — positive, negative, antagonistic, complementary. I believe more work is needed on substitution factors. For instance, what is the real significance of calcium – boron interactions in such physiological breakdown effects as « brown spots » « drought spots » in apple fruit. These two nutrients are concerned with the development of meristematic cells and I have found it difficult to distinguish between the effects of these two elements. Probably with your techniques you can do so and this is a real advance.

BUSSLER

We have some difficult problems here. Deficiency-symptoms of boron are very similar to those of calcium deficiency but it is possible to make a test of calcium with picrolonic acid to precipitate calcium. Even in a microscopic slice you can find the calcium in a single cell. Then you think it might not be calcium deficiency. When you make those reactions, and you should not contain any precipitate at all, then calcium deficiency is probable. But when you have the precipitate then you should direct your thoughts more to the boron direction. With a boron deficiency you have always a thick cambium by dividing cells. This is never the case with calcium deficiency but the calcium deficiency may appear as a secondary symptom of boron deficiency. Boron deficiency may induce calcium deficiency. The next point I would like to answer is the substitution. We have not included in our experiments substitution from calcium by small amounts of strontium and so on but I think that we have some substitution problems and that leads back to the form of the yield response curve. When we have ornamental flowers as Saintpaulia ionanthos, it is a plant not sensitive to the surrounding conditions, you can give different amounts of cations without serious effects. Then we have a flat curve, about the best ratio of potassium to magnesium. So we can say the optimum may be here or may be there. Could be, that in this limit the magnesium and potassium are exchangeable one against the other. Then we had cyclamen which are very sensitive to any change in the nutrient medium. We found a very distinct optimum and small limits. Here substitution may concern small amounts only.

THE EFFECT OF SULPHUR, MAGNESIUM AND SODIUM ON YIELD AND QUALITY OF AGRICULTURAL CROPS.

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1. Introduction.

As in most other countries of the world, consumption of mineral fertilizers and, as a consequence, harvesting yields have increased continuously during the last few decades also in the Federal Republic of Germany. Simultaneously, a change in fertilizing practices has taken place. Instead of single fertilizers with a low nutrient content, more and more high-percentage products have been used [10]. Furthermore, there has been a growing tendency in favour of an increased application of concentrated compound fertilizers [60] which, in comparison with low-percentage fertilizers, offer the advantage of lower transport, storage, and sometimes also application cost.

It is, however, a handicap that, as a corollary of increasing percentages of nutrients, as e.g. N, P or K, present in fertilizers, their content of the so-called "ballast materials" that may in turn he plant nutrients of vital importance, continues to decrease resp. vanished completely. This holds true for S, Mg and Na. In the Federal Republic of Germany the said development led to a constantly decreasing availability of these three nutrients. On the other hand, rising yields have gone hand in hand with higher S, Mg and Na requirements so that deficiencies have become more and more manifest. For this reason we tried to answer the following questions:

1. What is the effect of insufficient sulphur, magnesium or sodium availability on various cultivated plants?

2. Which possibilities exist for determining a deficiency?

3. To which extent a deficiency of the said three nutrients may be noted at present in the Federal Republic of Germany?

4. Which fertilizers should be applied as a remedy against such deficiencies?

5. Will it be necessary to develop new fertilizers?

In view of the fact that, as stated before, the tendency to be observed in the application of mineral fertilizers in the Federal Republic of Germany is to be increasingly noted also in other countries, it is intended, within the framework of the discussions on the "Use of fertilizers and its effect on increasing yield with particular attention to quality and economy", to give a report about the state of research work done at our Institute.

2. Sulphur.

2.1. *What are the effects of an insufficient sulphur supply of cultivated plants?*

The plant absorbs sulphur — mostly in the form of SO_4 ions — via its roots, as well as — in a gaseous form — via the leaves. Reduction is followed by incorporation into organic compounds, as e.g. certain amino acids, various vitamins and mustard and leek oils. Sulphur compounds furthermore activitate enzymes and affect the swelling state of the plasma. The influence on the amino acid synthesis, i.e. the formation of protein constituents, is, however, to be considered as the most important effect, as approx. 90% of the sulphur present in the plant are components of amino acids. Insufficient sulphur availability will therefore lead to diminishing yields and decreasing protein quality [49, 54]. The importance of sulphur for the quality of plant proteins will be dealt with more in detail.

2.1.1. The effects of sulphur deficiency on the protein quality with a view to human and animal nutrition.

In order to avoid growth and metabolism disturbances, men as well as animals have to consume regularly a minimum quantity of amino acids in the form of protein. The necessary protein quantity depends largely on the degree of conformity existing between the amino acid composition of the absorbed protein and the requirements of the human or animal organism.

The amino acid spectrum of animal protein fulfils these requirements to a larger extent than plant proteins. According to NEHRING [36] and BLOCK and BOLLING [6], the lesser quality of plant proteins is in the first place due to low lysine, methionine and cystine percentages. If plants are insufficiently provided with sulphur, the methionine and cystine percentages may decrease, a phenomenon detected by COÏC and Coll. [8] with barley, by SHELDON, BLUE and ALBRECHT [64] with soya beans, by RENNER, BENTLEY and MCELROY [39] with wheat and barley and by ourselves with oats [50] and forage plants [40]. The thus resulting lower protein quality leads to an even greater difference in value between animal and plant protein. As indicated by us in a different context [50], this is of particular importance for those regions where on the one hand the population does not get enough proteins, and where on the other the protein supply depends for the larger part on plant proteins, as e.g. the Far East and large regions of the

Near East, Africa and Latin America. In these regions it is necessary to consider the sulphur supply of plants not only with a view to yields but also to the quality of the proteins produced.

2.2. *Which possibilities exist for determining sulphur deficiency?*

2.2.1. Soils analysis.

Sulphur is present in the soil as an organical compound as well as in its inorganic form, mainly as sulphate. The organic fraction is considerably larger than the inorganic one and consists of proteins, polypeptides, sulphated polysaccharides, amino acids and other plant residues, the ratio of these groups of substances varying from one location to the other. On top of it, the various compounds are subject to different mineralization velocities. It is comprehensible that, in accordance with other authors [3, 29, 65, 69] we [42, 45] did not find any relationship between the total sulphur content of the soil and the absorption of sulphur by plants, either. It is therefore impossible to characterize the degree of sulphur availability with the help of the total sulphur content of the soil.

We tried to find a sulphur fraction in the soil suitable to serve as a measure for the quantity of plant-available sulphur [3, 23, 65, 69]. The process developed by Williams and Steinbergs [69] proved satisfactory. It implies, however, a relatively complicated technique and leads to comparatively large mistakes on specific soils. For this reason we developed onrselves a process for determining the sulphate sulphur content [42]. In pot-experiments it proved suitable to characterize the sulphur availability degree. In the presence of percentages of less than 10-12 ppm of SO_4-S, a sufficient sulphur supply of marrowstem kale was e.g. no longer secured [44]. It has not been possible to ascertain corresponding limits in the field, the sulphate content of the soil changing at short intervals by the influence of precipitations with their varying sulphur percentages, a phenomenon we demonstrated in a different context [45].

It seems unlikely that in regions marked by a predominantly humid climate and/or a dense population as well as by intensive industrialization, other processes for determining the plant-available sulphur fraction would serve to reach the desired objective, so that also in those cases soil analyses are unsuitable for characterizing the sulphur supply degree. As demonstrated by KAMPRATH, NELSON and FITTS [20], the situation may be different in countries with other climatic conditions and a smaller supply of sulphur by precipitations. During field trials with tobacco and soya beans, these authors detected a significant relationship between the sulphate content of the soil and the efficacy of sulphureous fertilization.

2.2.2. Plant analysis.

As already mentioned, sulphur is absorbed by the plant mostly in the form of sulphate ions. The portion not required for the synthesis of organic compounds remains in the sulphate form in the vegetative organs, thus representing a sulphur reserve that is incorporated into the metabolism only in the case of emerging sulphur deficiency.

We have not been in a position to ascertain any enrichment in the generative organs, as e.g. the grains of cereals [55]. The sulphate sulphur content is normally suitable to characterize the sulphur supply degree of growing plants [47]. Upon conclusion of the vegetative stage, one has to fall back on the N:S ratio. The same applies to forage-crops serving to feed ruminants. In case of a N:S ratio larger than 13.0, the micro-organisms of the rumen are no longer in a position to fully utilize the nitrogen present in the feed [13].

The minimum sulphate reserve, i.e. the critical sulphate content, as well as the critical N:S ratio vary from one plant species to the other. Evaluating experimental results found in the literature as well as our own data, we arrived at the values indicated in Tables 1 and 2 [54, 55, 59]. All situations where these values are not attained are sulphur deficiency cases.

TABLE 1 — *Critical SO_4-S Percentages.*

Plant Species	Plant Organ	SO_4-S% in Dry Matter	
Sugar beets	middle leaf without petiole	0.05	(37)
Oats	aerial plant start of panicle formation	0.08	(56)
Ray grass	total aerial plant	0.10	(54)
Green rape	total aerial plant	0.40	(54)
Marrowstem kale	leaves	0.40	(54)
Turnips	leaves	0.40-0.50	(54)
Wheat	aerial plant start of shooting into ear	0.05	

TABLE 2 — *Critical N:S Ratios.*

Wheat	grain	14.8
Oats	grain	9.1
Barley	grain	13.0
Sugar beets	leaves	11.0
Green maize		11.0
Lucerne		11.0 - 12.0
Clover species		15.0
Gramineae		12.0 - 14.0

Under the climatic conditions prevailing in the Federal Republic of Germany, plant analyses represent the only evidential method to ascertain the sulphur supply degree of a plant. The same will most probably apply to countries with similar meteorological conditions. The results make it at the same time possible to judge the sulphur supply degree of the soil during the vegetation of the analyzed plants up to the moment of sampling. Owing to the rapid change of the sulphate content of the soil, already mentioned, it is unfortunately impossible to make any long-term statements. On top of it, the sulphur requirements vary from one cultivated plant to the other, so that on one and the same location it is absolutely possible for one plant species to suffer from sulphur deficiency whilst the requirements of the other are still secured.

2.2.3. Sulphur deficiency symptoms of plants.

It is difficult to characterize sulphur deficiency by external symptoms in view of the fact that they hardly differ from those of nitrogen deficiency. A clear distinction is only possible in the presence of vigorous vegetative growth. During this stage emerging nitrogen deficiency is first marked by a lightening-up of the old leaves, whilst in the case of sulphur deficiency this phenomenon may first be noted on the young leaves. In the case of crucifers, as e.g. marrorwstem kale or turnips, sulphur deficiency may lead to a deficient formation of the leaf spade or to spoon-like deformations of the entire leaf, as may be seen from Fig. 1.

These deformations are to be found, however, only in the presence of very strong sulphur deficiency. In the case of the yields of marrowstem kale and turnips diminishing by 10-34%, we did not detect the said symptoms [40]. In view of the fact that an important sulphur deficiency is unlikely to occur at the present time in the field, it is impossible in outdoor cropping to determine insufficient sulphur supply from deficiency symptoms.

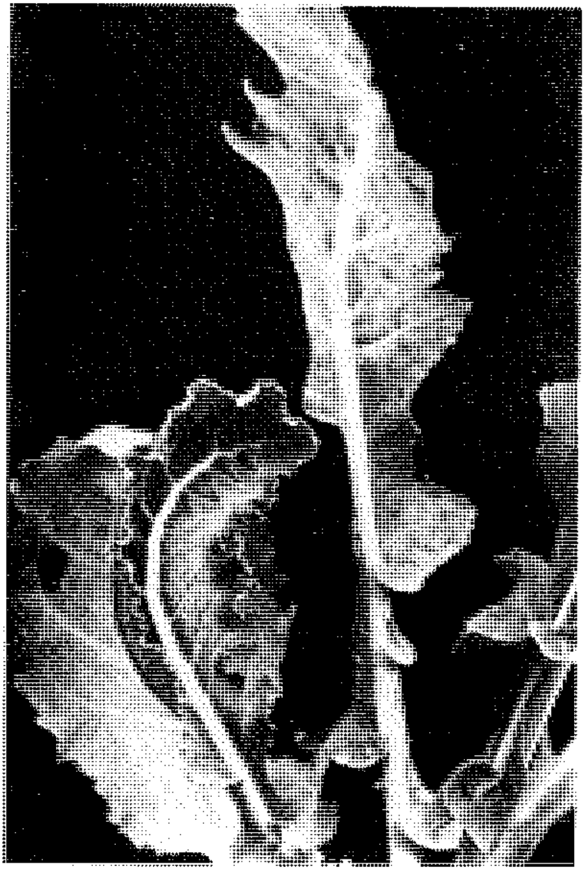


FIG. 1

2.3. *Which is the extent of sulphur deficiency in the Federal Republic of Germany?*

In order to characterize the sulphur supply degree of the arable surface of the Federal Republic of Germany, older articles [7, 27] contained sulphur balances showing that the sulphur supply from the atmosphere, by organic and inorganic fertilizers as well as by the mineralization of the organic matter in the soil was considerably larger than its removal by the plants and by sulphate leaching. As demonstrated by us [43, 46] and other authors [7, 27], these balances do not, however, permit any statement regarding the conditions prevailing at an individual location.

No systematic investigations into the sulphur supply degree of arable surfaces have up to now been made with the help of plant analyses. It is therefore impossible to give an idea of the extent of sulphur deficiency existing in the Federal Republic.

A lead is, however, given by the results of experiments with different echelons of sulphur applied to rape, marrowstem kale, turnips and pastures, which we carried out in the Federal Republic of Germany. Sulphureous fertilization produced higher yields only outside the areas of industrial concentration or other regions with elevated SO_2 percentages present in the air [46, 53, 54, 57].

2.4. *Which locations and crops should receive sulphureous fertilizers?*

We already indicated the difficulties existing for a determination of the sulphur supply degree of a specific location. In order to find out whether sulphureous fertilizers have to be applied, it is recommended to ascertain the sulphur supply degree of the plant species having the highest sulphur requirements of the entire crop rotation. If this species does not show any sulphur deficiency, the supply of the others is definitely secured. In case there are any symptoms of an insufficient supply, sulphureous fertilizers should be applied also to the other crops.

On the basis of the critical N:S ratios specified in Table 3 we calculated the sulphur requirements of various crops in order to detect the most fastidious one [59]. In the absence of any indications regarding the critical N:S ratios of straw and potatoes, we used the critical S percentages. The results are shown in Table 3.

TABLE 3 — *S Requirements for 10 Quintals of Dry Matter Yield.*

		N Percentages	S Requirements in kg
Wheat	grains	1.5 - 3.0	1.0 - 2.0
	straw		1.0
Oats	grains (husked)	2.0 - 3.5	2.2 - 3.8
	glumes		0.4
	straw		1.0
Barley	grains	1.5 - 2.5	1.2 - 1.9
	straw		1.8
Potatoes	tubers		1.1
	haulm		1.9
Sugar beets	roots		1.2
	leaves	2.0 - 3.5	1.3 - 2.3
Green maize		1.2 - 1.7	1.1 - 1.8
Lucerne		3.0 - 4.0	2.5 - 3.6
Clover species		3.0 - 4.5	2.0 - 3.0
Gramineae		2.0 - 4.5	1.4 - 4.2

Grassland (pasture, meadow) has not been included in the Table. Its plant population is, as you know, composed of gramineae, leguminosae, and herbs. In view of the fact that the ratio of these species varies from one location to the other, it is impossible to indicate any universal value, the individual values having to be calculated in each case on the basis of the critical content of gramineae, leguminosae and herbs.

It results from Table 3 that beets, maize and the forage-crops it enumerates have, indeed, the highest sulphur requirements, for which reason they have to be used as test plants.

2.5. *At which developing stage can sulphur deficiency be remedied with oats and wheat?*

In order to be able to answer this question, we, in 1966 and 1967, first made pot-experiments with oats on a sulphur-deficient soil [56]. Sulphureous fertilizers were applied before sowing, at the start of shooting or the beginning of panicle formation. As may be seen from Table 4, sulphureous fertilization at the start of shooting or the beginning of panicle formation produced, within the margin of error, the same yields as the dose administered before sowing.

TABLE 4 — *Influence of Doses of 100 mg S/Pot administered at Different Dates on Dry Matter Yield in g of Oats.*

	without S		S before sowing		S at beginning of shooting		S at panicle formation	
	1966	1967	1966	1967	1966	1967	1966	1967
Grain	56.7	53.7	60.6	*65.1*	*61.7*	*63.7*	*62.7*	*61.6*
Straw	44.4	51.8	*48.1*	*58.8*	*48.5*	*58.9*	*47.9*	*56.2*
Total	101.1	105.5	*108.7*	*123.9*	*110.2*	*122.6*	*110.6*	*117.8*

Italic data = significant against S_0

During a further experiment we found out that there is no relationship between the total S content, the SO_4-S content or the N:S ratio at the beginning of shooting and the grain yield. If, however, at the beginning of panicle formation the dry matter contained at least 0.08% of SO_4-S in the presence of a N:S ratio of 10.4 max., sulphureous fertilization did not produce any yield increase. Under the prevailing test conditions it was consequently possible at the beginning of panicle formation to ascertain the sulphur supply degree with a view to the yield and to remedy an eventual deficiency.

Experiments with spring wheat, that have not yet been published, produced the same result. Marginal values at the start of shooting into ears amounted to 0.05% of SO_4-S with a N:S ratio of 11.3. - 12.1.

The results obtained with wheat are, no doubt, of particular importance for practical agriculture. As you know, there is a growing tendency to apply an additional nitrogen dose of 40-60 kg of N/ha, at the moment of shooting into ears. If this dose is given in the form of a sulphureous nitrogen fertilizer, it is possible to remedy sulphur deficiency; this, however, on the condition that during their early developing stages the plants have been adequately provided with sulphur because, as we know from investigations made with most other nutrients, a deficiency prior to the shooting into ears can, owing to too small a number of grains per panicle or ear, never be completely made up for by later fertilizer applications.

2.6. *Sulphureous fertilizers.*

The penultimate of the questions listed at the beginning of this paper deals with the fertilizers that can be applied as a remedy against deficiencies. It will not be necessary in this context to enumerate the different products available on the market as they are, no doubt, well known. The list would, moreover, be very voluminous, as there are numerous sulphureous nitrogen, phosphate, potash and compound fertilizers on sale. Which fertilizer should be given a preference, will depend on price, fertilizer practices and the form in which sulphur is present in the individual products. It has to be kept in mind, however, that in humid climates the sulphate ion is subject to considerable leaching. There are many locations where sulphureous fertilizers applied in autumn will leave available only small traces of sulphur during the subsequent vegetation period. It is therefore advisable to administer the sulphur with products that are applied directly before or during the vegetation period.

3. Magnesium.

3.1. *What are the effects of insufficient magnesium availability?*

Magnesium is the central atom of the chlorophyll. In the case of insufficient Mg supply of the plants, the chlorophyll synthesis does not take an optimum course, and the Mg content of the leaves is smaller than with plants that have been adequately provided for. This leads to a reduced photosynthesis with, as a consequence, a smaller production of dry matter.

Only approx. 20% of the magnesium available in the plant are, however, present in the chlorophyll [4]. The remainder can be found in the sap of the cellules and the plasma, either in the form of free or sorption-bound ions [4, 24, 31]. These are the Mg fractions that chiefly exert an activating influence on various enzymes. They furthermore play an important part in maintaining an optimum swelling state of the plasma. In view of the fact that the functioning of the enzymes is greatly influenced by this swelling state, magnesium affects the course of the plant metabolism also unspecifically.

In addition to its importance as yield-promoting plant nutrient, magnesium also exerts an influence on the quality of the harvest products. Insufficient Mg supply entails a decrease of the starch content of potatoes, the sugar content of sugar beets [25] and the carotene content of spinach and carrots [35]. It is furthermore a well-known fact that too small Mg percentages in human nutrition may lead to disturbances in the metabolism, something that will, however, very rarely occur in practice, as human nutrition comprises normally various products that have moreover been produced on different locations. Grazing ruminants are in another situation, having to content themselves with a single feed, the pasture vegetation. The danger of an insufficient Mg supply is therefore much greater than in human nutrition. For this reason, the importance of magnesium for the feeding of dairy cows will be dealt with more in detail.

3.1.1. The magnesium supply of dairy cows.

According to the indications given by various authors [33], a dairy cow with a daily milking capacity of 20 l. requires on an average 25-30 g of magnesium per day. This figure was calculated on the basis of a medium resorption rate for the magnesium present in the feed of 17% [22]. In case of a consumption of 12-14 kg of dry matter, the magnesium content of pasture forage consequently has to amount to 0.18-0.24% in order to avoid any deficiency. Smaller percentages may result in the so-called "grass tetany". Fertility and power of resistance against the foot and mouth disease are also related to the magnesium supply. Owing to the fact that the full-grown animal organism is not in a position to mobilize magnesium from the bone deposit, the animals are dependent on a regular and adequate supply.

We stated in numerous experiments that in the presence of magnesium percentages of 0.13-0.14% in the dry matter of a pasture vegetation, magnesium fertilization did not produce any increase in yields. With respect to yield formation, the plants were adequately provided with Mg. For the nutrition of dairy cows, however, they represented a deficiency forage, consumption of which covered only approx. 2/3 of the magnesium requirements. On grassland the necessary magnesium content of the vegetation consequently has to be determined not with a view to the requirements of the plants but of the dairy cows.

3.2. *Which possibilities exist for determining magnesium deficiency?*

3.2.1. Soil analyses.

The magnesium supply of the plants depends in the first place on the interchangeable magnesium present in the soil, although in the soils of the Federal Republic of Germany it amounts in most cases to less than 5% of the total magnesium content.

Various authors have developed methods for determining the interchangeable magnesium content. In the Federal Republic we use the SCHACHTSCHABEL process [61] with a 0.025 n $CaCl_2$ solution serving as extration agent. By comparing the results of field fertilization experiments and soil analyses, the Verband Deutscher Landwirtschaftlicher Untersuchungs- und Forschungsanstalten (Association of German Agricultural Research Stations) set up the limits enumerated in Table 5 [11].

These limits have to be considered as guiding values for the plant-available magnesium content of the soil. They offer, however, only a clue of the secured degree of Mg supply of the plants, magnesium absorption being affected by the hydrogen, potassium and calcium ion concentrations in the soil solution.

It has furthermore to be mentioned that, as demonstrated by us [26, 41], the application of natural fertilizer may have a favourable effect on the magnesium supply of the plants.

Soil analyses have the advantage that with a relatively small expenditure it is possible to get an idea of the magnesium supply degree of a specific location.

TABLE 5 — *Magnesium limits in mg of Mg/100 g of Soil.*

Magnesium-		Arable Land			Fruit-growing, Gardening and Grassland	
Group	Content	Sand and Loamy Sand	Sandy Loam and Loess	Loam and Clay	Sand and Loamy Sand	Loess, Loam and Clay
I	high	> 5.0	> 7.0	> 12.0	> 15.0	> 20.0
II	medium	2.6 — 5.0	3.7 — 7.0	6.1 — 12.0	8.1 — 15.0	11.1 — 20.0
III	low	to 2.5	to 3.6	to 6.0	to 8.0	to 11.0

TABLE 6 — *Mg Limits in % of Dry Matter.*

Plant	Moment of Sampling	Plant-Organ	Deficiency	Sufficient
Wi wheat	shoots up to 40 cm	total aerial plant	< 0.10	0.21 — 0.40
Wi rye	shoots up to 40 cm	total aerial plant	< 0.09	0.30 — 0.60
Wi barley	shoots up to 40 cm	total aerial plant	< 0.05	< 0.20
Oats	shoots up to 40 cm	total aerial plant	< 0.08	0.18 — 0.32
Maize	plant up to 15 cm	total aerial plant	< 0.13	0.31 — 0.50
Potatoes	75 days after planting	top leaf	< 0.15	0.21 — 0.80
Sugar-beets	end June/beg. July	middle leaf without petiole	< 0.05	0.25 — 1.0
Meadow-grasses	beginning of flowering 1st cut	total aerial plant	< 0.10	0.20 — 0.60+

+ Taking into account animal nutrition.

3.2.2. Plant analyses.

Compared to soil analyses, plant analyses represent a much greater expenditure of energy. Their results offer, however, a direct measure for the magnesium supply. Limits for an adequate supply are specified in Table 6 compiled on the basis of data supply by NEUBERT, WRAZIDLO, VIELEMEYER, HUNDT, GOLLMICK and BERGMANN [37].

In the Federal Republic of Germany plant analyses are used much less frequently than soil analyses. They are of particular importance for fruit growing and, above all, for grassland. We found in our own investigations that soil analyses did not produce any satisfactory results in the determination of the Mg content of a pasture vegetation, for which reason we always fell back on plant analyses.

3.2.3. Symptoms of insufficient Mg supply of plants.

Particularly during the period of young and vigorous growth, magnesium deficiency may be noted from a partial lightering-up of the leaves, starting generally with the older leaves in view of the fact that with emerging deficiency, Mg is translocated from the older to the younger leaves. Its outward appearance is consequently the opposite of what we get in the case of sulphur deficiency. Pronounced deficiency may lead to typical foliar damages that have been described in detail by various authors, as e. g. KÜRTEN and AIGNER [25], so that in this context we may desist from such a description.

The observation of crops for these deficiency symptoms is a valuable means for judging the degree of magnesium supply.

3.3. *Which is the extent of Mg deficiency in the Federal Republic of Germany?*

As already mentioned, the magnesium supply degree of arable land is in the Federal Republic of Germany mostly determined with the help of soil analyses that are normally made by the Landwirtschaftliche Untersuchungs- u. Forschungsanstalten (Agricultural Research Stations) of the Länder. The results obtained are evaluated statistically and give a good survey of the prevailing situation. To give an example, Table 7 contains the data ascertained in Westphalia [11].

TABLE 7 — *Results of Determination of Mg Availability in Westphalian Soils* [11].

Years	Arable Land in %			Grassland in %		
	I high	II medium	III low	I high	II medium	III low
1954-1965	12	41	47	24	49	27
1966-1970	17	39	44	11	64	25

Whilst the ratio of arable soils with high, medium or low magnesium availability has during the two specified periods undergone only minor changes, the grassland locations we examined were marked by a distinct decrease of the percentage of soils well provided for, which during the period 1966-1970 amounted to still only 11%. Similar tendencies have become manifest also in other Länder of the Federal Republic. Magnesium fertilization has consequently to be given more attention than has hitherto been the case. This holds true in particular for grassland locations in order to reach elevated percentages in the pasture vegetation and, in this way, secure an adequate Mg supply to dairy cows.

3.4. *Which are the Mg requirements of the most important cultivated plants?*

It is easy to answer this question as far as pasture vegetation is concerned. As the necessary Mg content depends on the requirements of the grazing animals and, according to Paragraph 3.1.1. has to amount to 0.18-0.24%, it will not be difficult to calculate the quantity required on a specific location. Efforts should be made to attain the upper value of the indicated spread.

As may be noted from Table 8 specifying the average Mg removals, magnesium requirements differ from one field crop to the other [2].

TABLE 8 — *Magnesium Removals of Certain Field Crops.*

Plant	Removal per	kg MgO
Cereals	10 quintals of grains + straw	3 - 5
Grain maize	10 quintals of grains + straw	6 - 10
Early potatoes	100 quintals of tubers + haulm	10 - 20
Sugar-beets	100 quintals of roots + leaf	10 - 20

For availability group I, i.e. soils with a high content of interchangeable magnesium, one may say that normally the requirements of all crops will be satisfied. It may therefore be recommended to enrich soils of the availability groups II and III with magnesium in such a way that their content equals that of group I. Subsequently, the magnesium supply has to be rated so as to avoid any decrease of the Mg percentages.

3.5. *Magnesium fertilizers and their effects.*

The magnesium supply of field crops may be secured on the one hand by organic fertilizers, on the other by mineral fertilizers.

Farmyard manure is no doubt the most important organic fertilizer. According to investigations made by SCHARRER and PRÜNN [63], the Mg percentages of the dry matter of manure vary from 0.3 to more than 2.0%. On farms with locations marked by low Mg percentages, the Mg content of the manure is low, too, for which reason there is in that case hardly any possibility for organic fertilizer to improve the degree of Mg availability in the soil.

As regards mineral fertilizers with an elevated magnesium content, agriculture in the Federal Republic of Germany disposed up to 1962 mainly of magnesium containing potash and lime fertilizers. Although obtainable on the market, kieserite was used very seldom. In cooperation with the Developing Section of one of our fertilizers factories, we therefore developed, on the basis of ammonium sulphate nitrate and kieserite, a nitrogen magnesium sulphate. In view of the fact that many magnesium deficient locations also lack copper — which holds particularly true for grassland — we also added copper. The product in question thus has a nutrient content of 20% of N, 8% of MgO and 0.2% of Cu. It has been demonstrated by numerous experiments that by its application it has become possible to remedy magnesium deficiency of field crops and to increase on grassland the magnesium content of the pasture vegetation to the degree required for the nutrition of dairy cows. This is exemplified by the results of field trials, published by KÜRTEN and AIGNER [25] as well as by MUNK and JUDEL [34], Tables 9 and 10.

In view of the fact that in many regions of the Federal Republic of Germany grassland fertilization is carried out with compound fertilizers with, however, no product on the market that would have satisfied the particular requirements

TABLE 9 — *Yield Increases by Nitrogen Magnesia applied to Winter Wheat and Spring Barley as compared to Mg-free Nitrogenous Fertilization.* Average of all Tests made on Soils with medium to low Mg percentages (Groups II and III).

	No. of Experiments	NMgCu	KAS	Surplus Yield NMgCu in comparison with KAS	
Winter wheat					*GDP* 0,1%
Grain yield					
dz/ha	8	53.5	51.5	+ 2.0	1.42
relative figure		104	100		103
N content in grains %	8	2.00	1.94	—	
Mg content in grains %	8	0.15	0.14	—	
Spring barley					
Grain yield					
dz/ha	6	38.0	35.9	+ 2.1	1.8
relative figure		106	100		105
N content in grains %	3	1.91	1.86	—	
Mg content in grains %	3	0.18	0.17	—	

TABLE 10 — *Effects of three Years of Mg Fertilization with Nitrogen Magnesia on the Mg Content of Pasture Plants.* (Medium values).

NMgCu in various partial dressings		Mg Content in first upgrowth in % of Dry Matter					
		1961		1962		1963	
N (kg/ha)	MgO (kg/ha)	without Mg fertilization	with Mg fertilization	without Mg fertilization	with Mg fertilization	without Mg fertilization	with Mg fertilization
120	48	0.12	0.13	0.13	0.16	0.16	0.19
180	72	0.16	0.17	0.18	0.20	0.18	0.24

of grassland also with a view to the minerals needed by the grazing animals, we developed the compound fertilizer « RUSTICA Weidevollkorn » with the following nutrient content: 15% of N, 9% of P_2O_5, 5% of K_2O, 5% of MgO, 4% of Na_2O and 0.1% of Cu. The ratio nitrogen: magnesium is somewhat larger, it is true, in this product than in Nitrogen Magnesia with copper, but notwithstanding this fact both fertilizers proved equally effective on numerous locations and, indeed, increased the magnesium content of the pasture vegetation. The aforementioned compound fertilizer also contains sodium, for which reason it will be dealt with more in detail in the following chapter discussing the sodium supply of plants.

4. SODIUM.

4.1. *Which are the consequences of an insufficient sodium supply of plants?*

The importance of sodium as a plant nutrient has been the object of a large number of investigations without having been completely clarified up to this day. BAUMEISTER [5] who effected a summary evaluation of the results available up to 1959, arrives at the conclusion that on the basis of experimental investigations as well as theoretical considerations sodium may be qualified as an element that is very important, if not indispensable for the plant. A categorical appreciation of the effect of sodium on the plant is, however, complicated by the fact that sodium deficiency symptoms have up to now been described in very rare cases only. Nevertheless it has been established that sodium promotes the growth of various plant species, particularly in those cases where the potassium supply is inadequate. HARMER and BENNE [17] effected the classification given in Table 11, which was compiled on the basis of results obtained by COLLANDER [9] and LEHR [28] as well as proper investigations.

TABLE II — *Classification of Various Plant Species according to Dependency of Yields on Sodium Fertilization.*

1. Plants which show little or no response, even in the presence of potash deficiency: Maize, onions, potatoes, rye.

2. Plants with a feeble to medium response in the presence of potash deficiency: Barley, oats, tomatoes.

3. Plants whose yields will, in the presence of an adequate potash availability, increase by sodium fertilization: Rooted celery, wheat, rape.

4. Plants whose yields will, in the presence of an adequate potash availability, be promoted considerably by sodium fertilization: Celery, fodder beet, sugar beet, turnip.

It has to be underlined, however, that according to investigations made by EL-SHEIK, ULRICH and BROYER [12] sodium fertilization promotes, even for the sugar beet included in class 4, mainly the growth of the leaves and to a lesser degree that of the roots.

In the Federal Republic of Germany sodium is not consciously included in fertilization practices. In the cultivation of forage crops this may entail considerable deterioration of quality as sodium is an element of vital importance for animals. The rôle of sodium in animal nutrition will therefore be dealt with more in detail.

4.1.1. The importance of sodium for animal nutrition.

Various authors, as e.g. WIESNER [68] and WÜRTELE [71], state that sodium deficiency may produce defective growth by reduced utilization of proteins, lack of appetite, fertility disturbances, nervous disturbances and a decreasing milking capacity, phenomena they detected with rats, chickens, cattle and horses. Sodium deficiency will rarely occur during stabling, as normally all minerals required by the animal will be supplied. Grazing dairy cows are, however, often in a different situation, if the pasture vegetation has a low sodium content and no minerals are given in addition.

As may be noted from Table 12, indications to be found in the literature about the sodium requirements of dairy cows are differing.

TABLE 12 — *Sodium Requirements of Dairy Cows for 500 kg of Weight and 20 kg of Milking Capacity in g/day.*

Upkeep	Production	Total	Author
10	20	30	WIESNER [68]
—	—	25	BECKER [21]
9	15	24	DE GROOT [16]
7	10	17	KEMP [22]

According to these data, 17-30 g have to be absorbed in order to avoid sodium deficiency. Taking a daily consumption on the pasture ground of 12-14 kg of dry matter as a basis, one may conclude that the requirements will be satisfied by sodium percentages in the dry matter of the pasture vegetation of 0.15-0.20%. During a 6 months' feeding experiment, KEMP [22] discovered that a sodium content of 0.15% is sufficient even for dairy cows with a milking capacity of 20-30 l.

It is not intended to say any more in this paper about the importance of sodium as a plant nutrient. It will on the contrary only be considered with a view to the mineral supply of grazing cows, basing on the assumption that a sodium content of 0.20% in the pasture vegetation has to be considered as adequate for the support of dairy cows with a daily milking capacity of up to 20 l.

4.2. *Which possibilities exist for determining sodium deficiency in the pasture vegetation?*

4.2.1. Soil analysis.

The sodium content of the pasture vegetation depends essentially on the available sodium and the competing ions, as e.g. potassium ions, present in the soil, as well as on the specific capacity of absorbing and translocating sodium ions into the shoots. It has furthermore to be mentioned, that, similar to the sulphate ion, the sodium ion in the soil is subject to considerable leaching, for which reason, just like in the case of sulphate determination, it is not always possible, on the basis of the results of soil analyses to make any long-term statements about the sodium supply degree of a specific location. In the Federal Republic of Germany soil analyses are, therefore, used very seldom.

In regions with different soils, other climatic conditions and a different botanical composition of the pasture vegetation, as e.g. The Netherlands, soil analyses may be employed successfully. This results from papers by OOSTENDORP [38] and HENKENS [19]. It proves to be necessary, however, to determine not only the available sodium content but also the potassium percentage, a phenomenon confirmed by investigations made by MENGEL and MEMETH [32].

4.2.2. Plant analysis.

Plant analyses permit the most positive statements on the sodium supply degree. As normally the sodium percentages of the first upgrowth are lower than those of the following, it is the first vegetation that should be analysed, 0.20% of Na in the dry matter having to be regarded as a limit.

Sodium deficiency symptoms of forage crops being unknown, they cannot be drawn upon to characterize the sodium supply degree.

4.3. *Which is the extent of sodium deficiency on grassland?*

In the Federal Republic of Germany, no systematic evaluations of the sodium content of the pasture vegetation have been made. Analyses of a large number of samples from north-west German regions, which we effected at our Institute, proved that only 2% arrived at the necessary content of 0.20% of Na [33]. Other authors came to similar conclusions, as may e.g. be seen from Table No. 13 by WERNER [67].

TABLE 13 — *Na Content in 1st Upgrowth of Pasture Plants* [67].

Na Content in % D.M.	Frequency Distribution (312 = 100%)
to 0.030	17%
0.031 - 0.05	26%
0.051 - 0.07	20%
0.071 - 0.09	15%
0.091 - 0.11	10%
> 0.11	12%

These examples prove that the sodium content of most analysed samples was inadequate. Corresponding results could be obtained from most grassland regions of the Federal Republic.

4.4. *Sodium fertilizers and their effects.*

Of the fertilizers at our disposal, nitrogen, phosphate and potash fertilizers are the ones that contain larger quantities of sodium. Cattle lick may also be used for fertilizing purposes. Up to very recently, there was no sodium containing compound fertilizer on sale. In view of the fact that on many farms compound fertilizers are for grassland fertilization preferred to single fertilizers, we examined the question whether it would be worthwhile to develop such a product.

As stated in Para 4.1., the response to sodium fertilization varies from one plant species to the other. We had no knowledge of any results of systematical research work carried out with typical pasture plants. Investigations made by other authors mostly included only one or two grass species [14, 15, 62] or ascertained the sodium percentages of plants that did not originate from fertilizer experiments but from natural plant populations [18, 30, 66, 70]. For this reason we investigated into the influence exerted by sodium fertilization on the sodium content of various grass and clover species [51, 57] with the objective of detecting those for which it is possible, by way of fertilization, to lift the sodium content to the necessary level of 0.20%.

4.4.1. The effects of sodium fertilization on the sodium content of certain grass and clover species.

We first made pot-experiments. At the start of the vegetation, one test series received 1.5 g of N, 0.9 g of P_2O_5, 0.5 g of K_2O, 0.5 g of MgO and 0.01 g of Cu, whilst the other got an additional dose of 0.4% of Na_2O. After each cut, a further dressing consisting of half this quantity was applied. The nutrient ratio was chosen on the basis of the results obtained in preliminary investigations made in the field of plant physiology and production technique.

TABLE 14 — *Influence of Sodium Fertilization on the Na content of various Gramineae and Clover Species in % of D.M.*

Cut	without Sodium Fertilization				with Sodium Fertilization			
	1	2	3	4	1	2	3	4
Lolium perenne	0.09	0.25	0.22	0.19	0.34	1.50	1.54	1.34
Lolium multiflorum	0.07	0.22	0.17	0.17	0.44	1.40	1.28	1.20
Dactylis glomerata	0.03	0.14	0.15	0.15	0.06	0.43	1.03	1.13
Festuca pratensis	0.02	0.05	0.09	0.09	0.04	0.25	0.85	0.66
Festuca rubra	0.01	0.06	0.21	0.11	0.01	0.19	0.45	0.31
Agrostis gigantea	0.02	0.03	0.08	0.10	0.03	0.12	0.38	0.32
Poa pratensis	0.02	0.01	0.09	0.08	0.04	0.08	0.29	0.32
Phleum pratense	0.01	0.01	0.03	0.01	0.01	0.04	0.15	0.12
Trifolium repens	0.13	0.13	0.23	0.26	0.39	0.75	1.28	1.32
Lotus corniculatus	0.05	0.04	0.07	0.04	0.06	0.20	0.31	0.30
Trifolium hybridum	0.03	0.02	0.05	0.01	0.08	0.09	0.16	0.12

The influence of sodium fertilization on the sodium percentages results from Table 14. In the case of Lolium perenne, Lolium multiflorum and Trifolium repens it caused an increase of up to more than 0.20% already in the first cut. With Dactylis glomerata, Festuca pratensis and Lotus corniculatus this value was surpassed in the second cut, with the other species, apart from Phleum pratense and Trifolium hybridum, in the 3rd cut only. The last two species showed maximum percentages of 0.15 resp. 0.16% of Na.

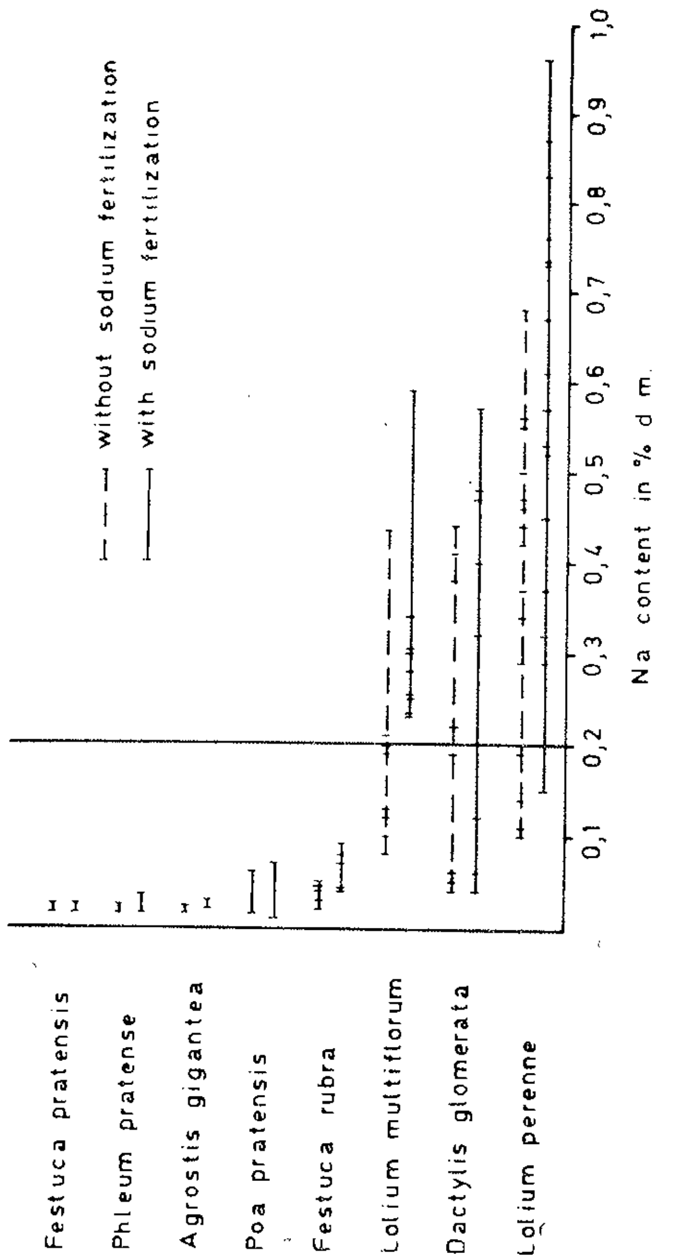
Herbs had not been included in the experiments. We analysed, however, individual plants or plant groups originating from outdoor fertilizer trials, thus arriving at the indications given in Table 15 [52].

TABLE 15 — *Sodium Percentages in % of Dry Matter of 1st Upgrowth of Pasture Plants.*

	I	II	III	IV
Gramineae	0.01	0.02	0.06	0.16
Clover species	0.01	0.02	0.12	0.17
Dandelion	0.02	0.08	0.16	0.25
Plantain species	—	—	0.26	0.50

Apart from one exception (experiment III), there were no differences in the sodium percentages of gramineae and clover species. This is largely in agreement with the findings of WALLACE [66]. Dandelion and plantain species contained more sodium than the aforementioned plant species, provided an adequate quantity of sodium was available in the soil. If gramineae and clover species of a plant population were marked by low sodium percentages (experiments I and II), this was also true for dandelion and plantain.

We know from investigations made by GRIFFITH and WALTERS [15] that there may be differences in the sodium absorption capacity not only between species but also between varieties. We therefore examined this problem in a field experiment with 58 breeding varieties officially recognized in the Federal Republic of Germany, as well as with 8 species [58]. Fertilization was effected with a compound fertilizer of the following composition: 15% of N, 9% of P_2O_5, 5% of K_2O, 5% of MgO, 4% of Na_2O and 0.1% of Cu, a sodium-free product that contained the other nutrients in the same ratio serving for comparison. Results may be noted from Graph I, the inserted marks representing the average values of the different varieties.


without sodium fertilization
with sodium fertilization
Festuca pratensis
Phleum pratense
Agrostis gigantea
Poa pratensis
Festuca rubra
Lolium multiflorum
Dactylis glomerata
Lolium perenne
0,1
0,2
0,3
0,4
0,5
0,6
0,7
0,8
0,9
1,0
Na content in % d m

GRAPH 1

The varieties of Festuca pratensis, Phleum pratense, Agrostis gigantea and Poa pratensis had a very low sodium content. Contrary to the pot-experiments, there was no response to sodium fertilization. This phenomenon may be attributed to the differing potash supply of the plants. The Festuca rubra varieties showed a feeble response to sodium fertilization, the Lolium multiflorum, Dactylis glomerata and Lolium perenne varieties a good to very good one. It became apparent that varieties that had a low sodium content without sodium fertilization, reacted in most cases only slightly to an application of sodium, varieties marked by a high sodium content already without sodium fertilization, utilized the sodium fertilization to a much greater extent. The capacity of specific varieties to absorb very high sodium quantities should be taken into consideration for resowing.

4.4.2. Influence of sodium fertilization on the cation content of various grass and clover species.

We mentioned in Para 4.2.1. that the sodium content of the pasture vegetation depends a.o. on the presence of competing ions. From investigations made with other plant species we know furthermore that also the sodium ion affects the percentages of other cations [5]. For this reason we investigated into the influence of sodium fertilization on the sodium, potassium, calcium and magnesium content [1]. Results are indicated in Table 16.

In all plants included in our investigation we detected a positive relationship between the level of sodium fertilization and the sodium ion content. Increasing sodium dressings exerted, however, only an insignificant influence on the potassium ion content. The influence on magnesium percentages proved to be negligible, too, an exception being made by the Lolium species. The somewhat greater decrease of the magnesium content observed with them has most probably been due to a diluting effect and not to a direct competition of ions,

TABLE 16 — *Correlation between Sodium Fertilization and Cation Content Correlation Coefficient r.*

	Na^+	K^+	Ca^{++}	Mg^{++}	Total Cations
		a) Gramineae			
Lolium perenne	0.77**	- 0.07	- 0.86***	- 0.40	0.74**
Lolium multiflorum	0.76**	- 0.10	- 0.82***	- 0.43	0.73**
Dactylis glomerata	0.56*	0.14	- 0.81**	0.03	0.50
Festuca pratensis	0.57*	0.13	- 0.83***	- 0.08	0.52
Festuca rubra	0.41	0.08	- 0.28	- 0.21	0.16
Agrostis gigantea	0.60*	0.10	- 0.73**	- 0.23	0.14
Poa pratensis	0.46	0.02	- 0.11	- 0.09	0.39
Phleum pratense	0.61*	0.02	- 0.47	- 0.06	0.02
		b) Clover Species			
Trifolium repens	0.75**	- 0.07	- 0.19	- 0.21	0.43
Lotus corniculatus	0.78**	- 0.08	- 0.05	- 0.14	0.34
Trifolium hybridum	0.85**	0.05	- 0.60*	- 0.05	0.09

Significance limits: * P = 5% 0.58
** P = 1% 0.71
*** P = 0.01% 0.82

because it were these two species where sodium fertilization had led to significant yield increases.

Sodium fertilizers exerted an adverse effect on the calcium content of the gramineae and of Trifolium hybridum. The absolute percentages amounted, however, in the presence of the low sodium dressing to 0.60-0.65%, in the presence of the high dose to 0.58%, thus maintaining a level that is adequate for the support of dairy cows.

4.4.3. Conclusions.

Although in the field experiment not all species reacted to sodium fertilization in the same way as during the pot experiments, the following considerations may be made in favour of a sodium application:

1. Most varieties of Lolium perenne, Lolium multiflorum and Dactylis glomerata absorb with corresponding fertilization much more sodium than is necessary for the support of dairy cows. It becomes in this way possible to compensate deficiencies existing in other plant species of the grassland population.

2. In the pot-trial with a smaller supply of competing ions the species that came off badly in the field experiment showed a better response.

3. The application of high nitrogen dressings, as is customary in intensive grassland farming, leads in the course of the years to a shift in the plant population. The Lolium varieties and dandelion, if they form part of the population, gain ground. These species are in a position to well utilize a sodium fertilization.

4. If yields are increased by fertilization, there is at the same time an increase in the removal of minerals that also affects sodium. If fertilization does not include this nutrient, inadequate availability in the soil will entail a decrease of the percentages present in the plant, and the situation that is unfavourable as it is will become even worse.

We therefore advocated the production of a sodium containing compound fertilizer which was put on sale in 1968. Practical use and numerous further field experiments confirmed the possibility existing on many pasture-grounds to lift the sodium content of the pasture vegetation without affecting the percentages of other minerals in such a way that the support of dairy cows would be jeopardized.

5. Summary.

As in most other countries of the world, consumption of mineral fertilizers and, as a consequence, harvesting yields have increased continuously during the last few decades also in the Federal Republic of Germany. Simultaneously with this development there occurred a change in fertilizing practices: Instead of using fertilizers with a low nutrient content but a relatively high percentage of secondary substances, consumers tended increasingly in the direction of high-percentage products. As a corollary, the sulphur, magnesium and sodium supply of plants became steadily worse. For this reason, the following problems have been dealt with:

1. What is the effect of insufficient sulphur, magnesium or sodium availability on various cultivated plants?

2. Which possibilities exist for determining a deficiency?

3. To which extent may a deficiency of the said three nutrients be noted at present in the Federal Republic of Germany?

4. Which fertilizers should be applied as a remedy against such deficiencies?

5. Will it be necessary to develop new fertilizers?

Sulphur deficiency leads to a decrease in yields and a deterioration of the protein quality. In the Federal Republic of Germany it can be proved by plant analyses only. It is not possible to give an idea of the extent of sulphur deficiency occurring in our country. For crops needing a lot of sulphur, as e.g. intensively used grassland, sugar-beets and field forage-crops, it is recommended to apply sulphureous fertilizers, unless a high SO_2 content is present in the air. Numerous sulphureous fertilizers are on sale.

Magnesium deficiency, too, reduces yields and quality of

harvest products. With a view to animal health, it is necessary for the upgrowth of pasture-grounds to contain more magnesium than necessary for optimum yield formation. Magnesium deficiency, at least on arable land, may be demonstrated by soil analyses. More accurate statements as to pasture-grounds become possible by plant analyses. Magnesium deficiency is to be found more often on pasture grounds than on arable land. The effects of a magnesium containing nitrogenous fertilizer on yield and quality are being examined.

The significance of sodium as a plant nutrient has still not been completely clarified. Sodium being, however, a mineral of vital importance for animal nutrition, attention has to be paid to the sodium supply of pasture plants. Sodium deficiency, too, can best be proved by plant analyses. Most grassland locations in the Federal Republic of Germany suffer from sodium deficiency. The paper studies the influence of a new, sodium containing grassland fertilizer on the sodium percentages of various grassland plants, investigating in particular into the response of the different plant species and varieties.

It has been the intention of the author to underline the importance of the nutrients sulphur, magnesium and sodium for yield formation and the quality of the harvest products, and to demonstrate, to which extent they have to play a part in fertilization in our country at the present time. The situation may be different elsewhere. With an increasingly one-sided fertilization with nitrogen, phosphate and potash, a similar development has, however, been initiated also in those countries. In order to be preserved from adverse effects, a more intensive fertilization should not only include the main nutrients but also the secondary elements.

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DISCUSSION

Chairman: J. T. Pesek

Primavesi

On page 7 of your interesting contribution you said that under your climatic conditions « *plant* analyses represent the only evidential method to ascertain the sulphur supply degree of plants ». I can confirm that we have the same experiences in tropical and subtropical climates.

On page 33, paragraph 4.4.4., you said « If yields are increased by fertilization, there is at the same time an increase in the removal of minerals that also affects sodium ». I agree perfectly with you. I am referring to all necessary nutrients, macro and micro-nutrients, of a plant. In the Tropics and Subtropics this is very much greater than in zones with temperate climates. Because of this, we have to make efforts to introduce fertilization with all necessary nutrients which are lacking in soil.

Hernando

I could not follow the exposition of your paper but I have read it already and I have several points to make, though I present only one. I think it is interesting in relation to other things. You say that you made experiments with sulphur in pots in relation to a soil test and you got a very good correlation, but when you try to do that in field trials, you do not get correlation. You offer an explanation of the sulphur coming with rainfall, but I think that it is the same as with other elements where it is not possible to explain it like that. Sometimes with phosphorus, sometimes with nitrogen, sometimes with potash and other elements, and I think we get a misunderstanding in the problem of checking the soil test. When we made a check of the soil test in greenhouse conditions we had all these things correlated: climate conditions, sometimes pest control, but in field conditions that is not possible for the moment. And when we don't find correlation in field trials and we do in greenhouses it does not mean that the soil test is bad. It means that in the whole problem there are other conditions to be taken into account: rainfall, temperature, etc. and the possibility of uptake of the elements by the plants. I think that this point is important and I suggest that we discuss it in our conclusions.

PESEK

I might comment that in the western cornbelt we do have areas of sulphur deficiency. In our particular state we have not observed any in the field. However, we know that we can bring soils into the glasshouse and crop them successfully to *Lolium perenne* and eventually reduce the sulphur content to the point where the sulphur becomes deficient and we find that there is a difference among soils in the rate at which sulphur deficiency is reached by continuous cropping in a glasshouse.

SAALBACH

We cannot find in pot experiments and field trials the same relations between the sulphate content of the soil and the sulphur state of the plant because the factor rainfall is eliminated in pot experiments. Under the influence of rainfall the sulphate content of the soil changes rapidly. This we have found in our field experiments during the years 1961-1963. The rainfall enriches the soil with sulphur and washes it out of the soil. But there is also another problem. The plant can absorb the sulphur from the air by the leaves. This sulphur which is very important for the nutrition of the plant, cannot be estimated by soil analysis. Therefore it is not possible to use the soil analyses in highly industrialized countries.

OBERLÄNDER

Dr. SAALBACH, I think your paper was an excellent example for the diabolic circle into which farmers have been pushed. First they got rid of the « ballast » for the sake of higher analysis products, and now they are forced to buy this « ballast » in a processed form at much higher cost again. I wonder if the benefit derived from high analysis products is worth the expense of additional micronutrient fertilizers.

SAALBACH

The farmers buy high concentrated fertilizers because storage and transport are cheaper and also the cost of package materials per unit of nutrient are lower. Of course, farmers can also buy lower concentrated products if they want to.

OBERLÄNDER

Maybe I wasn't quite understood. If you would take the old low analysis products with all the ballast, containing the necessary microelements at low cost and compare it with the present situation, with the higher level products without the ballast where you are forced to add some fancy micronutrient mixtures, now certainly the costs for the farmer became considerably higher and it is the question: is this worth the benefits derived from the improved conditions? Should not the old system be kept under certain conditions, to save the farmer's money.

PESEK

I suppose the answer to that is that we do not really know whether it is more expensive to replace the « ballast », so to speak, with pure salts that are needed or to go back to the old fertilizer. Anyway we are a long way from going back and it would take a major effort to go back.

RUSSELL

When you do get a response to sulphur I think you will find that adding two or three kilos of elemental sulphur per hectare is as good as any way of adding sulphur to the soil for groundnuts in Africa. It is better than transporting a lot of single superphosphate about the place, in case there is a sulphur deficiency.

PESEK

This reinforces the comment that I made previously that the problems have still not been clearly identified.

BUSSLER

I think we have some problems made by ourselves. We group the nutrients in two groups, the major elements and the minor elements and as we have seen by Prof. SAALBACH, he has some major elements in his additional fertilizers, sulphur and magnesium and one element could be a minor element — it is sodium. I think this grouping of the nutrients in two groups is not needed because there is no significant importance concerning the scientifical thinking of the nutrient effect and there is no importance concerning practical use. It would be easier to speak always about nutrients, and these nutrients start with nitrogen which is used in very high amounts and may be, on the other end Mo is used in only very small quantities. When we speak of nutrients we are always forced to think over the sitnation: are all the nutrients in the medium or solution in the right amount?

SAALBACH

I have the same opinion as you do.

BORNEMISZA

I have a point to make on the sulphur situation. I saw on your slide that you were working with sandy soils which are known to have very little sulphate retention. This might be the explanation why soil analysis is of very little utility. If you were to go over to heavier soils, where there is a medium and sometimes a quite serious sulphate retention, the situation might be changed.

SAALBACH

It is true that in heavy soils the sulphate content changes not as rapidly as in sandy soils — as we found in Lysimeter experiments. Bnt the sulphate content changes also. Therefore the soil analysis is also in this case of very little sncccss.

ARATEN

Dr. SAALBACH said that the content of sulphur in the soil is a function of rain but in Dr. SAALBACH's slides there is a minimum of sulphur in December 1962 when there is a maximum of rain.

SAALBACH

I have said that the rainfall influences the sulphate content in the soil. We have not been able to find a mathematical correlation between the amount of rain and sulphate content of the soil. We have investigated this problem with the help of Dr. VAN DER PAAUW who has studied the correlations between rainfall and nitrogen content of the soil. In the case of sulphur we had no success.

HERNANDO

I think we do not find correlation because there are two problems joined here, one is the amount of sulphur which comes with rainfall and the other is the retention of the soil. But on the other hand, there is a big difference with the area that Dr. BORNEMISZA spoke about — the regions in which he works — there are not many factories, there are not many industries and there is not much sulphur in the air. In your area, there is much sulphur in tbe air, the first rainfall brings a large amount of sulphur to the soil but the rainfall afterwards does not bring much sulphur. In any soil without good retention conditions, the high rainfall does not increase the sulphur as much as the low rainfall, because the drainage takes the sulphur away. I think it is a matter of these two points.

WALSH

I think we are forgetting something here. If you read Sir John Russell's book « Soil Conditions and Plant Growth » (1st edition) you will find there a chapter about the role of sulphur in the biological cycle in soils. Sulphur is part of the organic complex in soils and is liberated under microbiological activity. We must not forget this. We find this very important under our conditions where we have relatively high levels of sulphur in our soils in general. We do, however, get sulphur deficiency in some of our soils depending on the nature of the soil. We find quite a good relationship between soil type and sulphur level. Perhaps it would be useful to read RUSSELL's book again. In my young days we talked about sulphur, magnesium and sodium as secondary elements. They are not, of course, so secondary under the conditions of agricultural practice and commercial farming that we are now talking about. Another point is we cannot be transporting a lot of NPK around in low nutrient concentration unless you have a lot of money in your pocket to do so. On the other matter of magnesium, the situation is a bit more involved. Grass Tetany, a metabolic disturbance in dairy cows, is of course influenced by a number of factors, e.g. by imbalance of nutrition at high levels of N and K relevant to magnesium. It is also very much influenced by climate. On what may seem to be perfect pasture at this time of the year, a cold spell may come and dairy cows fresh out of the house, may go down almost overnight with tetany. In other words there is a trigger mechanism in operation. At high levels of magnesium in herbage the effect is, however, prevented or minimised. Sodium also becomes more important under conditions of highly intensive farming. Despite our nearness to the ocean we have some problems in Ireland. This question of sodium then needs much more attention under conditions of intensive farming. Finally again, it must be said that as we move into higher levels of production anywhere, that these secondary elements become more important and consequently need to be looked at anew.

FITTS

I was just going to point out that in our areas organic source of sulphur is probably much more important than the sulphate source and this is particularly true in the upper profile. If you look at the surface layer of 10 to 15 cms, most of the sulphur, particularly in sandy soils is in the organic form. There is not a lot of adsorption until we get down to the lower levels of the soil. I think this is one of the questions we run into: how to sample soil for sulphur, and then we have the question of relationship with the organic versus the inorganic and it makes it very difficult to make an analysis because you do have this biological activity going on within the soil. We do not have much sulphur from the rainfall, we have studied that too. We studied the problem of creating sulphur deficiency with use of high analysis fertilizer for five years on a sandy soil. A high analysis fertilizer free of sulfur was applied annually in order to get deficiencies established and each year the plant symptoms become more pronounced aud we thought the fifth year of growing the cotton that this would be when we would really have a severe deficiency. In the fifth year we got the highest yield of cotton we had had in all of the five years, with no deficiency symptoms whatsoever. That was when we started the study of the effect of light intensity. We asked ourselves why does cotton do what it does during growth?

BORNEMISZA

This comes back to the rainfall. I think if one calculates precipitation and sulphur concentration in the rain, the correlations would be better. The concentration of sulphate in rainwater varies quite a bit, I think that might be why the correlations do not agree with soil analysis.

SAALBACH

We have in our country large differences of sulphate contents of rainfall. The sulphate content of rainfall changes considerably. I think that we obtain no better results by taking regard of this factor.

MINERAL FERTILIZATION AND QUALITY OF THE CROPS

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I - Introduction.

The aim of the Agriculture is to obtain from a determined area in a profitable way the largest quantity of useful products, and from these the best quality.

Evidently we try continuously to replace the "qualitative" by the "quantitative"; in other words, to substitute the abstract notion of quality by the concrete notion of "biochemical composition" when this is possible. We proceed rapidly in this sense when it is a question of alimentary and technological value of the crops. The improvements are very slow when it is a question of organoleptic properties which are very subjective data. In many cases it is so difficult to find concrete characters of quality that one is led to define, not the product, but the conditions influencing this quality, hence the denominations of growth, of original designation which tried to define the whole "variety — soil — climate", hence the whole "variety — delimited surface — year of production".

It is not a question of treating the problem in its vast

For this paper in French language see Appendix Nr. 5.

extension but to give a general vue of the problems that arise in order to show, thanks to some concrete examples, taken particularly from our own works, how these problems can be solved.

The yield and the biochemical composition of the crop depend on one hand on the heredity, that is on the species, the plant variety, and on the other on the exterior environment. They are after all the result of the functioning of the variety in the exterior environment taken into consideration.

The factors acting on the physiology of the plant are not independent the ones on the others. Each one of them must therefore be brought to a value corresponding to an optimum equilibrium among all of them. Among all of these factors we must make a distinction between those on which we can act and those that are independent of us. The mineral nutrition belongs to the factors which we can control thanks to the works of the physiologists and agronomists of the soil science. The factors independant of us (climate, certain soil conditions) must therefore be the only ones which limit the yield or limit our action on the quality; and the factors on which we can act (heredity, mineral nutrition) must be "adapted" to the factors at the present time independent of us.

Our action on the yield and quality is also limited on one hand because of the poor knowledge in all of the agronomic disciplines (Amelioration of the plants, Physiology and Plant Biochemistry, Soil Science...), and on the other through the economical necessities, the profitableness.

The fundamental aim of the supply of mineral elements is to increase the *production in organic substances*. The mineral fertilization may also change the *biochemical composition* of the crops, and the object of this communication is to expose how it makes change this composition, and accordingly how it may be of use in associating yield and quality of the crops.

II - Diversity of the mineral alimentation conditions in natural soils, effect of the suppression of deficiencies.

In consideration of the diversity of the parent rocks which gave origin to the soils and to the assimilable nutrient elements limestone, granites, schists, etc.), one might think that the composition of plant species be extremely variable according to the type of soil, consequently to the considerable difference in mineral alimentation at their disposal. This is not the case.

In fact the plant possesses a certain discriminative power in the absorption of mineral elements. This discriminative power, for instance becomes evident in the following way: a plant deficient in an element like Phosphorus, will preferably and rapidly absorb the phosphoric ion when it will be placed in a complete and equilibrated nutrient environment.

Inversely the nutrient will be absorbed at a very reduced rate when the plant is rich in this element; it can even excrete it in a poor environment Y. Coïc and G. Vandewalle, 1956).

The discriminative power which explains itself with what one might call a "tampon" power, has certain limits, the study of which is besides the object of the present exposé.

On the other hand, the aptitudes and "exigencies" of the species or plant varieties are very different which permits, with the *choice of the cultivated plant*, a certain adaptation to the mineral alimentation conditions in the natural soils.

This means, the lack of such or such a mineral element is a primordial factor in limiting the yield on the surface of the ground. *How do these deficiencies explain themselves from the point of view of chemical composition of the crops?*

Let us take as example the deficiency of phosphoric acid. The deficiency of phosphoric acid diminishes the photosynthesis and thus the production of organic matter, so that the dilution of phosphoric acid is limited. One understands, however, that it cannot descend below a certain limit. This is shown by the table relating to an experience with wheat in vegetation pots containing a phosphoric acid deficient soil and permitting a variation of the nitrogen nutrition as from the beginning of the rising of the wheat.

TABLE I.

	Crop (in g per pot)	N % of dry mat. of the grain	P_2O_5 % of dry mat. of the grain	Nitrogen mat. of the grain in g per pot ($N \times 5,7$)
Without phosphate				
0 nitrate	16,4	2,43	0,44	1,95
1/2 nitrate	17,0	2,78	0,42	2,32
With phosphate				
1/2 nitrate	71	1,63	0,61	5,67
1 nitrate	93	1,92	0,58	8,75

The lack of phosphates reduced the yield so much (4 times) that the content of the grain was still 2/3 of the normal content. In other words, the considerable decrease in PO_4--- absorption expressed itself only by a relatively small decrease of the phosphorus content in the grain. Parallely, the content of protides in the grain was considerably increased (2,78 instead of 1,63 of nitrogen for 100 of dry material for a same nitrogen nutrition) which means that the proteosynthesis was much less affected by the deficiency of phosphoric acid than the photosynthesis. This experiment shows us also *that it is more difficult to obtain a high content of protides in the grain from a good nitrogen alimentation than with a phosphoric acid deficiency*.

In Agriculture the deficiency of one element which, by definition one might say, reduces the yield, generally increases the concentration of the other elements in the plant and finally in the crop.

For instance, one understands how difficult it can be to interpret the action of a fertilizer on the nutritional quality of the crops. In fact, the supply of a phosphatic fertilizer in order to correct a phosphoric deficiency leads in the chosen example to an increase in the phosphoric acid content of the grain, but also to a decrease in its nitrogen matter content.

The calcareous soil conditioning may have effects of much greater importance on the chemical composition of the crop than those resulting only from the amelioration of the calcium nutrition of the plant: the increase of pH changes the alimentary possibilities of the soil by liberating assimilable nutrients, and particularly nitrogen through mineralization of part of the organic matter; it can create antagonisms among the nutrient elements, decrease or increase the assimilability of certain among them, and thus make disappear toxicities (Aluminium, Manganese, Fluor, ...) or create deficiencies (Manganese, Zinc, Boron...).

III - The mineral composition of the crops.

The mineral composition interests more particularly the nutrition of the herbivores, and this the more since the modern techniques of grassland farming have as a result a less varied food.

But it interests also the nutrition of other animals and that of man too, in the regions where his alimentation is especially based on vegetables (grains, fruit). The recent researches concern more particularly the oligoelements. The researchers working on the plant production were at first interested in nutritional microelements essential for the physiology of the higher plants, that is Fe, Cu, Zn, Mn, B, Mo, Cl; then in elements essential or useless for the physiology of the plant when their concentration is low which, however, can cause toxicity when their concentration becomes elevated, especially Ca, Mn, B, Cl, Al, Cr, F, Pb, Li, As. The alimentary need in oligoelements of man and animals are in part different from those of the plants. Those indispensible for their physiology are the following: Co, Cr, Cu, F, I, Mn, Mo, Se, Zn, Sr; whereas As trivalent, Be, Bi, Cd, F, Pb, Mo, Se are sometimes toxic when they are absorbed in more or less elevated quantities. Now, the cultivated plants serving for the alimentation can have an optimum growth even when their contents of Co, Cr, Cu, I, Mn, Se, Zn are insufficient to provide for the wants of certain animals, or when, on the contrary, their contents of Se, Cd, Mo or Pb are such to cause a direct toxicity or a metabolic imbalance in the animals without damaging the plant.

1) *Indirect effect of the mineral fertilization through the variation provoked on the botanic composition of the grassland*:

The influence of the species on the content of mineral elements is determinant. It can be said that on a meadow the leguminosae are much richer in Calcium and Magnesium, in Fe, B, Mo, Cu and Co than the grasses, and less rich in Potassium and Sodium.

There are very great differences between the species, and one speaks even of plants as accumulators of Cobalt, Zinc, Selenium...

These differences between the species are so great that the action of the mineral fertilizers on the variation of the mineral composition of the pasture or of the hay is more often caused by the variation which they provoke in the botanic composition of the meadow.

2) *Influence of the nature of the nitrogen alimentation.*

The nitrogen alimentation of our plants can take place under ammoniacal or nitric form. In general it is chiefly nitric in proportion to the nitrification of the ammonical form and the easy migration of the NO_3^- ion in the soil.

As in one case the nitrogen is absorbed under the form of NH_4^+ cation, and in the other one under the form of NO_3^-, one understands, when absorbed, the antagonism of NO_3^- against the other anions, and of NH_4^+ against the other cations; all the more so since the nitrogenous ion is preferably absorbed by the other ions. With nitric alimentation there are less other anions, and particularly phosphoric acid absorbed, and less cations with ammoniacal alimentation.

On the other hand it is conceivable that the NO_3^- metabolisme in the leaves which changes the electrostatic cellular equilibrium, involves gross changes in the production of organic acids which assure this equilibrium: in ammoniacal nutrition, small quantity of cations and organic acids; in nitric nutrition, higher quantity of cations and organic acids in the leaves (Y. Coïc et al. 1961).

TABLE II

Values in milliequivalents per 100 g of fresh matter	Maize (leaves)		Tomatoes (leaves)	
	NH_4^+	NO_3^-	NH_4^+	NO_3^-
N total	49	45	63	43,1
P total (en PO_4^{3-})	12,4	7,5	15	6,6
K	13,1	13,1	8,3	11,1
Ca	4,0	6,2	4,1	26,8
Mg	3,3	5,2	2,9	8,6
Total cations	20,4	24,5	13,3	46,5
Organic acidity	3,6	12,4	0,6	26,8

In comparing the maize and the tomato we see that the tomato is particularly sensible to the influence of the nature of the nitrogenous nutrition: the content and the composition of the anions (mineral and organic), and of the mineral cations of the leaves present considerable variations.

The action of the type of nitrogenous nutrition on the content and composition of mineral cations as well as on the content of organic acids of the leaves is thus different according to the type of plants. We attribute this difference to the relative difference of the power of the NO_3- metabolism in the roots and the leaves, of which the plants of the Maize type (meadow grasses, wheat, asparagus...) reduce a higher proportion in the roots (and thus less in the leaves) than the plants of the tomato type (tobacco, potato...).

It should once more be pointed out that in Agriculture the exclusively "ammonical" nutrition is rarely to be found, and that in changing over from the "ammoniacal" nutrition to a "nitric" nutrition, the cationic and organic acids' composition of the adult or young leaves becomes rapidly modified (Y. Coïc et al.).

3) *Enrichment in certain oligoelements* (Y. Coïc and C. Tendille, 1971).

The enrichment of the crops with oligoelements is an important problem which must stir up the interest of the Agronomes, all the more since the usual fertilizers being more and more concentrated on N, P, K elements, generally contain less and less of the other elements. Each oligoelement constitutes a problem in itself: a problem linked to its dynamics in the different soils, its facility of absorption and migration in the plant which moreover depends on the plant itself and on its rhizosphere, on the antagonisme (PO_4 against Zn or Cu or Co) or synergisms (PO_4 against Mn) met with.

IV - The composition of organic substances.

Evidently the organic substances of the crops interest us mostly from the nutritional and technological point of view. The problem of modifying the composition of the crops in these substances is also the most complex one.

We shall speak only of the modifications produced by the fertilizers on *the content of protides* and on *the composition of these*, because this groupe of organic substances occupies a place of choice from the *nutritional* and *technological* point of view.

— *Observation*: When the agronomes are concerned with the influence of the mineral nutrition of the "quality" of the crops, they tend to study only the influence of a deficiency of an element or rather the effect of the suppression of this deficiency by supplying an appropriate fertilizer. Now in Agriculture one is generally more concerned about the yield than about the quality, because, for many of the agricultural products little is paid for the improvement of the quality. Hence results that the suppression of the deficiency of an element is remunerative through its increasing the yield; and that the *agronomic* definition of a deficiency refers chiefly to the yield. But it is very important for the modern Agriculture to know if, beyond the quantity of an element necessary for obtaining a maximum yield (or optimum from the economical point of view), a supplementary quantity of this element does not improve the quality without modifying the yield. This fundamental aspect will appear in the example we have chosen: increase in the nitrogenous matter content of the wheat grain. The inverse aspect, evidently, must also make part of our preoccupations, namely: supply a quantity of an element inferior to that leading to a maximum of yield in order to obtain an economically profitable combination "yield - quality".

1) *Variation of the nitrogenous matter content.*

The proportion of the nitrogenous matter among the synthesized total organic matter transforms the result of the interaction between the nitrogenous nutrition of the plant and the net photosynthesis.

We take as example wheat. The content of nitrogenous matter in the grain $= \frac{\text{nitrogenous matter}}{\text{dry matter}} \times 100$ generally varies like the ratio $\frac{\text{metabolized nitrogen}}{\text{net photosynthesis}}$. It will thus be function of the relative variations of the numerator and the denominator of this fraction.

All of the conditions and agronomic factors that diminish more the photosynthesis than the protidosynthesis increase the rate of the grain protides. We have seen the effect of a phosphorus deficiency of the soil and most of the deficiencies of nutritional ions have the same effect; it is the same with the lack of light, lack of water, cryptogamic diseases...

a) *Action of nitrogenous fertilizer on the protides content of the grain.*

The nitrogenous fertilizer increases the nitrogen quantity metabolized by that plant, but fortunately it increases also the net photosynthesis. According to the Mitscherlich's law, i.e. "yields less than proportional", it should always lead to an increase of the nitrogen content of the yields. This is not always true and depends on the quantity of nitrogen and on the date of the supply with regard to the stage of development.

A moderate nitrogen fertilizing of the wheat at the moment of the active growth permits the constitution of a photosynthetic leaf surface leading to a strong photosynthesis per unit of the soil surface. But later on (after the nitrogen of the nitrogenous fertilizer will have been used) the increase

TABLE III

	0 kg N	30 kg N/ha beginning March	30 kg N/ha end May	30 kg N beginning May + kg N end May
Rate of nitrogen of the grain (% of dry matter)	1,62	1,51	2,35	2,09
Yield (hundredweight per hectare)	19	32	21	36

of the photosynthesis compared with that of the control, will not be followed by an increase in protidosynthesis since the available mineral nitrogen, then deriving from the mineralization of a small fraction of the organic nitrogen of the soil, will be of the same quantity for both the control parcel and the parcel having received the fertilizer; the content of protides in the grain will be reduced by this fertilizer (Y. Coïc, 1950).

On the other hand, the same quantity of nitrogen applied at the end of the active growth increases relatively little the net photosynthesis per hectare and increases considerably the content of nitrogen in the grain, showing that the protidosynthesis is still very active during the last phase of development of tbe wheat (after flowering). We attribute this maintaining of the global proteosynthesis power to the *maintaining of the work of the root* which plays an important role in the protidosynthesis with wheat. Indeed, as we have said, the roots of certain plant species (Maize, Wheat) can transform a large part of the absorbed nitrates in amino and amino acids. Now this transformation is the most difficult phase, energetically the hardest of the proteosynthesis, and it is from the beginning of these organic links that the grain synthesizes its proteins.

A double fertilizing, during and after the period of active growth permits to conjugate the increase of the yield and the obtaining of a higher nitrogen content of the grain (Table III and IV).

This variation of the protides' content which can be controled up to a certain degree by nitrogenous fertilizer is of the importance that is known as regards the industries of the brewery, sugar refinery of the sugar beet, and the panification and the fabrication of food pastes.

b) *Variety interaction — nitrogenous fertilization.*

For a given and nitrogenously limited alimentation, the content depends upon the yield of the variety: the poorer the yield, the higher is the nitrogen content of the grain. Reciprocally, the more productive a variety, the greater is its need of nitrogen, not only for manifesting its productivity but also in order that the nitrogen content of the crops be not diminished in proportion to this productivity.

On the other hand, one must asks oneself the question: *Exists there a varietal aptitude for a nitrogen enrichment of the grain when the nitrogen alimentation is very abundant?* This is probable; and this possibility is function of the compared aptitudes of the variety vis-à-vis the photosynthesis and the synthesis of the protides. With an abundant regimen of nitrogen alimentation the nitrogen rate of the grain will vary on the whole like the ratio $\frac{\text{metabolized nitrogen}}{\text{net photosynthesis}}$

We have said that for certain plants, and in particular for the largest part of the cereals, the root plays a fundamental role. Now, there has chiefly been worked on selectioning the varieties of plants according to their photosynthetic capacity, their yield per hectare of useful products (grain for example) in various agricultural conditions. Few works have been realized as concerns the protidosynthetic capacities, and in particular on the metabolic power of the mineral nitrogen in the root. It is true that it may be assumed that the selection for the productivity is perhaps itself dependent on or correlative of a selection for the power of the proteosynthesis.

c) *Nitrogen fertilization and milling and baking quality of the grain* (C. Coïc & W. Alexinsky, 1953; W. Alexinsky & Coïc, 1954).

The technological quality of the wheat is on one hand function of the flour proportion that may normally be extracted from the grain (extraction rate), and on the other, of the value of this flour for making bread.

Weight per hectoliter: it is generally admitted that the extraction rate depends on the weight per hectoliter: the higher the weight per hectoliter, the greater the extraction rate. In reality the density of the grain is the important factor, but in practice the measurement is difficult, because the hectoliter of the grain includes at the same time the proper volume of the grain and the volume of the air in the interstices. The weight per hectoliter is therefore function of the density of the grain, and also of the volume occupied by the grain, the latter depending on many factors, as for instance, on the roughness of the grain, in itself related to its cleanliness and its humidity, so that the weight per hectoliter is a criterion of convenient nature but whose value is uncertain.

The table IV shows that the tardy nitrogen fertilization increases clearly the weight per hectoliter. It increases the weight per hectoliter hy increasing the density of the grain which is important from the point of view of the extraction rate.

Vitreosity. The grains enriched with nitrogen thanks to the tardy nitrogenous fertilization present a vitreous aspect (less starchy) and are more angular than those produced by wheats which have missed the nitrogen after the flowering. The data of table IV show that there are great differences between the varieties under this point of view (difference between Yga and Hybrid 40). This vitreosity (absence of "mitadinage") of the grain is an essential quality of the "hard wheats", because it conditions the yield of "semolina" intended for the fabrication of food pastes. The varietal differences concerning the vitreosity have thus more particularly been studied on "hard wheats".

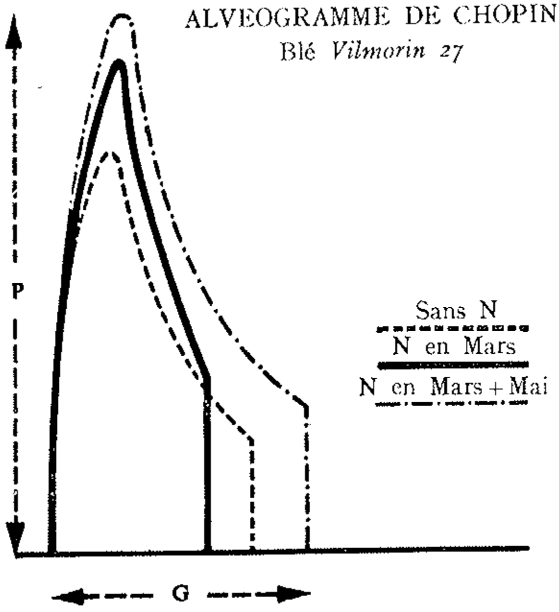
Alveogram Chopin. The value of the flour for the bread production depends essentially on its gluten: on its quality which depends mainly on the variety and on its quantity. For the baker, the quantity of water absorbed by the flour to obtain the consistency required of the paste, is important. The elastic and cohesive quality of this paste is in France expressed by the exterior W and the characteristics of the alveogram Chopin (where P indicates the pressure at the moment when the bubble of the paste bursts, and G the swelling).

From the experiment relative to table III it is understood that the nitrogen supplied to the Tillering (March) leads to a decrease of the nitrogen rate of the grain, and the flour gives an alveogram whose swelling is inferior to that of the control without nitrogen. A nitrogen supplement given when coming into ear, increases considerably the swelling and the W (graph 1).

In the experiments relating to Table IV, the semi-tardy nitrogen fertilization (at the shooting) which acted strongly on the yield, modified little the behaviour of the alveogram and the W value. On the other hand, in increasing the gluten rate the tardy fertilization improves the G swelling and sometimes the P pressure, the W being thus clearly increased (graph 2).

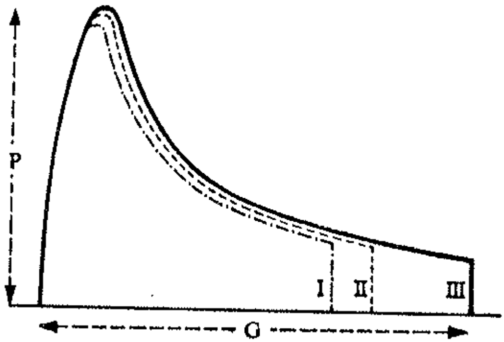
The experiments carried out on *Brabender's farinograph* show that the absorption of water, to bring the paste to a determined consistency, is higher in flours deriving from wheats enriched with nitrogen thanks to the tardy nitrogen fertilization (graph 3).

Panification trial: These tests have been completed with panification trials, and the graphs corresponding to table IV have had a most favourable influence on the absorption of water, the volume of the breads and the note attributed by the baker (graphs 3, 4 and 5).

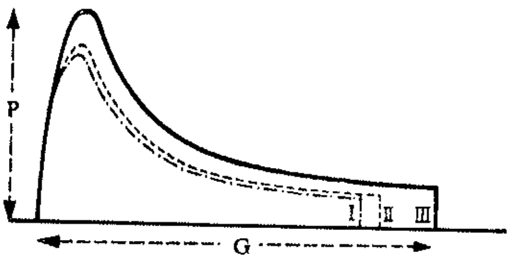


GRAPH 1

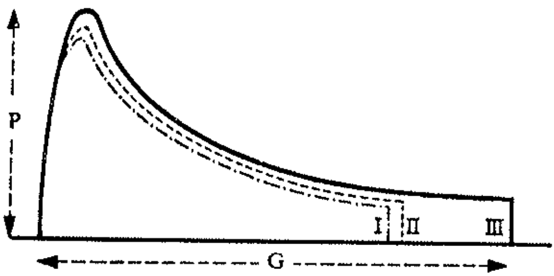
ALVEOGRAMMES



Yga

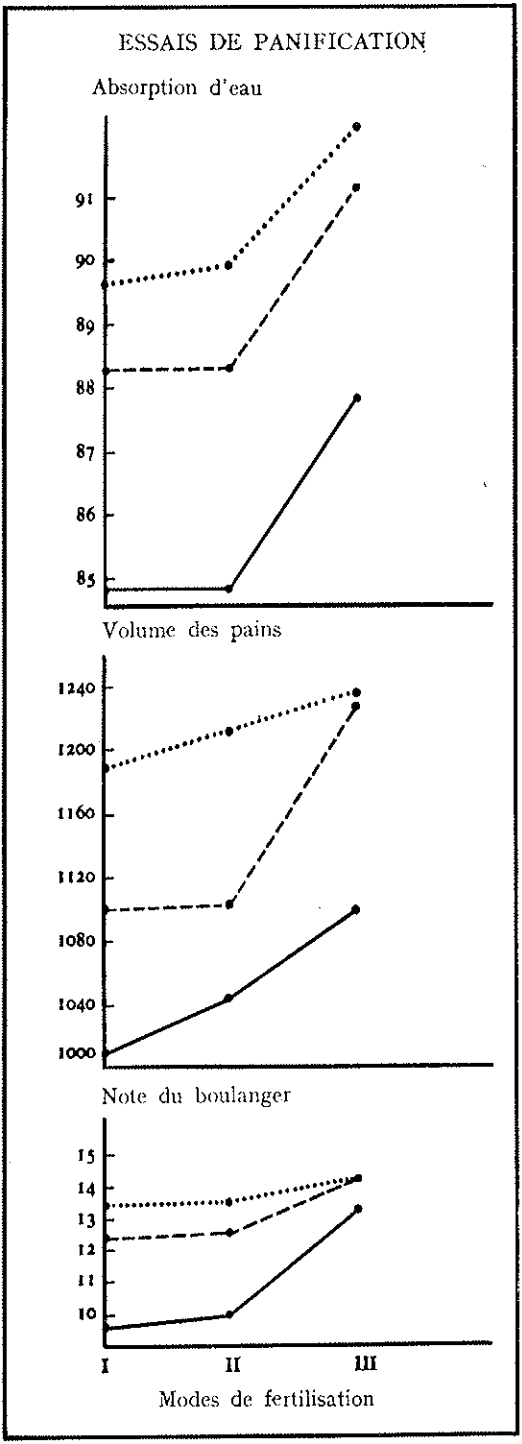


Hybride de Bersée



Hybride 40

GRAPHS 2



GRAPHS 3, 4, 5 — I, II, and III = Ways of fertilization corresponding to table IV.

These experiments with nitrogen fertilizer show clearly that yield and quality can be associated.

2) *Variation of the composition of protides.*

It is generally thought that *the proteines* of an organ of a determined plant species do not dispose of a large potential of variability of their composition: Table V, for instance permits us to see that the amino acid compositions of the protides of the grain of three varieties, one of soft wheat, two of hard wheat, are very near.

When the protides are constituted by a certain proportion of "soluble" organic nitrogen, both the variation of the proportion of this soluble nitrogen, whose composition of amino acids is different from that of the proteins, and *the variation of composition of this soluble nitrogen*, modifie the composition of the global protides.

a) *Variation of the proportion and composition of the soluble organic nitrogen.*

— *Influence of the type of nitrogenous nutrition: "nitric" or "ammonical".*

In the proportion of the nitric alimentation, the ammoniacal alimentation leads to an accumulation of the soluble organic nitrogen and more particularly of the amides (glutamine or asparagine according to the plant species).

— *Deficiency of mineral elements.*

The protides are fundamental constituents of the living matter, and it can be said that every serious deficiency of any element affects more or less the protein synthesis.

Besides nitrogen, sulphur is a constitutive element of the proteins since it makes part of two amino acids, the cysteine

TABLE IV

	Yield hundred weight per hectare	Weight of hl	W	In % of control	Proteic matter N × 5,7 in % of the flour	Proteic matter N × 5,7 in % of the control	Vitreosity %
Experiment 1952							
Yga							
I. 70 kg N February — March	42,5	80,4	96		7,60		10
II. 70 kg February — March + 25 kg N end April	49,5	80,8	108	113	7,85	103	30
III. 70 kg February — March + 25 kg N end April + 25 kg N end May	51	82,4	130	135	9,90	130	70
Hybrid of Bersée							
I. February — March	41,5	79 6	45		6,70		0
II. February — March + April	52	79 6	47	105	7,20	107	10
III. Febr. — March + April + May	54,5	80,8	65	144	8,70	130	40
Hybrid 40							
I. February — March	39 5	79,2	65		7,30		0
II. February — March + April	47,5	80	70	108	7·35	101	10
III. Febr. — March + April + May	49	81,2	94	145	9,60	131	40

TABLE V — *Variation of the composition of the grain protides of a wheat variety under the effect of nitrogen enrichment of the grain for tardy nitrogen fertilization.* (Amino acids expressed in grams for 16 grams of nitrogen).

	Florence-Aurore — N tardy	Florence-Aurore + N tardy	Florence-Aurore + N tardy / — N tardy	Qued zenati — N tardy	Qued zenati + N tardy	Qued zenati + N tardy / — N tardy	Mahmoudi — N tardy	Mahmoudi + N tardy	Mahmoudi + N tardy / — N tardy
N × 6,25 % of M.S.	12,0	16,0	1,33	11,7	16,3	1,40	12,0	16,7	1,39
Aspartic acid	4 8	4 2	0,87	4,9	4,5	0,92	4,8	4,5	0,94
Threonine	3,0	2,6	0,87	3,0	2,8	0,93	2,9	2,7	0,93
Serine	4,4	4,2	0,95	4,5	4,5	1,0	4,4	4,3	0,98
Glutamic acid	28,5	30,2	1,06	27,6	30,6	1,11	27,7	30,3	1,09
Proline	9,2	10,0	1,09	9,2	10,4	1,13	9,6	10,3	1,07
Glycine	4,1	3,6	0,88	3,9	3,5	0,90	3,8	3,5	0,92
Alanine	3,6	3,0	0,83	3,6	3,3	0,92	3,5	3,2	0,91
Valine	4,3	3,7	0,86	4,4	4,1	0,93	4,4	4,2	0,95
Cysteine	3,0	3,0	1,00	2,8	2,6	0,93	2,6	2,4	0,92
Methionine	1,4	1,1	0,78	1,3	1,6	1,23	1,3	1,3	1,00
Isoleucine	3,4	3,2	0,94	3,4	3,5	1,03	3,5	3,5	1,00
Leucine	6,3	6,1	0,97	6,6	6,7	1,02	6,7	6,6	0,98
Tyrosine	2,8	2,7	0,96	2,5	2,8	1,12	2,8	2,8	1,00
Phenylalanine	4,0	4,1	1,02	4,2	4,5	1,07	4,4	4,5	1,02
Lysine	2,8	2,5	0,89	2,9	2,5	0,86	2,7	2,5	0,92
Histidine	2,2	2,2	1,00	2,6	2,4	0,92	2,3	2,4	1,04
Tryptophane	—	—	—	—	—	—	—	—	—
Arginine	4,8	4,5	0,94	4,9	4,5	0,92	4,6	4,6	1,00

and the methionine, which are found in all of the proteins. The deficiency of sulphur is expressed by an accumulation "of soluble nitrogen", i.e. of amino acids and peptides which could no more be used for the edification of the proteins.

It is the same with other elements which, without being constituents of the proteins, are implicated in their synthesis. The deficiency of potassium leads also to the accumulation of soluble nitrogen in the plant.

b) *Variation of the composition of proteins.*

α) *Effect of the nitrogen nutrition* (Y. Coïc et al., 1963).

It is estimated that the amino acid composition of the wheat grain protides is little variable.

We have shown, however, that the enrichment of the grain with nitrogen, thanks to a tardy nitrogen nutrition — enrichment going from 33% for Florence Aurore (soft wheat) to 40% for Oued zenati (hard wheat) — had as result a modification of the amino acid composition of the grain protides.

The proportions of glutamic acid (or rather of glutamine) and of proline increase very clearly (from 6 to 13%), that of phenylalanine increases also though less clearly. The proportions of the other amino acids decrease passively (from 3 to 4%), but certain of them diminish more intensely: the lysine (8 to 14%), the glycine and alanine (from 8 to 13%).

The variation of the amino acid composition of the wheat grain protides expresses the preferential accumulation of the gliadine (group of the prolamines) which contains a large proportion of glutamine and is very poor in lysine (Mossé et al., 1966).

The nutritional value of the *protides* of the grain enriched with nitrogen through a tardy nitrogen nutrition, is diminished, but it is not the same with the nutritional value of the *grain*, because the enrichment of the grain with protides leads finally to an enrichment of the grain with indispensable amino acids.

The effect of the nitrogen nutrition is the same with barley (Y. Coïc et al., 1963). But it is only observed in cereals with prolamines where the indispensable amino acid content is decreased. For the sunflower it is the same when it can vary, to a considerable extent, the nitrogen content of its seed kernel with a very large variation of the nitrogen fertilization (see table IV). As for the wheat and barley, if the indispensable amino acid contents of the protides diminish, those of the seed increase.

TABLE VI — *Variation of the protide composition of the Kernal of the Sunflower seed under the effect of the variation of the nitrogen nutrition.* (The amino acids are expressed in grams for 16 grams of uitrogen).

	n without nt	n with nt	N without Nt	N with Nt
Aspartic acid	9,75	9,65	9,65	9,9
Glutamic acid	21,25	22,8	24,05	24,3
Serine	4,15	4,05	4,05	4,0
Threonine	3,75	3,45	3,4	3,2
Glycine	6,1	5,65	5,4	5,35
Alanine	4,1	4,0	3,9	3,8
Valine	5,1	5,25	5,0	5,15
Leucine	6,3	6,3	6,35	6,1
Isoleucine	4,0	4,4	4,25	4,1
Tyrosine	2,8	2,65	2,6	2,6
Phenylalanine	4,65	4,65	4,65	4,6
Proline	4,5	4,6	4,4	4,45
Lysine	3,7	3,0	2,9	2,75
Histidine	2,5	2,25	2,25	2,15
Arginine	8,5	8,95	9,2	9,4
Total	94,8	94,85	94,85	95,0

n = 4 milliequivalents of NO_3^- per liter of nutritional solution.
N = 12 milliequivalents of NO_3^- per liter of nutritional solution.
t = tardy, i.e. after flowering.

TABLE VII — *Variation of the protide composition of the barley grain under the effect of sulphur deficiency.* (The amino acids are expressed in grams for 16 grams of nitrogen).

	+ S	— S	+ S / — S
N × 6,25 % M.S.	15,3	17,4	
Aspartic acid	4,8	6,5	1,35
Threonine	2,95	2,7	0,91
Serine	3,9	3,65	0,94
Glutamic acid	24,2	25,9	1,07
Proline	14,0	14,4	1,03
Glycine	3,4	3,15	0,93
Alanine	3,5	3,2	0,91
Valine	4,6	3,95	0,86
Cystine	2,1	1,3	0,62
Methionine	1,1	1,0	0,91
Isoleucine	3,3	3,1	0,94
Leucine	6,4	5,8	0,91
Tyrosine	2,95	2,7	0,91
Phenylalanine	5,2	6,1	1,17
Lysine	3,2	2,75	0,86
Histidine	2,05	1,8	0,88
Arginine	3,95	3,8	0,96

β) *Effect of the deficiency of other mineral elements.*

These deficiencies lead generally to an increase in the protide content of the seeds, as we have shown it for Phosphorus. The effect observed on the protides quality of the grain is function of this variation of the content of protides (Y. Coïc et al., 1963).

γ) *Effect of the deficiency of Sulphur* (Y. Coïc et al., 1963).

Sulphur plays an essential role in the synthesis of the protides. Besides the action of the deficiency of Sulphur on the increase of the protide content of the grain, one notices a specific aspect: a clear increase of the proportion of aspartic acid (or rather asparagin) in the protides, and a very great reduction of the cystine content when there is a small decrease in the methionine content (Y. Coïc et al., 19??).

V - The principles of mineral fertilization.

The fertilization with Pet does not raise great problems: bring the soil in a state of richness dependent on the whole of the culture entering in one crop rotation; restore the exportations and the losses with the annual fertilization taking into account the intensity of the needs (need per unity of time) of the culture. The supplies of Calcium and Magnesium do not raise any problem. The same is valid for Sulphur, except from a global point of view, it disappears by degrees from the fertilizer for being only an accessory element. We have said that the oligoelements raise a difficult problem under the angle of the quality of the agricultural products.

The *nitrogen fertilization* puts arduous problems for intensive cultivation.

Immediate problems:

— it has often been said that the nitrogen fertilizer was an excellent annual fertilizer. It is so indeed as regards the following considerations;

— the mineral nitrogen is generally rapidly used (under the form NO_3^- which circulates easily in the soil) when supplying nitrogen substances which are the essential constituents as to the weight of the *living* matter. It conditions thus primarily the growth. Consequently the Agriculturalist can make use of the nitrogen fertilizer for directing the plant growth in agreement with the aim followed: he does this for wheat in searching the best equilibrium between the density of the seeds and nitrogen fertilizer (Y. Coïc);

— this fertilizer must quantitatively and in due time complement the supply of mineral nitrogen furnished by the soil. As the mineralization of a small fraction of nitrogenous organic matter of the soil is, on one hand, most variable in quantity and time according to the soils, climates, previous cultivating procedures, former fertilizers..., and on the other, according to the climatic conditions of the year, one understands the difficulty to assure a perfect nitrogen fertilization.

The nitrogen fertilizer depends evidently on the type of the cultivation: because the global needs of the cultures are different; because the biochemical expressions of the quality of the crops are different; because the utilization of the mineral nitrogen is quite different according to the plants. We have indicated the differences of power of the metabolism of mineral nitrogen in the root of the various plant species. It must also be emphasized that certain plants can accumulate large quantities of nitrates in the leaves and in the stems: for istance, the tobacco and the sunflower can accumulate large quantities of nitrates in the marrow of their stems (Y. Coïc et al., 1969, 1971).

TABLE VIII — *N of NO_3 (‰ of dry matter) in the organs of the Sunflower at the crop.*

	Young leaves	Old leaves	Stem + Petioles young parts	Stem + Petioles old parts
n without nt	traces	traces	3,3	3,2
n with nt	rtaces	0,1	17,1	15,3
N without Nt	traces	0,3	12,9	17,5
N with Nt	0,2	0,6	16,6	21,3

Thus, in order to obtain a high content of nitrogenous matter in the Sunflower seeds it is enough to assure a good nitrogenous alimentation before the flowering as it has a stronger action than the tardy nitrogen fertilization. We have observed that it is quite different for wheat.

TABLE IX

	Oil (% of dry kernel	oil crop (g per plant)	Proteines (N × 6,25) (% of dry Kernel	index	crop in protides (g per plant)	Protides (% of dry almonds' cake
n without nt	62,8	7,6	22,0	100	2,65	59
n with nt	58,4	10,9	29,6	134	5,50	71
N without Nt	31,9	24,5	34,7	158	16,40	72
N avec Nt	49,0	23,7	37,9	172	18,30	74

Further problems.

The increase of the fertilizer supply and particularly of nitrogen fertilizer in order to better satisfy the needs of the cultivations, permitted to increase the yields and, correlatively, the residues of organic matters and particularly of nitrogenous organic matters. Hence results a continuous *increase in the mineral nitrogen quantity supplied by the soil to the cultivations*. As the varietal productivity increases, the supply of nitrogen fertilizer which, in the course of the crop rotation, must at least restore the exportations plus the nitrogen losses, increases equally. It turns out, however, that the nitrogen fertilization of a special culture (wheat for example) following the preceding culture, becomes quite difficult in consideration of the large nitrogen quantity furnished by the soil and which escapes our control.

VI - Conclusion.

Thanks to the works of the physiologists, nutritionists, technologists, we know better the needs of man, animals, agricultural industries, that is to say that these needs can be expressed in a more concrete way.

Thanks to the researches made on cultivated plants and the environments in which they live, we can in certain particular cases already conceive mineral nutritions and realize fertilizers which lead to obtaining higher yields of crops of good quality.

There remain many progresses still to be made, and so as to attain this end, a collaboration among the researcher concerned with the plant production and those interested in the requirements of the users, is absolutely necessary.

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DISCUSSION

Chairman: J. T. PESEK

PESEK

The Chair would like to ask a question. Is it correct to assume that some of the differences due to added nitrogen fertilizer have made a significant change in the nutritive quality as far as the essential amino-acids are concerned in both wheat and sunflowers?

COÏC

Si j'ai bien compris la question, je pense qu'en effet l'emploi des engrais a modifié un peu la composition en acide aminé des protides, mais de toute façon le grain est beaucoup plus riche en ces acides aminés indispensables. Dans des conditions agricoles, où la récolte est normale, la variation de la composition en acides aminés des protides de la graine de Tournesol est faible.

If I understood the question alright, I think the use of fertilizers has indeed modified a little the composition of amino acid of the proteides, but the grain is at any rate much richer in these indispensible amino acids. In agricultural conditions, where the yield is normal, the variation of the amino acid composition of the proteides of the sunflower seed is weak.

HERNANDO

I have many things to ask about your paper but I will try to select the more important points. First, I would like to suggest that we include in the conclusions of this Study Week, the importance of giving a higher price for the best quality of the grain, but actually we cannot put in the work the system proposed by Dr. Coïc, in Spain because the farmers do not like to apply later on in the season additional amounts of nitrate since for the best quality, grain only 15 cents more in price, will be received, and that is of no use. It is necessary to point out, not only to the International Organizations, but also to the different countries, the importance of buying quality rather than quantity. That is one point. The other point is in relation to Table 1. I think we can deduce here in this Table the total export of phosphate as it is made of nitrogen. Then the difference with phosphate, or without phosphate, is quite larger than in the table. The last point is in agreement with one thing you say about the plant nitrogen content: one of the first factors is the water. In fact we found it in our recently irrigated area. In newly irrigated land farmers grow wheat as before and they get higher yields but these higher yields are lower in protein content.

COLWELL

I would like to comment generally on this concern of effective fertilisers on quality of crops, particularly wheat. Instead of trying to produce a perfect quality grain by correct use of fertilisers, I suggest it is more sensible simply to let the farmers concentrate on producing wheat and let other people concentrate on making up the deficiencies in the product by breeding and appropriate additives. Of course this applies not only to quality of bread — it can affect the quality of grass, of animals for example. Where animals suffer from a deficiency we give them a supplement.

Coïc

Il y a beaucoup de problèmes soulevés par le docteur COLWELL. L'Homme et les animaux sont incapables d'utiliser l'azote minéral pour fabriquer des acides aminés. Ils utilisent donc des protides fabriqués principalement par les plantes supérieures, nos plantes cultivées. Du point de vue de la qualité du grain de blé pour faire du pain, nos voisins allemands tiennent beaucoup compte de la teneur en protides, avec raison ainsi que nous l'avons montré dans notre exposé. Du point de vue de la qualité nutritionnelle, il est nécessaire de complémenter les protéines des céréales par des protéines de meilleure qualité (tourteaux (cake) de soja, d'arachide). Mais une teneur élevée en protides est cependant importante. Quant au problème des micro-éléments, le Dr. COLWELL a certainement raison dans certains cas particuliers, mais le problème est assez complexe et je pense que nous n'avons pas le temps d'en discuter avec efficacité.

Dr. COLWELL has raised many problems. Man and animal are uncapable of utilizing mineral nitrogen to make amino acids. Therefore, they utilize proteines which are mainly prepared by superior plants, our cultivated plants. From the point of view of the quality of the wheat grain to make bread, our German neighbours take the proteide content much into account for the reason we have shown in our paper. From the point of view of nutritional quality it is necessary to complement the cereal proteins with proteins of best quality (soybeans cake, groundnuts). However, an elevated content of proteides is important. As to the problem of micro-elements, Dr. COLWELL is certainly right in certain particular cases, but the problem is quite complex, and I think we have not the time to discuss it efficiently.

PESEK

Paraphrasing Professor COLWELL's comment, I have said that maize is a starch grain and it is grown for starch, so I am not concerned with the protein level which has gone down because of hybrid maize; likewise soybeans are a protein crop. When improving it is easier to concentrate on factors such as yield rather than also considering quality. For some crops such as wheat for example, there is some level of protein content which must be maintained for it to be satisfactory for many purposes besides its use for energy (starch).

Coïc

Par des moyens génétiques nous essayons aussi d'améliorer la composition des protéines des graines; ainsi pour le maïs, grâce au gène opaque 2; mais, jusqu'à maintenant, en France, nous n'avons pas obtenu le même rendement qu'avec nos hybrides franco-américains. Nous sommes toujours 10 à 15 pourcent au-dessous, et il est peut être plus facile de supplémenter les protéines du maïs soit par un acide aminé de synthèse, soit par une protéine de soja ou d'arachide.

With genetic means we also try to improve the protein composition of seed; thus for maize, thanks to the opaque gene 2. But in France up to the present time we have not obtained the same yield as with Franco-American hybrids. We are always 10-15 percent below, and it is perhaps easier to supplement maize proteins either with an amino acid of synthesis or with a protein of soybeans or of groundnuts.

Blanchet

Je voudrais demande à M. Coïc ce qu'il pense d'un problème pratique de qualité nutritionnelle qui me semble souvent important. Il s'agit du maïs en tant qu'aliment des animaux principalement, qu'il s'agisse d'ailleurs du grain ou de l'ensilage parce que l'un et l'autre sont assez pauvres en protéine, notamment en lysine, même dans les cultures irriguées où l'irrigation pousse en quelque sorte la production, c'est-à-dire la photosynthèse, peut-être plus que la protéosynthèse. Je voudrais demander à M. Coïc ce qu'il pense de ce problème et des solutions possibles, soit l'enrichissement par la fumure azotée, soit la complémentation en tant que teneur en protéines globale pour les ruminants par l'urée d'origine industrielle, soit enfin, pour les animaux monogastriques qui utilisent surtout le grain, les espoirs qu l'on pourrait tout de même fonder sur la génétique des nouvelles variétés; il n'y a que l'opaque 2, mais il y a aussi la gène Gloury, peut-être un peu plus productif que l'opaque et quelle solutions entrevoir dans tous ces domaines?

I would like to ask Mr Coïc what he thinks of a practical problem of nutritional quality which often appears important to me. It is a question of maize for being mainly an animal food; that it is moreover a question of corn or ensilage because both are rather poor in proteins, especially in lysine, even in irrigated cultures where the irrigation pushes the production in some way, i.e. the photosynthesis, perhaps more than the proteosynthesis. I would like to ask Mr Coïc what he thinks of this problem and of possible solutions, be it the enrichment with nitrogen fertilizer, be it the complementation for being the global protein content for the ruminants because of the urea of industrial origin, be it finally for monogastric animals which use especially the corn, the hopes one could just the same base on the genetics of new varieties; there is only opaque 2, but there is the gene Floury, perhaps a little more productive than the opaque, and what solutions do you see in all these fields?

Coïc

J'ai déjà répondu en grande partie a cette question à la suite de la question de M. le Président. Il y a pour le maïs, ainsi que vous l'avez dit deux possibilités de gène améliorant, opaque 2 et Floury. La composition des protéines des feuilles est généralement bonne. Pour la question de l'augmentation de la teneur en protéine: Je pense que les agronomes n'on peut-être pas assez travaillé ce problème de relation entre photosynthèse et protéosynthèse, parce qu'ils ont surtout travaillé sur la photosynthèse. Or, je pense que, puisque chez le maïs la protéosynthèse dans les racines est très importante, on devrait, par exemple penser que l'expérimentation sur la densité de semis devrait faire intervenir ce problème. Par exemple, on s'occupe de la densité de semis du maïs pour obtenir un rendement maximum, c'est-à-dire la photosynthèse maximum. Quand il s'agit de protéosynthèse dont une grande partie est faite dans les racines, le problème de la densitè de semis peut être différent. Il faudrait peut-être expérimenter pour savoir si en faisant varier la densité de semis il est possible d'augmenter le rendement en protides et la teneur en protides. Quant à la supplémentation par l'urée, elle interesse les animaux polygastriques et l'on continue à expérimenter sur ce problème.

For the most part I have already answered to this question when I answered to the question of the President. For maize, as you said, there are two possibilities to improve the gene, opaque 2 and Floury. The composition of the leaf proteins is generally good. As to the question of an increase in protein content, I think that the agronomists have perhaps not worked enough on this problem of relation between photosynthesis and proteosynthesis since they have mainly worked on the photosynthesis. Now I believe that, considering that for maize the proteosynthesis in the roots is very important, one should perhaps think that the experimentation on the density of seedlings might let interfere this problem. For instance, one occupies oneself with the density of maize seedlings in order to obtain a maximum yield, that is to say the maximum photosynthesis. When it is a question of proteosynthesis, of which a large part is made in the roots, the problem of the density of seedling can be different. Perhaps one should make experiments in order to know if by varying the density of seedlings it might be possible to increase the production of protides and the content of proteides. As to the supplementation with urea, this interests the polygastric animals and the experimention on this problem continues.

Oberländer

Dr. Colwell just suggested: let the farmers produce as they do and let others take care of improving the quality by processing.

This is a standpoint which cannot be adopted for the highly industrialized countries of Europe because in these countries the problem is how to market the surplus of production and if the farmers' income shall be raised in the highly industrialized regions of Europe. This can be done only by cutting down the yields by reducing the cultivated area and raising the quality at the same time, and only this will give the farmers in our countries the possibility of surviving in the highly industrialized society.

WALSH

I wish to refer back to what Dr. COLWELL said in his report on the question of counteracting deficiencies when they arise. What he was saying is a direct approach — recognize the « hazard » areas and then take appropriate steps to counteract deficiencies in these areas depending on each particular situation. For instance, to counteract hypocuprosis in livestock a massive injection of copper can be given. Cobalt deficiency can be counteracted by direct feeding or by a « hospital » plot technique. In the baking of bread low protein can be supplemented by adding protein of appropriate composition. You can separate protein from wheat and reinforce other wheat with it — modern technology has developed techniques to do this. I believe this is an important point for our report, that we should use these new developments to the maximum in order to get over some of the problems. We do not have to feed all through the fertiliser into the soil, into the plant, into the animal, into the human.

EFFECT OF FERTILIZERS ON YIELDS AND CROP QUALITY

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It is well known that agricultural production of the different countries is characterized by extremely varying natural and economic conditions and technical supply. Consequently, due to these divergencies, the aims and tasks of agricultural production in a given country get their specific features.

The differences manifest themselves primarily in the structure and level further in the efficiency of agricultural production and in some related parameters, too.

These differences between the agriculture of the countries involved present a more complex problem when regarded in dependence on the role and importance of agricultural production within the national economy. Lastly, one has to take into account the characteristic social conditions of a certain country which reflect themselves in its agriculture, too.

When setting the *objectives* and considering the *possibilities* given, we must mention the factors affecting the structure and level of agricultural production, so the quantity and composition of agricultural products per capita, the density of population, etc., on the one hand, and the potentials of production, primarily the natural and technical conditions, on the other.

Among these factors, for instance, that of technical supply itself is very complex. It involves the problems of up-to-date mechanization in soil cultivation and irrigation, the different soil reclamation practices, the application of herbicides, the growing of high-yielding selected plant varieties, etc. These measures, however, would not bring about positive results unless the efficient supply in nutrients of our cultivated plants is assured, and conservely. Therefore, the application of mineral fertilizers at higher rates is one of the most efficient means for increasing crop yields. Essentially, on a certain level of development, the increased requirements of nutrients necessary for attaining higher yields cannot more be satisfied by traditional methods but this function is becoming more and more the task of the chemical industry being able to produce more rapidly, increasing quantities of cheeper fertilizers of different kinds. Consequently, the application of mineral fertilizers is showing an upward tendency all over the world.

1. *Fertilizer production and consumption in the world and in Europe.*

According to FAO's data, the world production of fertilizers rose in 1968/69 by nearly 6 percent, to 61,3 million metric tons. Nitrogen output at 27,4 million tons, and that of potash at 15,9 million tons, increased by nearly 9 and 5 percent, respectively, while phosphate production at 18 million tons rose by only 2 per cent.

Table 1 and Fig. 1 illustrate the data referring to the development of the total fertilizer consumption in the world. In the average of the years 1952/53 - 1956/57 this came (expressed in million metric tons of $N + P^2o^5 + K^2o$) to 20,2 and in 1968/69 to 56,5 million metric tons, i.e. to its nearly triple

TABLE I — *World fertilizer consumption* (in terms of 1000 metric tons of nutrient contents).

Type of fertilizers	Continent	Average of 1952/53-1956/57	1964/65	1965/66	1966/67	1967/68	1968/69
N	Europe	2590	5886	6462	7139	7915	8754
	Soviet Union	475	1759	2282	2656	3089	3454
	North and Central America	1958	4844	5514	6333	7057	7292
	South America	103	273	285	309	348	387
	Asia	968	2077	2248	2804	3418	3785
	Africa	178	509	560	549	614	675
	Oceania	25	76	82	119	156	172
	Total	6297	15424	17433	19909	22597	24519
P_2O_5	Europe	3240	5684	5815	6063	6576	6818
	Soviet Union	655	1284	1504	1664	1697	1748
	North and Central America	2319	3607	4085	4515	4686	4852
	South America	116	287	270	302	395	480
	Asia	403	1012	1053	1314	1642	1651
	Africa	198	249	364	397	461	512
	Oceania	604	1212	1297	1287	1163	1214
	Total	7535	13335	14388	15542	16619	17275
K_2O	Europe	3361	5430	5645	5900	6301	6544
	Soviet Union	668	1421	1891	1902	2136	2210
	North and Central America	1798	2813	3195	3679	3854	4019
	South America	59	160	175	176	229	299
	Asia	421	812	914	1008	1183	1227
	Africa	52	166	173	203	212	240
	Oceania	36	153	171	175	157	174
	Total	6395	10955	12164	13043	14072	14713
All fertilizers (N, P_2O_5, K_2O)	World total	20227	39714	43985	48494	53288	56507
	Europe	9191	17000	17922	19102	20792	22116
	Soviet Union	1798	4464	5677	6222	6922	7412
	Europe and Soviet Union	10989	21464	23599	25324	27714	29528

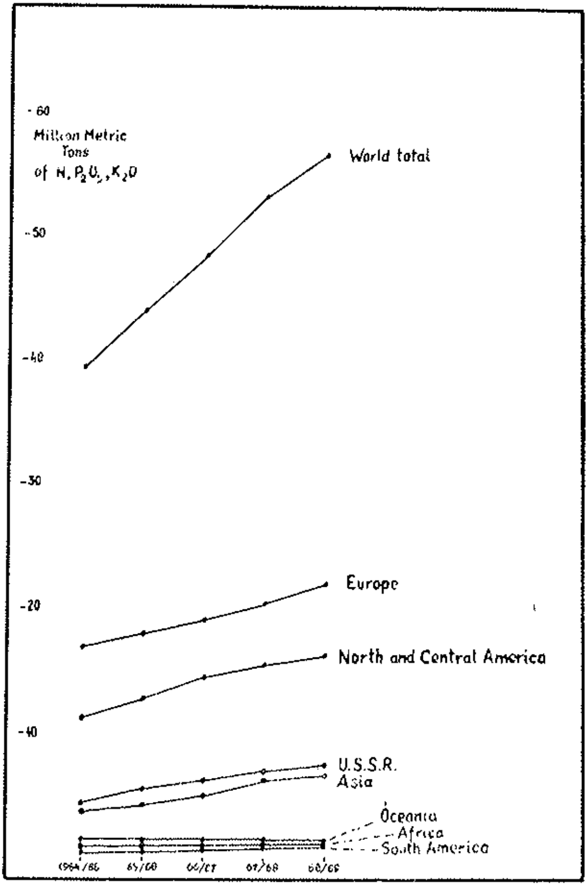


FIG. 1 — World fertilizer consumption.

amount. Thus, referring to the total arable area of the world — about 1,5 thousand million ha — on the average 39 kg/ha fertilizers of different kinds were applied. However, this figure itself does not show much as our data reveal the great divergencies in the fertilizer consumption of the different continents, too.

In 1968/69, 39,1 percent of the total fertilizer quantity consumed all over the world was applied in Europe, the continent with the most developed industry and densest population — on hardly 10 percent of the total arable area of the world. Fertilizer consumption in North and Central America — especially in the U.S.A. and Canada — was also high. Referring to all kinds of fertilizers, 28,6 percent of the world's total consumption falls on North and Central America, i.e. on the 17 percent of the total arable area. These data clearly show that a considerable part of fertilizer consumption (80,8%) is registered for Europe, the Soviet Union, North and Central America, and the remaining quantities (less than 20%) for the other countries of the world.

The fertilizer amounts applied on the arable lands in some European countries are summarized in Table 2 (data of the FAO). The great differences observed also reveal that in populous countries with developed industry, fertilizer consumption is generally higher and this fact can be expressed, among others, by the number of inhabitants pro person economically active in agriculture. Fertilizer consumption is extremely high, for instance, in the Netherlands, Belgium, Switzerland, German Federal Republic and German Democratic Republic. Relatively high fertilizer consumption can be observed in countries with well developed industry but rarer population and where agricultural production is carried on on smaller areas (Sweden, Norway, Ireland).

Beside the considerable increase in the production and consumption of fertilizers, important changes in their pattern are also to be established both in Europe and all over the world. The proportions in the amounts of N, P and K fertilizers have

TABLE 2 — *Fertilizer consumption in some European countries* (per 1 ha of arable land).

Country	Arable land 10000 ha	Fertilizer consumption N	P_2O_5	K_2O kg	Total	Population km²	Number of inhabitants pro person economically active in agric.
Austria	1672	68	68	85	221	84	10,5
Belgium	886	192	147	198	537	308	43,0
Bulgaria	4558	81	64	9	154	75	3,2
Czechoslovakia	5353	66	56	87	209	110	13,8
Denmark	2709	92	46	67	205	110	12,4
Finland	2761	46	55	43	144	14	6,9
France	19816	63	80	61	204	89	13,6
German Dem. Rep.	4974	103	73	131	307	176	10,8
German Fed. Rep.	8179	114	95	128	337	227	19,0
Greece	3851	37	30	4	71	64	4,4
Hungary	5613	54	31	26	111	110	6,6
Ireland	1194	54	134	112	290	39	8,0
Italy	15195	34	31	12	77	170	10,3
Netherlands	913	372	114	137	623	364	30,4
Norway	843	84	64	71	219	11	14,6
Poland	15494	46	31	58	135	98	5,0
Portugal	4370	23	14	4	41	103	6,5
Rumania	10560	31	13	1	45	79	3,0
Spain	20482	28	19	5	52	62	7,7
Sweden	3031	63	46	42	151	17	19,4
Switzerland	404	80	107	149	336	142	21,6
United Kingdom	7382	129	61	66	256	222	57,0
Yugoslavia	8246	33	19	15	67	75	4,2
Europe, total	149000	59	46	44	149	—	—
Soviet Union	224300	15	8	10	33	10	5,9

changed in favour of N. This displacement was undoubtedly influenced by the development in the technology of ammonia synthesis and consequently by the relative reduction of nitrogen prices, but agricultural experience and the results of scientific researches have also supported the growing significance of N fertilization.

Recently, efforts have been made to produce and apply more economic and highly efficient, concentrated single and compound fertilizers. Table 3 shows the changes in the pattern of fertilizers applied in the different European countries. Referring to the period examined, these data show significant upward tendencies in the proportional use of concentrated single and compound fertilizers compared to the traditional ones. In the years 1967/68, this increase was especially high in Denmark, Finland, France and Sweden, while in Norway compound fertilizers were applied in considerable rates already at the beginning of this period. In the United Kingdom, the complex forms of N and P fertilizers were primarily favoured.

As supported by a lot of data, the application of larger fertilizer quantities generally results in higher yields. In Fig. 2, the applied fertilizer rates are plotted against the yield of two cereals — winter wheat and barley — grown in almost every European country. These data are only informative ones as the fertilizer quantities related to the arable areas are distributed in a different way among the cultivated crops and the yields of a certain year could be greatly influenced by environmental conditions and seasonal factors, too. Considering these circumstances, Fig. 2 shows that in case of wheat, 100 kg/ha fertilizer brings about an average yield of 12-22 q/ha. When applying fertilizers at rates of 100-200 kg/ha, the yields surpassed 20 q/ha in each of the five countries indicated, in Sweden they were even above 40 q/ha. This may be explained by the fact that in Sweden wheat is grown on small areas only and on the most fertile soils and the most efficient fertilizing methods and agrotechnics are used. From the 1968 year's data it also appears that when applying fertilizers at rates of 200-

ABLE 3 — *Consumption of fertilizers by kinds in some European countries.*

Country	Years	N				P₂O₅			K₂O	
		Increase % (1962/63 = 100)	Urea %	Other complex fertilizers %	Other nitrogenous fertilizers %	Increase % (1962/63 = 100)	Concentrated super-phosphate %	Other complex fertilizers	Increase % (1962/63 = 100)	Muriate %
ustria	1962/63	139,4	0,2	9,4	—	108,8	—	6,3	137,2	15,5
	1966/67		0,2	15,4	—		5,7	19,0		39,7
lgium	1962/63	106,3	3,4	18,4	—	125,9	6,9	25,8	86,4	25,7
	1967/68		9,5	17,1	—		10,5	42,6		15,1
nmark	1962/63	162,6	1,6	1,4	10,1	99,6	—	1,5	94,0	98,0
	1967/68		1,1	33,0	33,4		—	37,5		58,4
nland	1962/63	184,1	—	12,9	37,5	150,4	0,1	6,8	153,4	25,2
	1967/68		1,7	39,0	22,4		0,2	39,2		7,0
ance	1962/63	165,9	2,9	22,7	> 0,1	145,8	16,1	9,7	—	—
	1967/68		2,5	38,5	5,8		5,8	63,2		—
rman Fed. Republic	1962/63	122,7	—	27,9	0,9	111,0	—	31,9	—	—
	1967/68		—	29,1	0,2		—	36,1		—
eece	1962/63	162,2	0,2	0,9	3,1	124,7	14,6	1,7	—	—
	1967/68		—	1,6	2,1		3,6	3,5		—
ly	1962/63	127,4	5,3	25,5	0,1	123,4	2,3	42,1	132,7	3,9
	1967/68		9,5	30,6	0,05		2,0	45,3		4,6
therlands	1962/63	116,9	—	17,6	4,4	103,9	< 0,1	51,5	103,0	6,0
	1967/68		0,1	16,8	0,3		0,6	49,7		6,5
rway	1962/63	114,3	0,8	63,8	—	119,7	—	70,4	122,6	25,7
	1967/68		1,5	61,6	—		2,3	82,1		0,9
rtugal	1962	184,9	0,5	3,7	—	88,9	35,0	3,2	190,0	67,0
	1967/68		8,1	2,6	0,2		27,2	3,7		82,6
ain	1962/63	145,8	0,1	—	—	107,7	0,2	—	108,1	77,1
	1967/68		5,0	11,6	—		—	24,6		72,7
eden	1962/63	163,1	0,9	9,9	1,8	125,0	0,8	9,4	—	—
	1967/68		10,3	27,0	0,2		0,4	38,9		—
itzerland	1962/63	133,6	7,6	16,9	8,4	99,7	—	8,3	120,8	100,0
	1967/68		9,5	11,0	4,7		0,6	9,1		100,0
ited Kingdom	1962/63	168,0	—	38,7	—	111,7	12,1	28,6	112,8	89,3
	1967/68		—	52,3	—		12,2	49,8		86,1

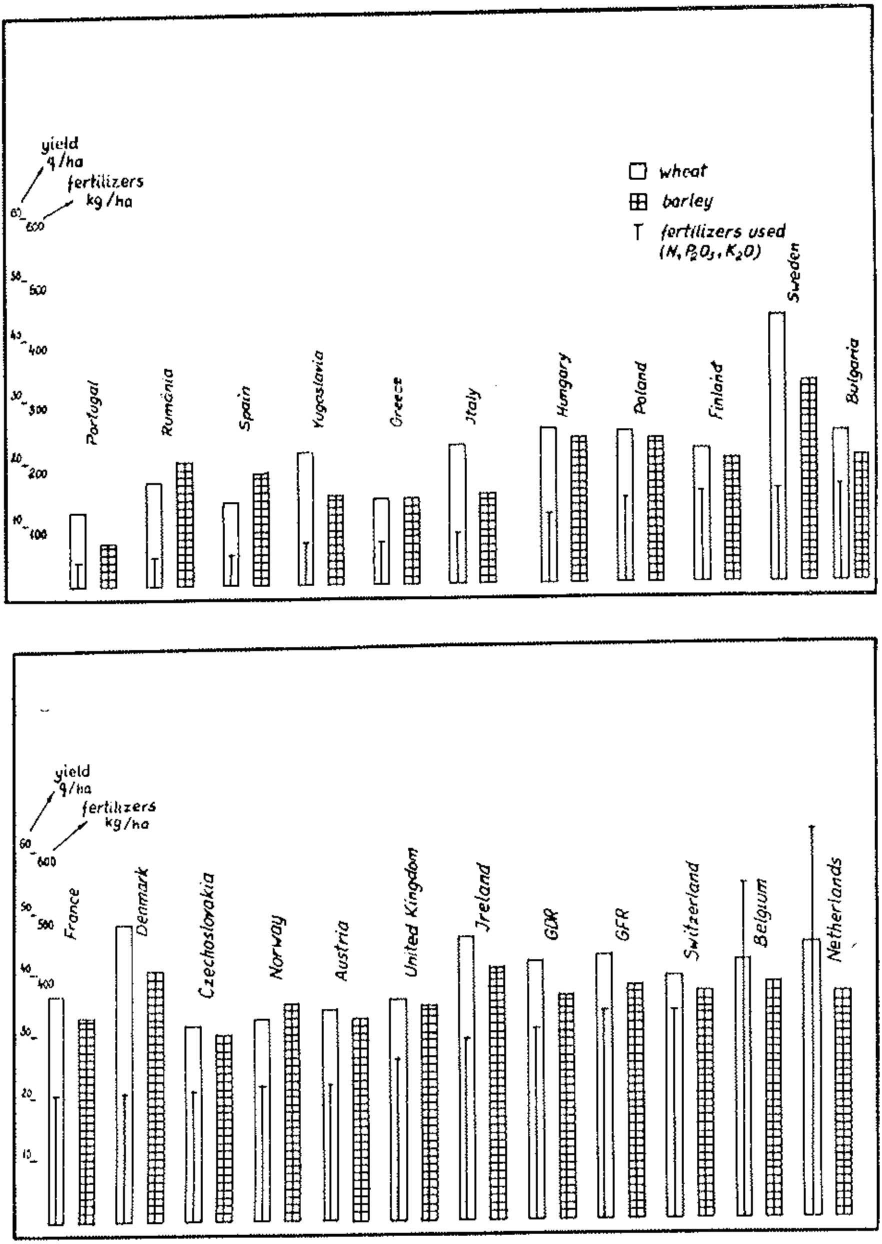


FIG. 2 — Fertilizer consumption in some European countries plotted against the average yields of winter wheat and barley.

300 kg/ha, the yields were never below 30 q/ha in neither of these seven countries, independently of their geographic sites. The application of higher fertilizer rates (above 300 kg/ha) results in average yields of about 40 q/ha.

Our data reveal that in some of the main maize growing countries, for instance in Rumania, Yugoslavia and Hungary, the maize yields are from 20 to 30 q/ha. In France and Italy, the 1968 year's yields were 52,6 and 41,3 q/ha, resp., influenced considerably — beside the use of proper hybrid sorts and agrotechnics, also by the efficient fertilizer rates. Throwing a glance at the yields of sugar-beet, one of our most exigent crops, we may see that just in the countries with highest fertilizer consumption, so in the Netherlands, Belgium, German Federal Republic, France, Denmark and Austria the yields were about 500 q/ha in 1968. In the majority of cases we found the average yields to be from 200 to 300 q/ha, where fertilizer consumption was below 100 kg/ha (Rumania, Spain). The same correlation could be established between the yields of potato, one of our main food crops, and the fertilizer rates applied. Similarly to sugar-beet, the highest yield — 344 q/ha — was reached in 1968 in the Netherlands where the fertilizer rates applied per ha of arable land surpassed 600 kg. Potato yields above 200 q/ha were equally reached in the countries (Denmark, Belgium, German Federal Republic, France, United Kingdom and Austria) with relatively high fertilizer consumption.

The data reported show that in spite of the manifold factors involved, there is a definite correlation between the yields of the main crops grown in the different European countries and the fertilizer amounts applied.

In the past 10-15 years the development in the production and consumption of fertilizers became very apparent in Hungary, too. In the pre-war years between 1931 and 1940 only insignificant fertilizer quantities were utilized. In 1950, fertilizer consumption was still below 50 thousand metric tons and less than 10 kg/ha were used on the arable lands. As a result of recent progress, the total fertilizer consumption in 1969 — as seen in Fig. 3 — came to 698,6 thousand metric tons, and fertilizer quantities applied on arable lands reached 125 kg/ha. From the data it also becomes evident that simultaneously with the increase of fertilizer consumption, there is a change in the ratios of these nutrients to the advantage of N. According to the estimations, the foreseeable fertilizer consumption in 1975 and 1985 will exceed 200 and 400 kg/ha, resp.

Fig. 4 summarizes the correlations between the fertilizer rates applied pro ha and the yield of some crops. There, it can be observed that, with the exception of potato, the yield of each crop increased considerably during the late years due primarily to the application of proper fertilizer doses.

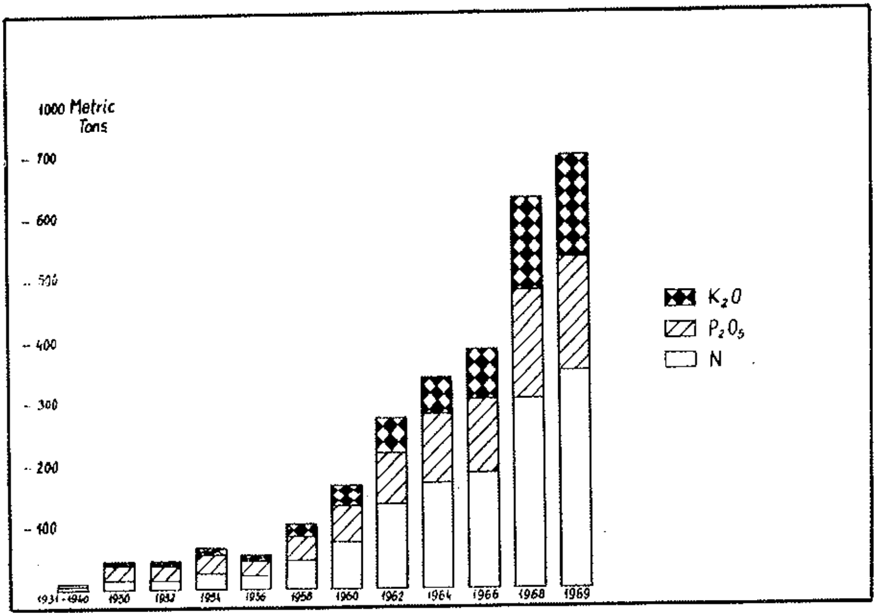


FIG. 3 — Development of fertilizer consumption in Hungary.

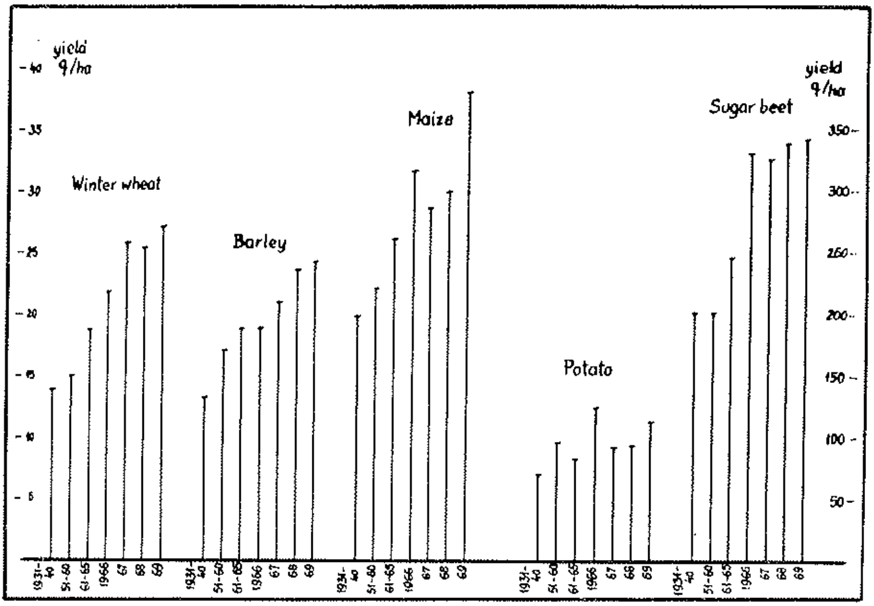
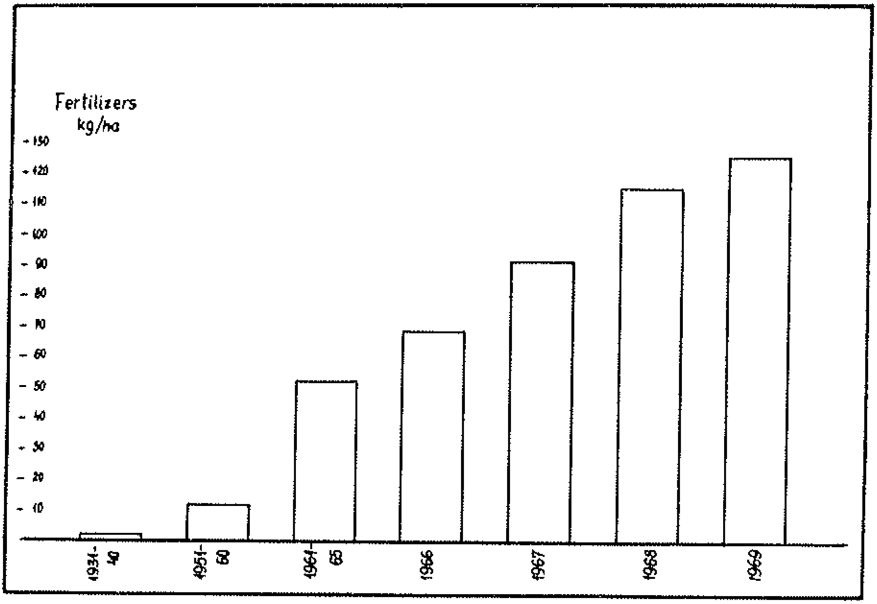


FIG. 4 — Average yields of some cultivated crops, q/ha Winter wheat, Barley, Maize, Potato, Sugar beet.



Fertilizers used kg/ha arable land.

2. *Effects of NPK fertilization.*

We know that the effect of fertilizers on crop yields and their qualities depends on some definite and complex factors involved in the conditions created for the cultivated plants. Consequently, the data and the conclusions as to the efficiency of fertilization, drawn on the basis of experiments carried out in the different countries, do not agree in many cases though their trends are mostly similar. The reference books and a great number of publications summarizing the scientific results underline the responses of winter wheat to N and P fertilizers, too.

In Hungary, experiments on the efficiency of fertilization were already started by the end of the past century but extensive scientific work in this field was only realizable in the last decade simultaneously with the vast development in the production and consumption of fertilizers. It is, of course, not possible to present the results of every experiment on the efficiency of fertilization. So, in the following, the aggregated data of some field trials are dealt with.

2.1 *Rates and ratios of fertilizers.*

At first, I want to illustrate the experiments with several fertilizer rates and ratios conducted on 13 different places of this country. Thus, Fig. 5 shows the aggregated 386 data of 36 experiments with winter wheat. It is observable that if we take the mean values received, i.e. when disregarding the modifying influence of soil type, preceding crop, plant varieties, etc., we get the maximum effect with 85 kg N as single fertilizer or 105 kg N when applied with additional P and P plus K, resp. P alone had little effect but, in agreement with the literature, combined with N it gave better results than N alone.

The curves drawn on the basis of about 300 data got from

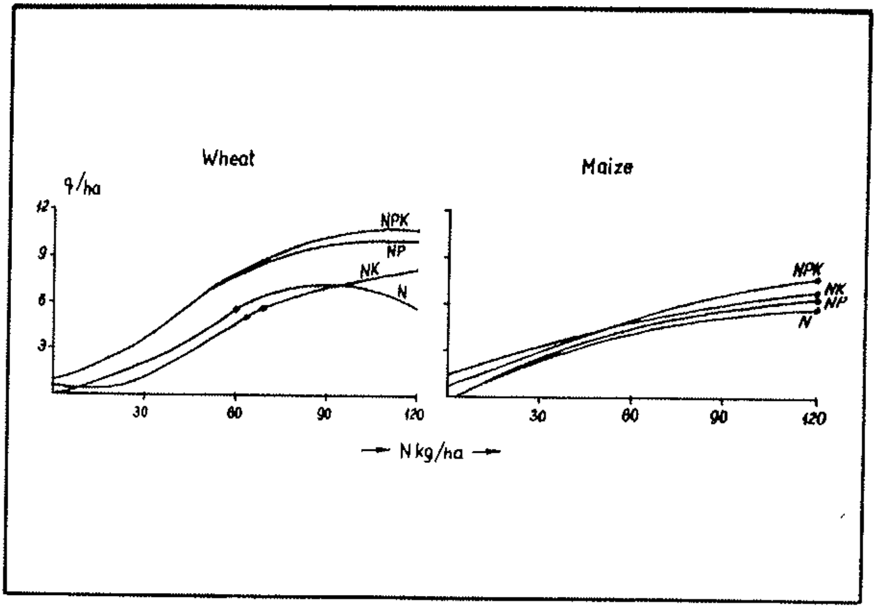


FIG. 5 — Grain yield increase.

30 experiments with maize show also the decisive effect of N. As in the case of wheat, P without N has only slight effect but combined with greater doses of N, K was effective, too. In this Figure, one may observe that on the average of the experiments, the effect of N showed a rather evenly increasing trend upto a rate of 110 kg/ha.

The curves presented refer only to the average values of the experiments and give little information about further yield-increasing factors which are, however, not negligeable, as seen in Fig. 6. The results of experiments with maize and wheat carried out on two characteristic soil types, indicate that on chernozem soil the application of 60 kg/ha N gave a surplus yield of 5-8 q/ha, while the further increase of N fertilizer rates was no more reasonable. By the use of P and K together

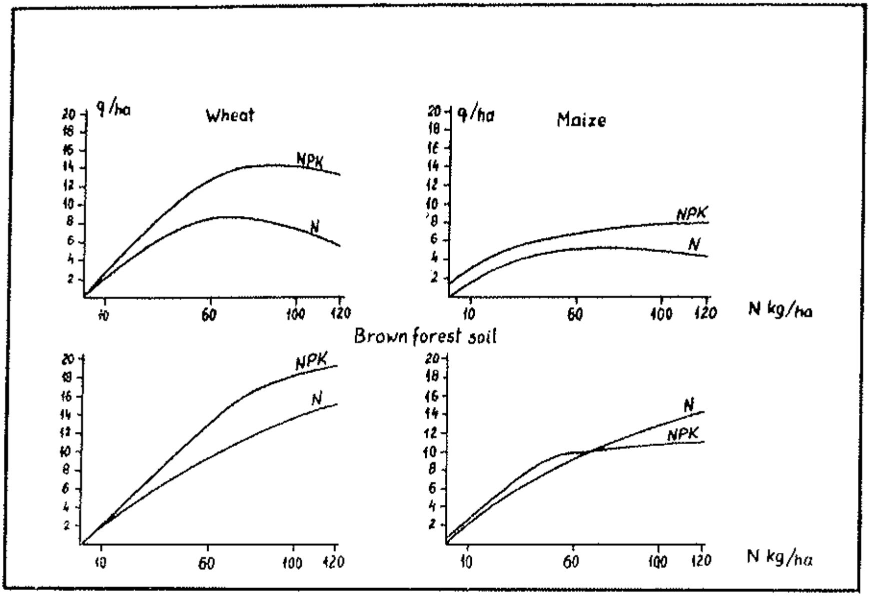


FIG. 6 — Grain yield increase Chernozem soil.

with N, the yields could be further increased. On brown forest soil poor in nutrients, N fertilization — depending on the rates applied — resulted in a surplus grain yield of 9-14 q/ha with wheat and 8-13 q/ha with maize. By fertilization with PK — together with N — the wheat yields were further increased, while P and K fertilization had no effect with maize.

The foregoing correlations were established primarily on the basis of one-year experiments. Now, I wish to present the results of some long-term trials carried out with wheat and maize on areas differing considerably in their climate and soil conditions. In order to be able to observe precisely the responses to residual effects and to soil and climate, resp., the above mentioned crops were grown in monocultures alternating every four years. In the following I will deal with the results of the first four-year period, obtained on two experimental fields.

Taking into account the years' averages of the different effects, the results of the long-term experiments show also the definite advantage of N fertilizing (Table 4). The single application of 60 kg/ha N fertilizers bi-annually resulted in an average yield increase of 3,9-5,4 q/ha with wheat and 8,9-9,5 q/ha with maize annually, on chernozem and brown forest soils. By the application of 120 kg/ha N fertilizers once during two years, the grain yield was further increased on brown forest soil but on chernozem soil this treatment remained ineffective. From these results the conclusions can be drawn that it is not reasonable to increase the rates of N fertilizers when applied alone on chernozem soil rich in nutrients. Also, that in case of both test crops the greatest effect was reached by using the proper combinations of NPK.

Our data demonstrate that 60 kg/ha N applied annually was more efficient for wheat and especially for maize than 120 kg/ha N added bi-annually, though this treatment had considerable residual effect on some of the experimental fields.

Though the available P contents of our soils examined were not high, on one-year's average we did not observe any significant P effect that could be attributed to single P fertilization. On the other hand, heavy N dressing in combination with the application of P increased considerably the yields of both maize and wheat on chernozem soil. From the Table it can be seen that on chernozem soil with relatively good natural N-supply, P fertilization is especially efficient and N and P showed significant interactions in case of both test crops.

Reliable K effect was equally observed when applying N and K fertilizers together for maize on chernozem soil where, similarly to the case of P fertilization, significant NK interactions could be established.

Calculations concerning the efficiency of fertilization indicate that by the application of 60 kg/ha N bi-annually with

TABLE 4 — *Effect of N fertilization on grain yield, q/ha/year.*

Treatment P_2O_5 kg/ha (for 2 years)	K_2O	N_{60} added bi-annually Effect	Interaction	N_{120} Effect	$N_{120}-N_{60}$ Interaction	Effect	N_{60} added annually Effect	$N_{60}+N_{60}-N_{120}$ Interaction	Effect	Yield increase kg/year pro 1 kg N: N_{60} added bi-annually	N_{120} added bi-annually	N_{60} annually
					Chernozem, winter wheat							
—	—	3,9	—	3,3	—	−0,6	3,8	—	0,5	13,0	5,5	6,3
60	—	5,4	1,5	7,5	4,2	2,1	5,5	1,7	−2,0	18,0	12,5	9,1
—	60	5,0	1,1	5,2	1,9	0,2	4,7	0,9	−0,5	16,6	8,7	7,8
60	60	4,9	1,0	4,8	1,5	−0,1	5,5	1,7	0,7	16,3	8,0	9,1
120	120	6,4	2,5	8,2	4,9	1,8	7,5	3,7	−0,7	21,3	13,7	12,5
LSD5% I.		3,1		3,1		3,1	3,1		3,1			
LSD5% II.			2,8		2,8			2,8				
							maize					
—	—	9,5	—	10,9	—	1,4	13,9	—	3,0	31,6	18,1	23,1
60	—	8,1	−1,4	15,4	4,5	7,3	15,8	1,9	0,4	27,0	25,7	26,3
—	60	8,4	−1,1	13,7	2,8	5,3	15,6	1,7	1,9	28,0	22,8	26,0
60	60	13,5	4,0	20,6	9,7	7,1	22,9	9,0	2,3	45,0	34,3	38,1
120	120	13,7	4,2	21,2	10,3	7,5	25,9	12,0	5,1	45,7	35,3	43,[illegible]
LSD5% I.		2,4		2,4		2,4	2,4		2,4			
LSD5% II.			2,7		2,7			2,7				
					Brown forest soil, winter wheat							
—	—	5,4	—	9,1	—	3,7	10,0	—	0,9	18,0	15,1	16,6
60	—	4,9	−0,5	8,3	−0,8	3,4	8,7	−1,3	0,4	16,3	13,8	14,5
—	60	4,0	−1,4	10,2	1,1	6,2	10,3	0,3	0,1	13,3	17,0	17,1
60	60	6,2	0,8	9,9	0,8	3,7	11,6	1,6	1,7	20,6	16,5	19,3
120	120	6,4	1,0	9,8	0,7	3,4	11,6	1,6	1,8	21,3	16,3	19,3
Average		5,4		9,4		4,0	10,4		1,0	18,0	15,7	17,3
LSD5% I.		5,2		5,2		5,2	5,2		4,9			
LSD5% II.			3,2		3,2			3,2				
LSD5% III.		4,7		4,7		4,7	4,7		4,4			
								maize				
—	—	8,9	—	14,4	—	5,5	21,6	—	7,2	29,6	24,0	36,0
60	—	11,1	2,2	15,4	1,0	4,3	22,3	0,7	6,9	37,0	25,7	37,1
—	60	10,4	1,5	17,4	3,0	7,0	22,0	0,4	4,6	34,7	29,0	36,7
60	60	5,9	−3,0	13,2	−1,2	7,3	18,1	−3,5	4,9	19,7	22,0	30,1
120	120	9,1	0,2	15,6	1,2	6,5	20,0	−1,6	4,4	30,3	26,0	33,3
Average		9,1		15,2		6,1	20,8		5,6	30,3	25,3	34,7
LSD5% I.		6,0		6,0		6,0	6,0		6,0			
LSD5% II.			5,5		5,5			5,5				
LSD5% III.		5,0		5,0		5,0	5,0		5,0			

Significant differences
I. For N-effects in case of equal P and K rates.
II. For the interactions of N and different P and K rates.

the various combinations of PK, wheat yields can be increased by 17,0 kg (pro 1 kg fertilizer N) on chernozem soil and by 21,5 kg on brown forest soil. When raising the N rates to 120 kg, the annual grain yield increases reached 9,7 kg on chernozem soil and 18.8 kg on brown forest soil, calculated pro 1 kg fertilizer N, in the average of the treatments. The efficiency values were similar — 8,9 and 20,8 kg yield increase — after the application of 60 kg/ha N annually on both soil types. These data demonstrate that on chernozem soil 120 kg/ha N was markedly less effective than 60 kg/ha. On brown forest soil, however, the grain yield increases (pro 1 kg fertilizer N) due to the application of 60 and 120 kg/ha N were nearly identical (18,8 and 20,8 kg, resp.).

In case of maize grown on chernozem soil, the treatments with NPK were of maximum efficiency depending on the N rates, time and method of application. Here, the average grain yield increases amounted to 27,2-35,5 kg pro 1 kg fertilizer N. On brown forest soil these values ranged from 36,3 to 30,4 kg when bi-annually 60 and 120 kg/ha N were applied with the various combinations of PK, while in case of N fertilization at rates of 60 kg annually, the average yield increase amounted to 41,5 kg.

Beside increasing yields, mineral fertilization has favourable effects on crop quality, too. On the basis of our results obtained with the experiments in 1964 and 1965, we have summarized the parameters characterizing the nutritional value and baking quality of wheat (Table 5). These data show that the hectolitre weight of Besostaja 1 winter wheat did not change considerably as influenced by fertilization and its residual action. On the other hand, fertilization affected favourably the 1000-grain-weight on chernozem soil. Flour yield determined by the milling equipment of Quadratum-Junior displayed, in the majority of cases, certain slight decreases caused by fertilization. These values prove also the considerable changes in the gluten content in the grains of some wheat varieties, depending on the site and year of the experiment. In each

TABLE 5 — *Effect of fertilization on wheat grain quality.*

Treatment	Hectolitre weight, kg	1000—grain weight	Flour yield %	Gluten content wet %	Gluten content dry %	Water uptake %	Farinographic analysis Value number	Farinographic analysis Value group
				Chernozem Effect of fertilization, 1964				
Ø	81,0	34,0	73,5	25,5	8,5	58,6	43,4	C-1
N_{60}	81,0	33,8	72,0	30,5	9,0	59,6	45,8	B-2
$N_{60}P_{60}$	81,0	37,6	71,2	29,0	9,3	59,6	48,3	B-2
$N_{60}P_{60}K_{60}$	81,5	36,6	68,9	30,0	10,0	58,4	39,5	C-1
N_{120}	81,7	34,2	70,2	31,0	10,0	60,0	57,9	B-1
$N_{120}P_{60}$	82,2	37,0	71,5	31,0	10,0	60,0	53,3	B-2
$N_{120}P_{60}K_{60}$	82,6	37,2	72,2	33,5	10,5	60,0	62,9	B-1
				Residual effect, 1965				
Ø	80,0	36,0	64,9	33,5	11,5	66,0	76,2	A-2
N_{60}	79,9	37,6	64,4	37,3	12,5	66,6	86,5	A-1
$N_{60}P_{60}$	80,7	40,4	63,5	38,0	12,8	67,0	88,4	A-1
$N_{60}P_{60}K_{60}$	80,6	40,9	64,3	39,0	12,5	66,5	84,0	A-2
N_{120}	80,0	35,4	65,9	35,3	12,0	66,4	77,6	A-2
$N_{120}P_{60}$	80,5	39,5	65,5	35,0	11,8	66,5	83,0	A-2
$N_{120}P_{60}K_{60}$	80,3	35,7	61,8	34,8	11,8	65,8	78,5	A-2
				Brown forest soil Effect of fertilization, 1964				
Ø	80,8	39,4	72,4	31,5	10,5	61,0	75,6	A-2
N_{60}	79,9	36,6	71,1	27,0	8,5	59,4	46,0	B-2
$N_{60}P_{60}$	78,6	37,2	70,3	28,0	9,5	60,0	49,2	B-2
$N_{60}P_{60}K_{60}$	78,6	38,4	71,1	22,5	7,0	58,0	24,3	C-2
N_{120}	77,7	34,2	69,9	31,0	9,0	59,4	48,4	B-2
$N_{120}P_{60}$	77,7	36,0	70,6	28,0	8,5	58,8	44,8	C-1
$N_{120}P_{60}K_{60}$	78,6	34,4	70,3	27,0	8,0	59,2	36,6	C-1
				Residual effect, 1965				
Ø	77,5	32,4	64,9	23,0	7,5	62,1	46,8	B-2
N_{60}	79,7	34,3	64,4	25,3	8,5	62,3	55,2	B-1
$N_{60}P_{60}$	80,3	37,2	61,8	24,0	8,3	63,1	55,2	B-1
$N_{60}P_{60}K_{60}$	78,9	35,6	62,9	19,0	6,5	61,8	42,3	C-1
N_{120}	78,2	33,5	65,3	21,5	7,0	61,5	43,9	C-1
$N_{120}P_{60}$	78,3	33,7	64,0	23,8	8,0	61,5	46,1	B-2
$N_{120}P_{60}K_{60}$	79,6	36,9	63,5	19,5	8,5	61,0	40,9	C-1

case, the gluten content of wheat grown on chernozem soil was significantly increased by fertilization, while on brown forest soil this response could not always be established. The differences in the values obtained by farinographic analyses point also to the primary influence of the site. According to these evaluations, mineral fertilization on chernozem soil did not unfavourably affect flour quality compared to the control, moreover, in the year of fertilizing the results were positive with each of the treatments. Analytical data obtained with flours of crops grown on brown forest soil are contradictory and consequent effects could not be demonstrated.

Table 6 presents the quality characteristics of maize grains.

TABLE 6 — *Effect of fertilization on the crude protein content in maize grains.*

Treatments	Crude protein %	Increase	Crude protein yield, q/ha	Increase	Crude protein %	Increase	Crude protein yield, q/ha	Increase
	Chernozem				Brown forest soil			
	Fertilizer effects in the average of the years 1962 and 1964							
Ø	6,3	—	1,5	—	6,2	—	2,7	—
N_{60}	8,0	1,7	2,9	1,4	7,1	0,9	4,1	1,4
$N_{60}P_{60}$	7,7	1,4	2,8	1,3	7,5	1,3	4,5	1,8
$N_{60}P_{60}K_{60}$	7,6	1,3	3,2	1,7	7,2	1,0	3,8	1,1
N_{120}	9,0	2,7	3,2	1,7	8,1	1,9	5,2	2,5
$N_{120}P_{60}$	8,8	2,5	3,9	1,4	8,6	2,4	5,4	2,7
$N_{120}P_{60}K_{60}$	9,3	3,0	4,4	2,9	8,5	2,3	5,0	2,3
	Residual effects in the average of the years 1963 and 1965							
Ø	6,5	—	1,8	—	6,6	—	1,9	—
N_{60}	6,7	0,2	2,3	0,5	6,6	—	2,2	0,3
$N_{60}P_{60}$	6,5	—	2,0	0,2	6,6	—	2,2	0,3
$N_{60}P_{60}K_{60}$	6,7	0,2	2,4	0,6	6,7	0,1	1,8	−0,1
N_{120}	6,9	0,4	3,0	1,2	6,7	0,1	2,5	0,6
$N_{120}P_{60}$	7,3	0,8	2,8	1,0	7,4	0,8	2,8	0,9
$N_{120}P_{60}K_{60}$	7,3	0,8	3,3	1,5	7,1	0,5	2,5	0,6

It is to observe that, dependently on the treatment, the crude protein content of the grains increased from 0,9 to 3,0 percent on both soil types and the surplus crude protein yield pro ha was 1,1-2,9 q in the year of fertilization and an increase of about 0,2-1,5 q in the subsequent year was due to residual action.

In experiments conducted over several years with maize on chernozem soils with forest remains, we have studied — beside crop and crude protein yields — the effect of N and the various combinations of NPK on the fat and starch content of the grains.

The results summarized in Tables 7 and 8 show the annual variations in the chemical composition of maize grains. Application of N and of NPK favourably affected the N and crude protein content of the grain. Due to these treatments the fat contents rose but the starch contents decreased in the majority of cases. From the data characterizing the nutritional value

TABLE 7 — *Effect of fertilization on the chemical composition of maize grains.*

Treatment	Yield q/ha			Crude protein %			Fat %			Starch %		
	1956	1957	1958	1956	1957	1958	1956	1957	1958	1956	1957	1958
Ø	71,1	81,4	69,2	7,24	6,77	7,68	5,80	4,62	3,60	72,60	69,53	69,20
P_1	68,9	83,5	75,9	7,16	6,94	8,15	6,38	4,34	5,43	68,36	65,97	66,40
K_1	75,2	85,0	68,5	7,08	6,93	8,15	6,39	4,42	5,11	66,41	66,56	69,70
N_1	75,4	85,9	72,6	7,44	7,75	8,29	6,01	5,42	4,96	68,22	65,60	67,40
N_1P_1	78,3	83,5	74,0	7,69	7,79	8,15	6,33	4,66	4,99	69,09	67,30	67,50
N_1K_1	77,4	88,8	77,1	7,69	7,23	8,34	6,65	5,11	4,77	68,75	66,92	69,20
$N_1P_1K_1$	83,9	87,4	75,0	7,51	7,70	8,26	5,46	4,82	4,40	64,57	67,30	69,70
$N_2P_2K_2$	—	92,5	72,8	—	7,63	8,38	—	4,94	5,09	—	64,77	69,20

Fertilizer rates: N_1 = 52 kg/ha N
P_1 = 47 kg/ha P_2O_5
K_1 = 52 kg/ha K_2O

$N_2P_2K_2$ is the double amount of $N_1P_1K_1$

TABLE 8 — *Changes in the yields characterizing the nutritional value, as affected by fertilization.*

	Treatments							
	Ø	P_1	K_1	N_1	N_1P_1	N_1K_1	$N_1P_1K_1$	$N_2P_2K_2$
Yield q/ha								
1956	71,1	68,9	75,2	75,4	78,3	77,4	83,9	—
1957	81,4	83,5	85,0	85,9	83,5	88,8	87,4	92,5
1958	69,2	75,9	68,5	72,6	74,0	77,1	75,0	72,8
Average	73,9	76,1	76,2	78,0	78,6	81,1	82,1	82,6
D	—	2,2	2,3	4,1	4,7	7,2	8,2	8,7
Crude protein yield q/ha								
1956	5,1	4,9	5,3	5,6	6,0	6,0	6,3	—
1957	5,5	5,8	5,9	6,7	6,5	6,4	6,7	7,1
1958	5,3	6,2	5,6	6,0	6,0	6,4	6,2	6,1
Average	5,3	5,6	5,6	6,1	6,2	6,3	6,4	6,6
D	—	0,3	0,3	0,8	0,9	1,0	1,1	1,3
Fat yield q/ha								
1956	4,1	4,4	4,8	4,5	5,0	5,1	4,6	—
1957	3,8	3,6	3,8	4,7	3,9	4,5	4,2	4,6
1958	2,5	4,1	3,5	3,6	3,7	3,7	3,3	3,7
Average	3,5	4,0	4,0	4,3	4,2	4,4	4,0	4,2
D	—	0,5	0,5	0,8	0,7	0,9	0,5	0,7
Starch yield q/ha								
1956	51,6	47,1	49,9	51,4	54,1	53,2	54,2	—
1957	56,6	55,1	56,6	56,4	56,2	59,4	58,8	59,9
1958	47,9	50,4	47,7	48,9	50,0	53,4	52,3	50,4
Average	52,0	50,9	51,4	52,2	53,4	55,3	55,1	55,2
D	—	−1,1	−0,6	0,2	1,4	3,3	3,1	3,2

we can observe that the application of N and the combinations of NPK caused increases of 4,1-8,7 q/ha in the grain yields, 0,9-1,3 q/ha in the crude protein, 0,8-0,9 q/ha in the fat and 0,3-3,3 q/ha in the starch yields.

In order to give further illustrations as to the efficiency of mineral fertilizers, I will now deal with the results of multifactorial long-term trials carried on over eight years on brown forest soil receiving precipitations in moderate amounts. Table 9 shows the grain yields in the averages of plants and periods. In Table 10 we see the effect pro unit of nutrient element, i.e. the so-called specific effect, while the numerical

TABLE 9 — *Grain yields q/ha/year* (86 percent dry matter).

Crop	Period	N level	P level 0 +O	P level 0 +K	P level 1 +O	P level 1 +K	P level 2 +O	P level 2 +K	$LSD_{5\%}$
Barley									
Winter wheat	1960-61	0	12,5	12,3	13,8	15,5	14,1	14,1	
		1	19,8	19,1	23,8	24,4	25,7	26,0	3,5
		2	23,0	23,0	29,3	30,0	29,5	33,7	
Maize	1962-65	0	9,9	8,0	8,4	10,1	12,5	8,6	
		1	27,0	27,4	27,1	29,7	28,3	29,5	4,1
		2	34,7	34,3	35,4	38,2	33,7	36,3	
Winter wheat	1966-67	0	13,4	13,0	16,7	16,0	15,6	15,0	
		1	24,0	22,1	28,3	31,0	31,2	28,3	4,6
		2	26,8	35,8	39,7	41,9	40,4	43,1	

Fertilizer rates: N, P_2O_5 and K_2O kg/ha, resp.

	N_1	N_2	P_1	P_2	K
1960-61	55	100	42	95	50
1962-65	60	120	60	120	60
1966-67	60	120	30	60	45

TABLE 10 — *Effect of fertilization on grain yields, q/ha* (86 percent dry matter).

Crop	Period	Treatment	Averages of K and P treatments, resp.			$LSD_{5\%}$
Barley	1960-61					
Winter wheat			P_0	P_{42}	P_{95}	
		N_0	—	2,2	1,7	
		N_{55}	7,0	11,7	13,4	2,5
		N_{100}	10,6	17,1	19,1	
Maize	1962-65					
			K_0	K_{60}		
		N_0	—	−1,4		
		N_{60}	17,2	18,6		2,4
		N_{120}	24,3	26,0		
Winter wheat	1966-67					
			P_0	P_{30}	P_{60}	
		N_0	—	3,2	2,1	
		N_{60}	9,8	16,5	16,5	3,2
		N_{120}	18,1	27,6	28,6	
			K_0	K_{45}		
		N_0	—	−0,5		
		N_{60}	12,6	11,9		2,7
		N_{120}	20,4	25,1		

values of the significant effects due to fertilization are to be found in Table 11.

These data reveal that, similarly to our previous short-term experiments with monocultures, the application of N and — in case of cereals — N and additional P fertilization were very efficient on these soil types, too. After the treatments with $N_{55}P_{42}$ and $N_{60}P_{30}$, resp., the grain yield increase pro 1 kg fertilizer N was between 17 and 22 kg. On the average of all combinations, the application of N at rates of 60 kg

TABLE II — *Grain yield increases* (kg) *in terms of 1 kg NPK nutrient content.*

Crop	Period	Treatment	Averages of K and P treatments, resp.			$LSD_{5\%}$
Barley	1960-61					
Winter wheat			P_0	P_{42}	P_{95}	
		N_{55}-N_0	12,7	17,3	21,3	6,3
		N_{100}-N_{55}	8,0	12,2	12,7	7,7
			N_0	N_{55}	N_{100}	
		P_{42}-P_0	5,2	11,2	15,7	8,3
		P_{95}-P_{42}	−0,9	3,2	3,6	6,6
Maize	1962-65		K_0	K_{60}		
		N_{60}-N_0	28,7	28,7		5,6
		N_{120}-N_{60}	11,8	12,3		5,6
Winter wheat	1966-67		P_0	P_{30}	P_{60}	
		N_{60}-N_0	16,3	22,2	24,0	7,7
		N_{120}-N_{60}	13,8	18,5	20,2	7,7
			N_0	N_{60}	N_{120}	
		P_{30}-P_0	10,7	22,3	31,7	15,4
		P_{60}-P_{30}	−3,7	0,0	3,3	15,4
			K_0	K_{45}		
		N_{60}-N_0	21,0	19,0		6,3
		N_{120}-N_{60}	13,0	22,0		6,3
			N_0	N_{60}	N_{120}	
		K_{45}-K_0	−1,1	−1,6	10,4	8,4

gave a surplus maize grain yield of 28,7 kg pro 1 kg fertilizer N. When raising the N doses up to 120 kg, the grain yield increase was about 12 kg (pro 1 kg fertilizer N) both with cereals and maize in the first six years of the experiment.

In the seventh and eighth year, the application of N with additional P and K, resp., resulted in yield increases of 18,5-22 kg due to specific effect.

As for P, its efficiency was demonstrated only in case of cereals, when applied together with N upto the rates of 30-42 kg P_2O_5. In the conditions given, P fertilization produced the most marked effect in the treatment of $N_{120}P_{45}K_{30}$ where the grain yield increase was 31,7 kg pro 1 kg fertilizer P_2O_5.

K fertilization had no effects in the first years of the experiment neither with cereals nor with maize. In the last two years, however, a significant grain yield surplus of 10,4 kg (pro 1 kg fertilizer K_2O) was received in the average of the different P-treatments when 120 kg N was also applied.

The analysis of variance of the eight years' cumulated grain yields showed also the significant effects of N and P fertilization and there were no statistically reliable differences between the K_0 and K levels. The effects of heavy dressing (in interaction with K) showed raising trends, therefore, the tendency of influences exerted by K on the efficiency of N and P fertilization, i.e. the response surfaces and their levels, the isoquantes, were separately represented for K_0 and K (Figs. 7 and 8). The isoquantes between the N and P rates necessary to reach a given yield prove the possibility of using various fertilizer combinations for this reason. The higher curvature and the more pronounced streching out of the level lines at higher yields, that is, at the upper phase of the response surfaces, indicate the decrease in the additional effects of the fertilizers and, at the same time, the growing necessity of applying K together with N and P each and both.

From the crop quality analyses we may see (Table 12)

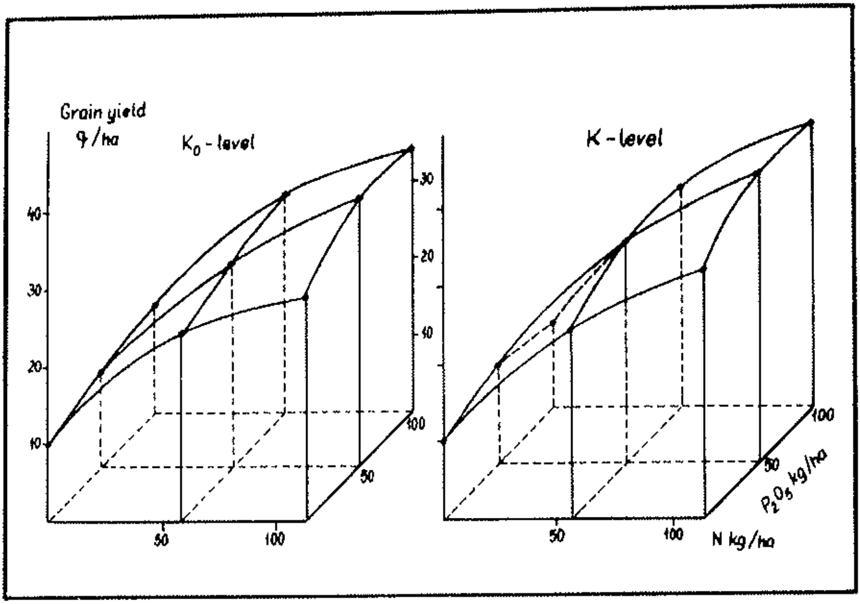


FIG. 7

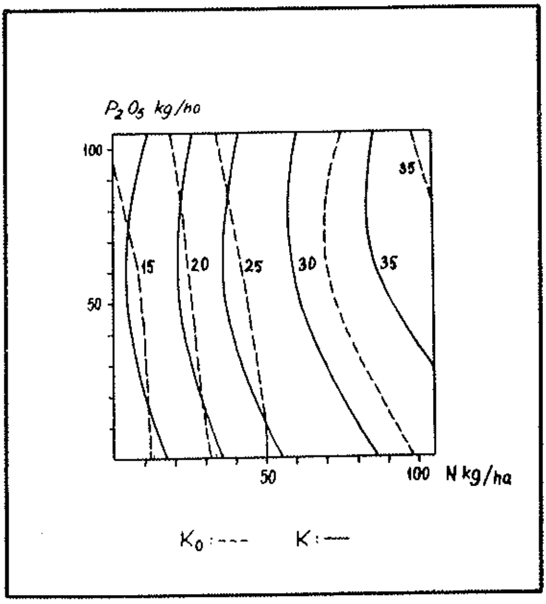


FIG. 8 — Jsoquantes.

TABLE 12 — *Effect of fertilization on winter wheat quality*, 1966.

Treatment	Hectolitre-weight, kg	1000-grain-weight, kg	Flour yield %	Gluten content wet %	Gluten content dry %	Farinographic analysis Water uptake %	Farinographic analysis Value number	Farinographic analysis Value group
Ø	84,1	36,4	56,6	26,5	8,8	61,5	45,7	B-2
N_{60}	83,6	39,1	60,6	26,5	8,8	63,0	49,3	B-2
N_{120}	83,1	37,6	59,6	30,0	10,0	65,0	42,5	C-1
$N_{60}P_{60}$	84,2	38,7	59,9	25,0	8,5	63,1	47,7	B-2
$N_{120}P_{60}$	84,5	39,5	58,7	28,8	9,5	64,2	40,6	C-1
$N_{120}P_{120}$	84,5	38,2	56,3	27,5	9,0	64,1	40,7	C-1
$N_{60}P_{60}K_{60}$	84,5	39,7	55,7	24,8	8,3	62,9	45,2	B-2
$N_{120}P_{60}K_{60}$	84,7	41,3	54,2	28,0	9,3	64,2	55,3	B-1
$N_{120}P_{120}K_{60}$	84,6	42,8	56,9	28,8	9,5	64,1	55,2	B-1

that in the seventh year of this experiment, when considering aggregated fertilizer effects, there were increases in the 1000-grain-weight, flour yield and gluten content compared to the control. The different combinations of NPK had no unfavourable effect on flour quality, on the contrary, after certain treatments these flours got higher classifications on the basis of farinographic analyses.

Our results presented here to demonstrate the efficiency of fertilizers when applied in proper rates and ratios, reveal that most of the Hungarian Soils are of low N-status but besides a N-supply, the P fertilization of cereals was also successful in the majority of cases. We could further observe the responses of maize to K in interaction with N. Simultaneously with the increase in the consumption of mineral fertilizers, first of all in that of N, the necessity has arisen to assure the adequate nutrient supply by the application of optimum NPK combinations after taking into account the conditions of soil, climate, plant, etc.

3. *Methods of fertilizer application.*

In order to be able to increase the effect of fertilizers, the methods and time of their application should also be considered. In the course of the years, a lot of experiments have been carried out to establish the optimum time for the incorporation of fertilizers into the soil and at present it is generally well-known that by N top-dressing in spring the yield and quality of winter wheat can beneficially be affected and the adverse influences of preceding crops decreased.

While in the conditions of our country the N top-dressing of wheat proved to be successful in most cases, opinions concerning the proper methods and time of applying fertilizers to maize are very diverse, though the results of recent experiments have demonstrated that N top-dressing of maize is not reasonable in Hungary. Our series of experiments conducted over several years on different soil types support also this latter view. The data in Table 13 show that, compared to a yield of 38,1 q/ha received in the average of 22 experiments, there were no significant yield increases as affected by P and K fertilization without the application of N. The effect of N fertilization was more pronounced. On PK base we reached in the average 6 q/ha significant yield increase due to the effect of 120 kg N given in the form of calcium ammonium nitrate (Pét salt). These data also show that the effect of N fertilizers broadcast in autumn was very different depending on the soil type and on the site. We are also informed that in the average of the experimental sites and of all experiments, the split application of N was not more effective than N as basic fertilizer ploughed down into the soil in single operation in autumn. It is to be observed that, in dependence on the sites and plant sorts, the crude protein content in the grains of the untreated control plants was varying between 7,4 and 9,2 percent, and, that as a response to 120 kg active N it displayed a reliable increase upto 9-12,2 percent.

Compared to the effect of N fertilization, NPK applied

TABLE 13 — *Effect of the method and time of N fertilizer application on the yield and crude — protein percentage of maize grain.*

Soil type	Year	Maize variety	(1) Ø	(2) P_{60} K_{90} (autumn)	(3) P_{60} K_{90} N_{120} (autumn)	(4) N_{120} (spring)	(5) N_{60} (autumn) N_{60} (spring)	(6) N_{60} (spring) N_{60} top-dressing	(7) N_{120} top-dressing	(8) N_{40} (autumn) N_{40} (spring) N_{40} top-dressing	LSD5%
							Treatments (4)–(8): with $P_{60}K_{90}$ as base fertilizer in autumn				
			Grain yield q/ha			Yield increase compared with treatment (3)					
Meadow soil	1962-64	Mv 1	44,4	46,5	45,1	1,1	−1,6	5,5	4,2	3,8	3,2
		Mv 40	36,8	37,0	39,7	−0,4	−3,6	−0,7	−0,2	−1,6	4,6
		Average	40,6	41,7	42,4	0,4	−2,6	2,4	2,0	1,1	2,8
Chernozem	1962-64	Mv 1	39,6	38,4	48,2	−0,7	1,3	0,0	1,9	0,4	4,1
		Mv 40	34,8	37,1	43,7	−1,1	1,0	0,7	1,1	0,4	3,2
		Average	37,2	37,7	46,0	−0,9	1,1	0,3	1,5	0,4	2,6
Sandy brown forest soil	1962-64	Mv 1	30,0	27,2	33,8	0,4	−1,7	−5,6	−4,4	−0,4	5,6
		Mv 40	27,7	30,0	35,1	0,1	−3,2	−1,2	2,3	3,1	5,7
		Average	28,8	28,6	34,4	0,25	−2,5	−3,4	−1,1	1,3	4,0
Brown forest soil	1962-64	Mv 1	54,1	51,4	61,9	−0,2	−5,7	−5,7	−8,0	−6,9	5,7
		Mv 40	45,3	45,3	56,3	−1,6	−4,1	−2,1	−3,4	−3,6	7,3
		Average	49,7	48,4	59,1	−0,9	−4,9	−3,9	−5,7	−5,2	4,6
Average (total)			38,1	38,2	44,2	−0,23	−1,98	−,90	−0,37	−0,18	1,7
			Crude protein percentage								
Chernozem	1962	Mv 1	8,1	7,6	11,0	10,4	11,2	10,6	10,6	10,9	1,27
		Mv 40	8,0	8,3	10,8	10,9	11,3	10,7	10,3	10,6	0,64
Sandy brown forest soil	1962	Mv 1	9,2	8,0	10,2	10,9	12,2	10,8	10,9	11,1	1,48
		Mv 40	8,6	9,6	11,8	10,3	11,3	11,2	11,0	11,2	1,59
Brown forest soil	1962	Mv 1	7,4	7,7	9,4	9,4	10,2	9,2	9,0	9,5	0,21
		Mv 40	8,2	9,1	10,5	10,0	10,1	9,8	9,0	9,6	0,42

together seemed to result in further reliable yield increase as shown in Table 14. At the same time, one can observe that on the average of 14 experiments, split-dressing did not give better results than the same amount of NPK broadcast in autumn as basal fertilizer. Application of NPK in spring gave never better results than base fertilizing in autumn, moreover, in some cases it caused significant yield depressions. On the average of the results, neither the placement of fertilizers in rows at sowing, nor top-dressing at a later date seemed more advantageous than basal fertilizing in autumn. From among 180 cases, it occurred only on two of the experimental fields and in four instances each that split application of fertilizers was more effective than base fertilizing in a single operation in autumn.

TABLE 14 — *Effect of the methods and time of fertilizer application on the grain yield of maize.*

Treatment	Meadow soil	Chernozem	Sandy brown forest soil	Brown forest soil
		Grain yield q/ha		
1. N_{120} in autumn	31,1	36,3	38,4	37,8
2. N_{120} in spring	31,1	35,2	40,0	38,9
3. $N_{120}P_{60}K_{90}$ in autumn	34,7	43,0	42,3	42,9
	Yield increase compared with treatment 3			
4. $N_{120}P_{60}K_{90}$ in spring	−2,3	−3,7	−4,8	−3,3
5. $P_{60}K_{90}$ in autumn N_{120} in spring	−2,6	−1,2	1,2	−1,4
6. $N_{60}P_{40}K_{60}$ in autumn $N_{60}P_{20}K_{30}$ in spring	−1,0	−2,8	3,2	−1,6
7. $N_{60}P_{40}K_{60}$ in autumn $N_{60}P_{20}K_{30}$ in rows	−0,9	−0,6	−0,9	−2,2
8. $N_{40}P_{40}K_{60}$ in autumn $N_{40}P_{20}K_{30}$ in rows Topdressing with N_{40}	−3,5	−1,1	2,1	−2,3
$LSD_{5\%}$	1,6	1,5	3,7	1,5

4. *Efficiency of concentrated and compound fertilizers.*

Due to recent progress in the production and consumption of concentrated single and compound fertilizers, changes have occurred in the assortment of mineral fertilizers in Hungary, too. In 1970, 21 percent of the N fertilizers was produced in the form of urea, and this ratio will even increase in the forthcoming years. Consequently, the necessity has arisen to gain experiences as to the efficiency of urea in the conditions of this country, as well.

For several years we have carried on experiments on different soil types, in order to compare on four levels the efficiency of urea and calcium ammonium nitrate (Pét salt) given to wheat and maize. The aggregated data are presented in Table 15. Though there were some deviations in the yields and mean N-effects on the different experimental fields, the application of both fertilizer forms resulted in significant yield increases. When raising the N rates, urea gave better results on the average of eight experiments, than calcium ammonium nitrate did. The trends in crude protein and grain yields are similar though the differences in the responses to these two fertilizer forms are small. Urea can properly be used for both basal fertilization and top-dressing and in most cases it assures an equivalent effect to that of calcium ammonium nitrate widely used in Hungary (Table 16). From the Table it becomes evident that no differences were found in the grain and crude protein yield when applying these two fertilizer forms at rates of 70 and 140 kg N, resp.

The results of our 4-year grassland experiments carried out on salt-effected soils also show that urea containing 150 kg/ha N has nearly the same effect as the other kinds of N fertilizers applied and it can be used with success for the fertilization of pastures and meadows.

We have not sufficient data available to be able to draw definite conclusions as to the efficiency of the different compound and mixed fertilizers. The results received hitherto seem

TABLE 15 — *Effect of urea and calcium ammonium nitrate.*

Treatment	A Urea	B Calcium ammonium nitrate	A-B	LSD₅ %	Effect of urea (calcium ammonium nitrate = 100)
	Grain yield q/ha				
$P_{60}K_{60}$	21,4				
» + N_{35}	26,7	26,7	0		100
» + N_{70}	30,6	30,5	0,1	1,7	100
» + N_{105}	33,8	31,5	2,3		107
» + N_{140}	34,4	33,3	1,1		103
Ø (untreated)	20,6				
LSD_5 %	2,7	2,7	2,8		
Average of the N-doses	31,4	30,5	0,9		103
	Crude protein yield q/ha				
$P_{60}K_{60}$	2,21				
» + N_{35}	2,53	2,62	−0,09		97
» + N_{70}	3,14	3,16	−0,02		99
» + N_{105}	3,75	3,41	0,34		110
» + N_{140}	4,00	3,90	0,10		103
Ø (untreated)	1,62				
Average of the N-doses	3,36	3,27	0,09		103

to indicate, however, that in case of both wheat and maize, N was primarily effective from among the components of compound fertilizers, and that the average responses of these crops to compound and mixed fertilizers were practically the same as those to single fertilizers added in different combinations.

During the past ten years we have carried out several experiments some of which I have dealt with here. On the basis of our data we could examine with considerable success the efficiency of the different fertilization systems, the interactions between the rates and ratios used, the methods and time of application, irrigation and soil reclamation, as well

TABLE 16 — *Effect of placement method and time of urea and calcium ammonium nitrate.*

Treatment			A Urea	B Calcium ammonium nitrate	A-B	Effect of urea (calcium ammonium nitrate = 100)
			Grain yield q/ha			
$P_{60}K_{60}$			27,8			
»	$+N_{70}$	before ploughing	33,8	33,9	−0,1	100
»	$+N_{70}$	before sowing	33,3	34,3	−1,0	97
»	$+N_{70}$	early spring	34,6	33,9	−0,7	98
»	$+N_{70}$	late spring	34,6	34,9	−0,3	99
»	$+N_{140}$	before ploughing	36,3	36,7	−0,4	99
»	$+N_{140}$	before sowing	35,4	36,2	−0,8	98
»	$+N_{70+70}$	before ploughing + early spring	38,1	37,0	1,1	103
Ø (untreated)			26,7			
Average of the N-doses			35,2	35,3	−0,1	100
			Crude protein yield q/ha			
$P_{60}K_{60}$			2,99			
»	$+N_{70}$	before ploughing	3,63	3,62	0,01	100
»	$+N_{70}$	before sowing	3,73	3,78	−0,05	99
»	$+N_{70}$	early spring	3,86	3,73	0,13	103
»	$+N_{70}$	late spring	4,12	4,22	−0,10	98
»	$+N_{140}$	before ploughing	4,30	4,31	0,01	100
»	$+N_{140}$	before sowing	4,04	4,17	−0,13	97
»	$+N_{70+70}$	before ploughing + early spring	4,65	4,44	0,21	105
Ø (untreated)			2,75			
Average of the N-doses			4,05	4,04	0,01	100

as of the responses of crops to the new forms of mineral fertilizers.

Though the application of higher fertilizer rates, i.e. the more intensive fertilization resulted in yield increases of our cultivated crops, at the same time a lot of problems presented themselves which require different new measures and modifications that could promote the economic utilization of these greater amounts of fertilizers.

The rising costs of intensive fertilization will be returned if we change over to the production of crops with higher economic value, in case of which intensive fertilization is profitable and if we make further progresses in the development of crop production technology.

Certainly, the favourable effects of intensive fertilization manifest themselves not only in crop yields but in their quality, too, exerting hereby manifold influences on agricultural production.

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DISCUSSION

Chairman: Y. Araten

Araten

Dr. Latkovics, I would like to ask you two questions which may add to the picture of your presentation. In your report you mentioned the use, as you said, of ten kilos of fertilizers per hectare in 1950, going up to 135 in 1969 and you also mentioned that the yield which rose for wheat from 15 quintals to 27, for maize from 20 to 40 and for sugar beet from 200 to 350, but for potatoes there was no increase in yield. Can you explain why potatoes did not show any increase, despite the large amount of fertilizers? The second question: you mentioned the amount of fertilizers per hectare and yield per hectare, but can you give us the total amount of yields for Hungary in those products; wheat, maize, sugar-beet in 1950 and in 1969?

Latkovics

First question: the yield of potato did not increase because we have other problems too, for example we did not have high quality seeds, they did not resist disease.

Second question: the grain production for 1969 was the following: winter wheat about 4 million metric tons, corn about 4.8 million metric tons and potatoes about 1.6 million metric tons. For 1950 I do not have the figures.

HERNANDO

The first question I have in relation to your paper is something similar to that which Prof. ARATEN asked you: how do you not get increase in yield when you apply high amounts of fertilizers on potatoes? I ask you this in relation to the last four years of experiments we are doing in the south of Spain, in the Granada area, where we have a very intensive application of fertilizers, because they get normally three crops every year. It is very surprising to find that we get there a better yield without applying fertilizer, only with nitrogen we increase the yield a little and also in areas where the soil is very low in phosphate and potash. The only explanation we have found for the moment is that maybe it is better not to apply the fertilizer, as the farmers do, deep in the furrow and it will be better because potatoes have their main uptaking roots very near the surface and for that reason, in the method we are using this year, we put the fertilizers 3 or 4 cms down from the surface. We do not know the answer yet, but it is the question I want to put to you and I shall be interested in knowing pour opinion.

LATKOVICS

Potatoes in our country are planted in sandy soils. These soils are poor in nutrients, but we give the potatoes about 80 to 100, kgs of nitrogen and about 50-70 kgs of phosphate and we give from 100 to 120 kgs of potassium. This fertilizer is ploughed in rather deep, 25-30 cms.

HERNANDO

I have another question. You said in page N. 10 of your paper that the application of fertilizers for sugar-beet in Spain is below 100 kgs per hectare and that you think the low yield is related to that. I cannot say that it is not true, but the real reason for the low average yield, which is about 300 quintals/ha is that we have a problem with nematodes because we do not use the correct rotation. In some areas farmers grow sugar-beet nearly every year, and the problem after twenty years is terrible with nematodes. That is one problem more important than the fertilizer use. But I think we have another reason for this low level of yield. I say low level because we have been able to make trials close to Madrid in Alcala de Henares where the conditions are not the best for sugar-beet and therefore, amongst other reasons, farmers do not grow sugar-beet so frequently there. We can get there, I say, 700 quintals per hectare with a normal application plus boron, because many of our areas growing sugar-beet are high in calcium carbonate and we have a boron deficiency. It is possible to see the roots with the deficiency. This is important in the total weight but also in the sugar content. The last one is lower than normal with the same type of variety. For many years the industries in Spain paid the farmers according to the weight of the roots of sugar-beet, but now they found that it is no good, alltough they give the farmers the variety to grow, and the reason is just a problem of fertilization. Therefore, now they pay for sugar contents as in other countries. It is a good improvement for industry, but we are interested in the farmer's use of boron, in order to reduce the deficiency.

LATKOVICS

I have used the official FAO figures which give averages.

PRIMAVESI

I think you said « agricultural production of the different countries is characterised by extremely varying natural and economical conditions and technical supply » is very important not only for our meeting here, but for all studies and improvement programmes. This is true because transference of results from an experience in one country to another country with very much different conditions and production factors, frequently is not applicable.

You have given a very good survey about the effects of NPK fertilization in Hungary. Have you also experiences with the other macronutrients and with micro-nutrients, their effects on yields (quantitatively, qualitatively)? It is true you have in Hungary, very rich and fertile soils and so, it is possible, that you do not yet have problems with the other macro and micro-nutrients, at least urgently In this case, do you have also other data about the mentioned nutrients? With which macro- and with which micro-nutrients do you have problems in Hungary?

LATKOVICS

In our country the most important nurtients are nitrogen, phosphates and potash. Now sandy soil also needs magnesium. Magnesium results are positive, principally with potatoes. Our industry produced ammonium-nitrate containing about 2-3% magnesium. Today in my country micronutrients are not critical except on organic soils.

WALSH

I wish to raise the problem about the method of application of nitrogen. Dr. LATKOVICS has given results about split dressings of the nutrient. This, of course, raises a very major problem, the whole problem of method of fertilizer application. For instance, you said you did not get any effect with spring top dressing. Was it the effect on quantity or quality you were looking for? Was there a differential effect on different kinds of soil? On what kind of soil did you get best response, or did you try it under a number of soil conditions? Have you had any experience in your country on the placement of fertilizers? You indicated a low response for your potato crop. Was this due to method of application? What is your approach to the placement of fertilizers? Also I think you had experience with different forms of nitrogen. You mentioned urea. Have you used anhydrous ammonia? We should like to hear of some of your experiences in these matters.

LATKOVICS

The effect of the divided N and NPK fertilization was not better than that of NPK in basic fertilizers ploughed down in autumn. At the same time the data show that side and top dressing of maize are not advisable because, as compared with the effect of the autumn basic fertilization or with the divided autumn and spring fertilization on certain soil types, the yield is not increased in the majority of cases. The results of chemical studies on grain show that the percentual raw protein content significantly increases due to the effect of N fertilization, and accordingly in the examined cases the quantity of raw protein increased 170%-260% per hectare. For several years we have carried on experiments on different soil types in order to compare on four levels of fertilizer application the efficiency of urea and calcium ammonium nitrate given to wheat and maize. The data presented show that raising the N rates, urea gave better results on the average than calcium ammonium nitrate. The trends in crude protein and grain yields are similar though the differences in the responses to these two fertilizer forms are small. The results of our grassland experiments carried out on salt-affected soils show that urea and calcium nitrate have nearly the same effect as the ammonium nitrate.

WALSH

Regarding your chernozem soils: there has been a lot of talk here about organic matter in soils. Might I ask how much nitrogen would normally become available in a year from a chernozem soil subject to an ordinary biological cycle. Have you made any measurements?

LATKOVICS

Our chernozems are very rich in nutrient containing about 4% humus and about 0.2% nitrogen. On the chernozem soil we apply lower amounts of nitrogen than on sandy and brown forest soil. I did not bring the data on minerals.

WELTE

You said the nitrogen release from sandy soil is higher than from chernozem — this is very surprising. Coming back to the point Dr. WALSH mentioned, chernozem has a high content of humus of high quality (normally 10:12:1 C/N ratio). The amount of humus may lie in your case between 5 and 7%. The mineralisation rate varies strongly according to the season. Due to the macro-climatic conditions in Hungary summer is the dry season. Only in spring and autumn there is enough water in the soil and the microbiological activity is of high intensity. Thus, at the beginning of the growing period, a high amount of mineralized nitrogen is at the disposal of the plant. The question, how large this amount of N could be, we have tried to answer from many data we got from long-term field experiments in Europe. One of the results was that the annual mineralisation rate varies between 1 and 5%. Let us concern a rate of about 2% per year and a content of 7% organic matter in your case. In combination with the C/N ratio, the amount of mineralised N can be calculated approximately from these figures. As a result the total amount of humus nitrogen will be about 10-12,000 kgs in the soil. At a rate of 2% then 200-240 kgs N per year will be available from humus. The figure may be more or less high or low with respect to the local field conditions you mentioned. But if you have exact figures from that area you may estimate the amount of deliberated N on more than hundred kilogrammes. Of course only a part can be utilised by sugar beet; but the figure you mentioned seems to be very small.

LATKOVICS

I would like to make clear that no more N is released, but that this is more effective in sandy soils. We have many experiments where we use not only 100 kgs, but 150, 200 depending on the site and the plant. The average we give on chermozem is about 100 kgs of nitrogen of course with P and K.

JOINT DISCUSSION ON POINT IV

Chairman: Y. ARATEN

WALSH

I am rising again Mr. CHAIRMAN on a point relevant to this. I think that Dr. FRIED mentioned at a very early stage in this meeting something about nitrogen. He wanted to question how and in what quantity nitrogen became available. With us soil nitrogen is a main source of nutrition for pastures. Consequently the nitrogen cycle and the biological transformation process is of special interest. At this meeting here we have heard much about tests for phosphorus, potassium, and trace elements. We have not, however, advanced so well in the field of nitrogen determination. It would obviously be advantageous to have a good diagnostic method for soil nitrogen status, in order to rationalise nitrogen application. We fully appreciate the climatic factors involved. Indeed in my paper I have pointed out how, in making recommendations for nitrogen application, we take summer rainfall into account. Perhaps a better approach has been developed in some countries. If so I would like to hear about it, because I think this is a rather important point for this meeting to consider. I expect we do not want to continue regarding nitrogen as something about which we can do nothing more specific. Perhaps some discussion as to how the position could be rationalized and improved might be rewarding.

FITTS

I should like to comment on the question which Prof. WALSH has raised. In our project we are very much interested in the question of nitrogen because of the wide deficiency we run into in countries all around the world. Dr. W. V. BARTHOLOMEW of our staff, I think many of you have heard of him as the soil micro-biologist, (he was the editor of the book put out by the American Society of Agronomy, entitled « Nitrogen »). For the last couple of years he had been studying data on this question from various sources around the world and he will be publishing fairly soon a rather detailed bulletin from our programme which discusses the nitrogen availability, which includes factors influencing the availability and puts some rationals into it. I thought you might be interested in this and, if anybody is interested, when it is published I shall be glad to send copies to you, but I think he is doing a very good job of bringing this information together; what are the sources of nitrogen, what are the factors influenced in it and what is probably the best method to evaluate the need for it.

PESEK

I would like to comment further on this nitrogen test. I expected Prof. FITTS to respond to this because he was the one who helped to develop the aerobic nitrification test, when he was at Iowa State University during the time I was on the staff there. This test was used for a number of years for assaying the nitrogen availability in soils as the base from which to make recommendations for nitrogen-fertilization. This nitrogen test required two weeks of incubation under aerobic conditions at approximately 95 degrees Fahrenheit, and we found that it was rather slow as a test to use in a service laboratory for making recommendations to farmers. (Farmers always seem to want the test the day before they take the sample. This is what drives them to finally take a sample). From this test we moved on to some work by J. M. BREMNER, to an anaerobic ammonification test, this was a test which required only seven days and calibrated somewhat better with the results from glasshouse cultures and from field experiments. While our agriculture was grounded fairly soundly in a rotation system involving leguminous crops from time to time, the nitrogen supply among soils of the same soil type varied and these tests identified this variation. Since the production of maize in our State has gone more to monoculture of the crop the soils have tended to become rather uniform in their supplying power for nitrogen during any one year, and we have abandoned the use of the nitrogen tests for that purpose because it simply tells us the soils are all alike. So we have returned to making recommendations for nitrogen use according to the cropping system or the previous crop. Other nitrogen tests have been worked on; an alkaline permanganate distillation of ammonia was used in Wisconsin and there have been others which have been published which are effective if there are differences in the soil nitrogen supplying power. I think I will stop at this point though and let any others comment because this is not a new test.

FITTS

I will just comment a little more on this, I have worked on the nitrate production test which has been used in many areas. The procedure gives a guide to the amount of nitrogen you can get from the soil, and I think that as long as you are on a traditional yield level or low yield levels that it has a lot of merit. Once you get above the relatively low yield level and the goal is high yields, and the organic matter level in the soil is in a state of equilibrium, then the amount of nitrogen needed is likely to be 4-5 times that obtained from the soil. The amount of information you get from the incubation test may separate soils from one another say from 10 to 50 ppm but it really is a small percentage of what you're going to end up using anyway and our philosophy is that soil analysis tells us pretty much whether we need it or not. If you know much about the cropping system that is being followed, you'll know the yields that are being obtained and if the yields are low, you will suspect that the amount of nitrogen available is not large. Then if you have experience with the crops they are growing, the management practices they are using and if they are trying for 5,000 to 8,000 or more kilos per hectare of yield, you are almost certainly going to have to have additional nitrogen on almost all soils. We do not think that soil analysis will give you rate of nitrogen or any other element to add; it simply tells us whether we needed it or not, and for the majority of our soils, as far as nitrogen is concerned we will say yes we need it. Then it boils down to how much are you going to set for the standard yield, what is the nutrient requirements, how much is it going to take to obtain it, what are your losses, and I think you can work out a pretty good balance sheet to come up with an estimate on nitrogen which will be closer than any tests that we have been able to develop so far.

RUSSELL

I refer to the use of soil tests for available nitrogen in Great Britain. In general more attention is often paid to the past cropping of the field than to the soil test as an estimate of the nitrogen status of the soil. But the crop response to nitrogen also depends on the climate, and in particular the rainfall, both before the fertilizer has been applied and also after it has been applied. So the optimum dressing of nitrogen cannot be known early on in the growing season. The advantage of splitting the nitrogen fertilizer dressing is that the amount of nitrogen applied at the later date can be adjusted to the amount of rain that has fallen between the two times of application.

FITTS

If I may comment on this Dr. RUSSELL, this is pretty much what we do on tobacco production in our State. We know if the farming is striving for 3,000 or more kilos per hectare of a yield, and we know almost how much total nitrogen it is going to take to produce it. We know we are producing it on a certain soil type, we know the water holding capacity and so they start of plotting this against their rainfall that they are receiving and if they get heavy rains at a certain stage of growth they simply subtract nitrogen utilized at whatever stage of growth the crop is in and then add additional nitrate nitrogen to replenish the loss. I think this comes a lot closer to telling us where we are than trying to make a nitrification study ahead of time, or ammonia analysis some other time.

FRIED

I am glad to hear this discussion because I think this is one of the crucial points. We talked about soil testing. If there is no suitable soil tests for nitrogen should we be looking for one? The latter speakers have suggested almost that we should not be looking for one, and it is certainly true that the nitrogen system is quite a different system than the phosphorus or potassium system. I would like to see the group come up with a recommendation in relation to nitrogen. There are a lot of people still working on trying to find some convenient test, maybe that is the answer the group wants to come to; but perhaps the group does not think this is necessary. I think they should come up with some recommendation in relation to this.

PESEK

One further comment on nitrogen tests in the northern great plains of the United States and the Canadian Wheat area. There is a service of testing soils for nitrate content of the rooting profile in which not only the nitrate content is determined but also the moisture content and recommendations based on both the nitrate present and the moisture present. There also has been a nitrate electrode developed and which has been tried for direct determination of the nitrate present in the soil, and there is an ammonium electrode being tested currently which may be used to determine the nitrate in solution after Nesslerization, I think, and followed by a simple test for the ammonium ions present.

Primavesi

Your paper is very interesting, specially what you said about the micronutrients; we have also studied them during the last twenty-five years.

Now, I have a question. We know that top dressing of nitrogen improves grain quality, but we can use only a fraction of the nitrogen fertilizer you apply in temperate climates. Fungus destroy heavy N-dressed crops, or a least makes them lay down. Have you any experiences about this in tropical soils?

Coïc

Non, je n'ai pas l'expérience de sols tropicaux. Lorsque j'étais en Bretagne le rendement du blé était environ de 30 quintaux/hectare et je désirais obtenir le rendement obtenu dans les régions du Nord de la France qui, à cette époque (1945), était environ de 50 quintaux. J'ai donc essayé de connaître les besoins en azote du blé au cours de sa végétation, puis les moyens de les satisfaire. Quelques années après nous avons pu porter le rendement en Bretagne et dans bien d'autres régions à des valeurs comprises entre 55 et 70 quintaux. Je fais remarquer que, lorsque les conditions climatiques son favorables, il est plus facile d'obtenir un rendement très élevé (70 quintaux par exemple) lorsque le sol fournit seulement une quantité modérée d'azote que lorsqu'il fournit beaucoup d'azote, car il est difficile de contrôler la chronologie de la fourniture de cet azote du sol: par exemple s'il est libéré trop tôt il provoque la « verse » (lodging) du blé.

Il est très difficile de trouver un test indiquant la quantité d'azote que fournira le sol à la culture, dans les conditions de la culture. Dans beaucoup de tests de minéralisation utilisés, les conditions de minéralisation sont très différentes de celles se présentant naturellement, ce qui explique qu'il soit très difficile de passer des résultats de tests à la réalité pratique.

No, I have no experience with tropical soils. When I was in Brittany the wheat yield was about 30 hundredweigths/hectare and I wanted to obtain the yield in regions of North France which, at that time (1945) was about 50 hundredweights. Therefore, I tried to know the nitrogen needs of the wheat in the course of its vegetation, then the means to satisfy them. Some years later we could bring the yield in Brittany and in other regions to values between 55 and 70 hundredweights. I may stress that when the climatic conditions are favourable, it is easier to obtain very high yields (70 hundredweights for instance), when the soil furnishes only a moderate quantity of nitrogen than when it furnishes much nitrogen, because it is difficult to control the chronology of the supply of this nitrogen of the soil: For example if it is too early liberated it provokes the lodging of the wheat.

It is very difficult to find a test indicating the quantity of nitrogen that the soil furnishes to the plant in conditions of culturing. In many mineralization tests used, the mineralization conditions are very different from those presenting themselves naturally; this explains that it is very difficult to pass the results of tests on to practical reality.

HERNANDO

We are at the end of this discussion, and we may now put some questions on the morning session. But before I would like to return to the previous discussion on nitrogen, that is to the point suggested by Prof. PESEK.

Last year we made a study in Spain in a zone of homogeneous micro-climatic conditions. After several years we tried to find there — because the weather is rather changing — the amount of nitrogen that the crop receives from the soil. Nitrogen was not used at all but only potash and phosphate. We found a representative response for this type of soil under these climatic conditions for a special crop. This, however, means very hard work, because it must be performed for five years in every soil type with the same crop, and especially with the same seeds since we found out that there are clear differences between the varieties in the production of wheat. The work, of course is rather complicated, but I daresay that within the next ten years it will be possible. In several countries many people have the same problem, on the same line of work, in the same type of soil. I think that the use of the computer will be very helpful in the future. I am thinking of the paper Dr. PESEK will present tomorrow. Ten years ago it was impossible to consider the possibilities of such a complicated version. Now we all have a method to interpret these variabilities, because the computer enables us to do it. Well, that is one point. The other point is concerned with the paper of Dr. Coïc. I would like to ask two questions, but I shall limit myself to one only as I think that also other gentlemen would like to ask questions.

In your paper you indicate data on ammonia and nitrate fertilization, and in the leaf analysis of maize and tomatoes you find different amounts of organic acids. I believe that there are two different meanings. It is possible to apply nitrogen as ammonia which enters as ammonia in the plant without changing there and without requiring more organic acids. This means that there is no increase in the competition with potassium and other cations.

With nitrates there is an increase in organic acids because of the higher amounts of potassium, the competition with ammonia and other cations not being possible in this case. Now this means that the uptake is produced inside the plant as ammonia though it is not possible to explain its relations with nitrate. Did you not find, especially at the beginning with maize, that there are some deficiency problems, with ammonia fertilizer, especially at the beginning of the growing season? That is my question.

Coïc

La quantité d'acides organiques dans la feuille est en relation étroite avec la quantité de nitrates qui y est métabolisée. Les nitrates arrivent dans la feuille en équilibre électrostatique avec les cations minéraux (K, Ca, Mg). Lorsque les nitrates sont métabolisées et perdent leur qualité d'anions, ils sont remplacés pour le maintien de l'équilibre électrostatique par une quantité équivalente d'anions d'acides organiques.

Pour la question de la toxicité ammoniacale, son déterminisme n'est pas complètement connu: l'acidification physiologique du milieu alimentaire est excessive et cause certainement une toxicité. Nous avons aussi constaté une difficulté dans l'alimentation en eau. Les problèmes de détoxication ammoniacale ne sont pas complètement connus et peuvent être différents suivant les genres de plantes.

The quantity of organic acids in the leaf is in close relation with the quantity of nitrates which is metabolized. The nitrates arrive in the leaf in electrostatic equilibration with mineral cations (K, Ca, Mg). When the nitrates are metabolized and lose their quality of anions, they are replaced by an equivalent quantity of organic acids, in order to maintain the electrostatic equilibrium. As to the question of ammoniacal toxicity, its determinism is not quite known: the physiological acidification of the nutritional milieu is eccessive and certainly causes a toxicity. We have also stated a difficulty in the alimentation with water. The problems of ammoniacal detoxication are not quite known and may be different according to the plant species.

HERNANDO

With sap analysis we found in maize that the application of a high ammonium level caused toxicity in the plants; we noticed this at the beginning of the growth season in the experiment (I do not know if you remember one of my slides). For this reason I put the question of acidity I mentioned.

Now I have another question in relation to Dr. SAALBACH's paper.

CAPÓ

I would like to make some comments about the determination of available nitrogen in the soil. As you may remember, in the first part of my paper, I discussed the utilization of the Mitscherlich equation to relate the content of available nutrients in the soil and the content of the same element in the leaf, and that applies to nitrogen, phosphorus, potassium, calcium and magnesium. This type of equation fits the data very well with acceptable coefficients of correlation, going up to .98 sometimes. I believe that this equation would be very useful in calculating the available nutrient content of the soil, and that includes nitrogen, it is not only potassium or phosphorus. I have here the reprint of the article in which that information was presented, and I have more copies in my room in case someone is interested in going over it.

HERNANDO

This question concerns Dr. SAALBACH's paper. We believe that the moment has arrived to develop large glasshouse experiments with fully controlled climatic conditions so as to be able to check the soil test methods. Many of our trials like those we were doing before, were mainly connected with field trials. Now the fields are certainly most important for farmers, but we must bear in mind that the field involves quite a lot of other problems owing to the very changeable conditions, especially climate and rainfall. What we ought to know is to what extent a soil is capable of liberating phosphate and potash to the plant. Therefore it is better to do this under glasshouse conditions with climate control. In this way any climatic problems will be eliminated and also pest control can be very easily handled. There may still be a long way before to find the best method; it may be that several methods will correlate with the yields under such conditions — to be used later on — for our fields trials.

WELTE

I want to refer to quality because it seems to me that this was the real subject under Item IV. Coming back to the remark of Dr. COLWELL I would like to say: I agree and I disagree. That depends on the definition of quality. The word yield is well defined, but what does qnality mean? Quality always has to be put into relation to whom, who wants quality and who says what he wants. Therefore the subject is very complicated. Quality besides quantity is of tremendous importance in the developing countries. The reason is that in these countries many consumers live on the farm and get their food from their own agricultural produce — maiuly plant products in countries with high population density. Under those conditions the nutrient status of a soil will be reflected in the health of human beings living on it. It is a closed system, and deficiencies or excesses of nutrients in the soil will appear to a certain extent also in the human beings. Therefore, quality of plant products in those areas plays a very important role. But if you ask me what is the influence of fertilizer use on human health in highly developed countries based on nutrition, then I would like to say it is very small. The reason is, first, the consumer will mostly buy his products on the market. These products may be delivered from Holland, France, Italy or other countries or farms. The other point is that many products will be changed during processing — and processing plays a very important role in our modern food industry. Processing is often followed by a devaluation of the quality. Preparing and cooking in the kitchen is another factor which should be considered. And last but not least, one plant product doesn't mean the whole diet. There comes first the meal. It consist of various products, and is also a question of quantity, what I am willing to consume during breakfast lunch or dinner. The next point is, how many meals a day. Then we have to concern the change in the diet during the week, during the month, throughout the year. In general, if we consider the food chain system in a highly industrialized country, we have a lot of variations in it. I would like to say a modern tourist will get a balanced diet because he may today be in Rome, tomorrow in Paris etc. There is a certain mixing effect by the market we have always to keep in mind. But nevertheless, we should not neglect quality despite this situation, and do our best. What Dr. WALSH has mentioned about animal nutrition, and I believe he was quite right, is not controversial to this. In the highly developed countries, animals, mainly ruminants, are in the same position as the human beings in the developing countries. On grassland the ruminants are in direct contact to the food coming from the soil. Therefore, the quality of grass and fodder crops, is very essential. Quality is also important with respect to cereals, and I am in full agreement with that what Dr. Coïc has said about the necessity of late N dressings on wheat. With this method of N application, we get in our temperate climate a distinct better quality of wheat, which is paid by the millers and bakers. So far there are many quality problems also with other plants in the developed countries, but from the point of the farmer, quality must be paid.

COLWELL

I also agree and disagree on this matter. I think undoubtedly in developing countries where people are, as you put it, living directly on the soil, quality becomes much more important; but given these difficult conditions, is it easier to overcome say a protein deficiency by getting people to put nitrogen onto maize, or sorghum or whatever they are growing, even though they will not get an increase in yield to increase their protein intake or is it easier to educate them to use some other food which contains the needed proteins?

BUSSLER

I would like to refer to the remarks just given to all the papers given today I hope. The question is about increasing yields and quality, and the first thing I heard when I came to Rome was a remark from Mme HOMÈS. Mme HOMÈS talked to my wife that we have changed our mind, it is not only that, la « dose totale » but also the *ratio* is important, and I found that the ratio was a very important factor in all the papers we had. Now the ratio in the fertilizer is influencing the ratio inside the plant and it is now a question of quality. When we want to have high yields we must give large dressings of fertilizer. If we give high dressings of fertilizer to the plants, the plants cannot resist, they must take up higher amounts of the fertilizer given in higher amount, and now our meanings about quality are I think different. I think it is influencing the quality when I have a large ratio of K : Ca in the plants than when I have a small ratio. What I don't know is what ratio is the better one, and so I would think it is most important to examine what follows a very wide ratio and a very narrow ratio in the consumer. I would not agree with Professor WELTE, I think the meal that I get in Paris would be in the manner of composition nearly the same as that which I get in Rome or in another place, because there is always the same practice of fertilizing and that is the fertilizing with N and P and K, and the way off from this three element fertilizing is, I think, the only way of the method of HOMÈS systematic variations, and I think all who have tried this method will agree that it brings the best results.

CAPÓ

I want to point out that it should be kept in mind that the influence of the total quantity of the nutrient in the soil on the crop is different from the influence of the fertilizer on the yield or quality. The influence of fertilizer may be known only if you already know how much of the nutrient is available in the soil.

ARATEN

Coming from a country rich in potash and phosphates and very poor in raw material, for nitrogen production, I am not an expert in nitrogen products, and I would like to ask Prof. FITTS if he would be kind enough to summarize, the various opinions we heard regarding the nitrogen problems in order to facilitate the work of the committee which will have to draft the conclusions. We have had discussions where most of the pertinent people took part and I believe that if you agree, that would be very helpful.

FITTS

I shall be happy to do so, but time doesn't permit it.

V

NOUVEAUX FERTILISANTS ET ASPECTS SPECIAUX ET FUTURS DANS LEUR EMPLOI