Chemical Events in the Atmosphere and their Impact on Environment
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EFFECTS OF CHEMICAL EVENTS ON ENVIRONMENT IN AFRICA

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1. Ecological Changes

Africa with less than 6% of its area covered by tropical forest is one of the least forested areas in the tropical region [1]. At the same time Africa has one of the fastest growing populations [1]. There are at present over 146.1 million heads of cattle with an annual growth of 1.7 percent. At the same time the number of sheep and goats in Africa have been estimated to be 250.6 million heads with annual growth rate of 2.1 percent [1]. By the year 2000 there will be 169.8 million heads of cattle, 292.8 million heads of sheep and goats [1]. Increased livestock population will accelerate rangeland deterioration, soil erosion and desertification. The amount of soil dust arising from areas with no vegetation cover may change the sun's albedo of the region.

It is not only the increase in livestock population which has deleterious effects on Africa's environment, but the human population will also result in high pressures exerted on the existing life-supporting resources. Africa's increasing population must be fed, they must be housed, they deserve decent jobs and standards of living as a right. In order to provide for the above the African peasants have to clear more land areas occupied by virgin forests for shifting to agriculture, livestock raising and settlement. According to the study group on "The Global 2000 [1], Report to the President of the U.S.", there will be 50-70 percent population increase in the areas practicing shifting agriculture, the area of land burned and cultivated each year hy shifting agriculture will also increase. The study estimates that 25 percent of the land surface primarily in the tropical region is occupied by 300 million people who practice shifting agriculture. Thus, shifting agriculture on lands that cannot sustain continued intensive agricultural use are beginning to damage permanently the productivity of the area and to reduce its carrying capacity, according to the report.

A second compounding factor is that to cook food energy must be used. The surest alternative energy source for the peasants is firewood. The rural people depend on firewood for cooking and lighting, the increasing urban population also depends to a large extent on firewood or charcoal. The burning of forests for shifting agriculture and the burning of wood for charcoal making increase the amount of carbon dioxide and particulates in the atmosphere.

Africa is rich with variation of traditional cultures which have existed for centuries in equilibrium with their environment. Today, population growth in Africa, changing technologies, and altered life-styles have made the balancing mechanisms ineffective. Social-ecological systems which took centuries to evolve are being broken down with disastrous results for both humans and their life-supporting environment.

There is a great need for land use planning and policy in order to achieve the objectives of the African governments and satisfy the needs of the people. However, one generality which is common in Africa is the fact that qualified staff to organize and man the projects are few, money may be limited and many land use problems are of great urgency. For many countries in Africa land use planning is as much a problem of the densely settled areas as it is of the sparsely peopled regions. These seemingly contradictory survival and development endeavours pitched against conservation and nature in Africa will continue. In the words of the International Union for the Conservation of Nature and Natural Resources [2], "the dependence of rural communities on living resources is direct and immediate . . . unhappily people on the margins of survival are compelled by their poverty — and their subsequent vulnerability to inflation — to destroy the few resources available to them".

The ecological changes taking place in Africa could affect the local climates in three ways.

1) The ratio of solar radiation reflected from and absorbed by the earth's surface could change;

2) the ratio of convection and evaporative heat released from the earth's surface could change; and

3) the hydrological cycle could be modified.

There is some evidence that these changes might be taking place already in Africa. Reference here is made to the very severe drought which occurred in the Sudano-Sahelian belt of Africa extending from the Sahara to the Equatorial forest between 1968 and 1974. In 1982/83 Eastern and Southern Africa is undergoing yet another severe drought affecting both nature, animals and human life. Although one cannot extrapolate the regional situation to translate into a global situation due to lack of scientific data, it cannot be ruled out completely that what we see in Africa will not affect other regions either directly or indirectly. The changed climatic pattern may be a result of chemical events which are taking place in Africa.

1.2 *Termites Shorten the Carbon Cycle*

One such event is the role played by termites in altering the ecological pattern of an area. Termites consume large quantities of wood — 90 to 98 percent of the consumed cellulose is respired as carbon dioxide [3]. Figure 1 is a diagrammatic model of the terrestrial carbon cycle. Given the present atmospheric carbon dioxide concentration of 330 ppmv, the atmosphere contains about 700 Gt (1 Gigaton = 10^9 metric tons) of this gas. Measurements of CO_2 made at Mt. Kenya [4] show that the concentration of CO_2 in Africa is not different from that measured elsewhere (328.5 ppmv *vs* 330 ppmv). Therefore, it can be assumed tbat despite the low number of industries and automobiles that emit CO_2 in the continent, the atmospheric CO_2 must have come either from the biota within Africa or drifted from other regions into the continent. Woodwell *et al.* [5] have estimated that in the 1950's the total amount of carbon held within the living biota was about 830 Gt. More than 90 percent was in the standing crop of plants in forests and woodlands. Of the total within forests and woodlands, 461 Gt or nearly 60 percent was in tropical forests. The carbon held within terrestrial humus has been estimated recently as 1000 to 3000 Gt, or one to four times the quantity in the living biota [6, 7]. The distribution of carbon in the biota is greatest in the tropical regions, while the humus is more abundant in the temperate and boreal zones where lower temperatures retard decay.

Previous estimates of biotic carbon pool losses have used forest harvesting as the measure. Bolin [8] using data from Food and Agriculture Organization (FAO) and otber sources calculated the net release of CO_2 from the harvest of forests globally as 1 Gt of carbon per year. The estimate is indeed on the low side. Figure 1 shows the total dead organic carbon

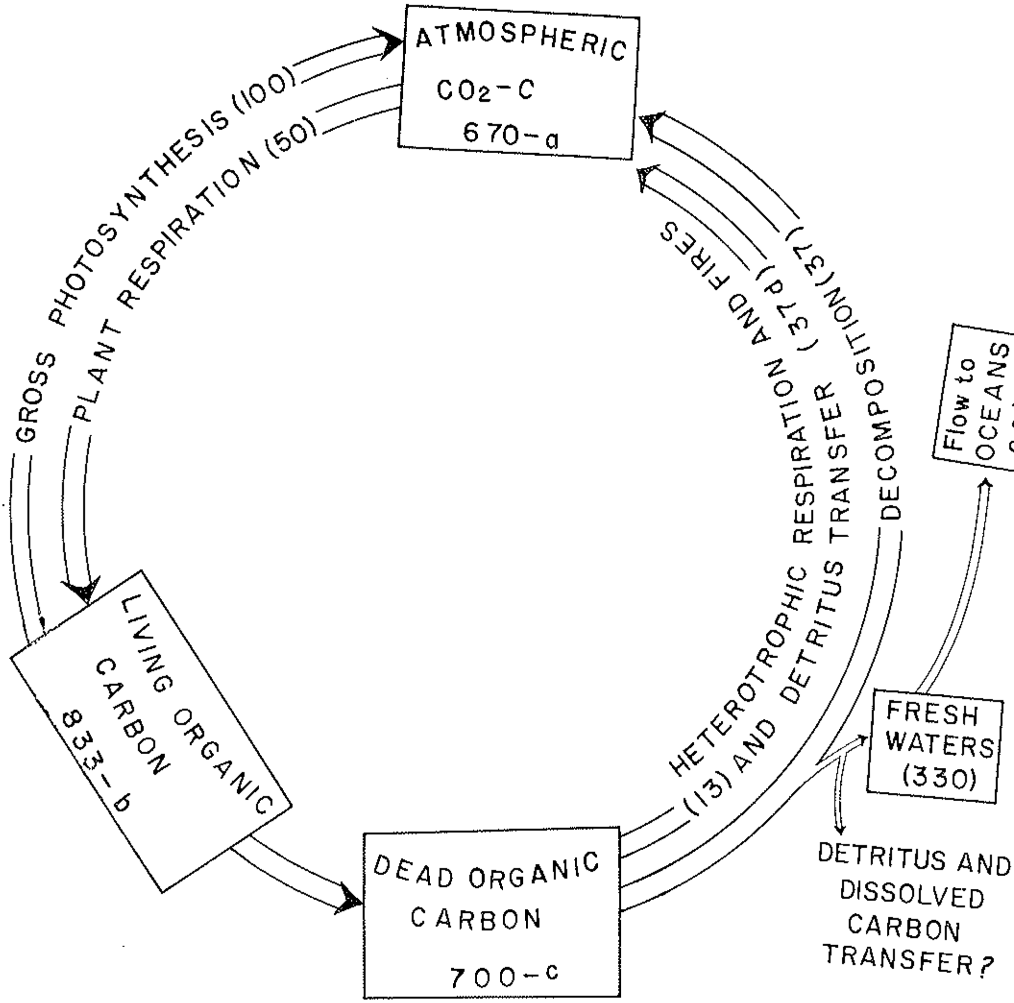

FIG. 1. Diagrammatic model of the terrestrial carbon cycle. Estimates are given in 10^9 tons. Question mark indicates that estimates are not available.

a) other estimates are 683 (SCEP, Ref. 1, page 161) and 700 Gt (Bolin).

b) Bolin estimates 450 Gt.

c) Bolin, based on Delviche's nitrogen estimates and a carbon/nitrogen ratio of 12, an alternative estimate is 9,000 Gt.

d) Bolin estimates 25 Gt.

as 700 Gt. Of the dead organic matter it is estimated that 76 percent is carbon with decay rate of $< 0.001\ yr^{-1}$ and 24 percent carbon with rapid turn-over rate of a few years. Therefore, given the global deforestation rate of about 1 to 1.5 percent per year one would conclude that since 1950 only 33 to 49.5 percent of living biota carbon has been released to the atmosphere. Furthermore, given the fact that of the released carbon dioxide about 50 percent is deposited in the oceans or used for photosynthesis, and given further that the amount of fossil fuels burned in Africa during the same period is possibly less than one percent of the total burned globally, the 328.5 ppmv CO_2 concentration found in Africa is too high for an isolated continent. Both the first and second alternative sources of CO_2 are important and we may assume that this level of CO_2 came from sources within the continent. The previous estimates of carbon release quoted above did not take into account the role played by other living organisms such as termites.

In our previous report [9] we showed that termites occupy 68 percent of the terrestrial land area where 77 percent of the terrestrial NPP is produced. We estimated the world's termite population to be 2.4×10^{17} and they consume materials equivalent to 28 percent of the earth's NPP and an average of 37 percent of the NPP in areas where they occur. These estimates are biased to the low side. We calculated that globally termites emit 13 Gt of CO_2 carbon per year. Our recent measurements of CO_2 emitted by higher termites (Cubitermes, Trinervitermes and Macrotermes species) show our previous estimates to be slightly high. Nevertheless, the role of termites is to shorten the carbon cycle which otherwise would have lasted a few decades to 100 decades. We have in Africa the high concentration of atmospheric carbon dioxide which has been released from the dead organic matter by termites.

A much more serious aspect of the carbon dioxide scenario is the fact that to an already high atmospheric CO_2 is being added an increasing amount of CO_2 released from fossil fuels burning. The number of cars with inefficient combustion engines is increasing in Africa. Similarly, the number of industries burning fossil fuels is also increasing. Given this trend, I can therefore foresee the carbon dioxide situation worsening in Africa unless corrective actions are taken.

1.3 *Termites Emit Methane*

Methane is an important atmospheric trace gas which affects the chemistry of the troposphere [10] and of the stratosphere [11]. It is also a "greenhouse gas" with the potential to affect the earth's radiation balance [12]. The major sources of methane emission into the atmosphere have been reported to be rice-paddy fields, natural wetlands, enteric fermentation processes in ruminants, biomass burning, and leakages from geological gas reservoirs [13]. The estimated tropospheric reservoir of methane [13] is 3.5×10^{14} g to 12.1×10^{14} g (0.35 – 1.21 Gt). Recently, it has been suggested by Rasmussen and Khalil [14] that the methane content of the atmosphere has been increasing by 2 percent annually.

Methane has been found in the guts of various xylophagus insects, including scrab beetles (*Oryctes*), wood-eating cockroaches (*Cryptocercus*), and various lower termites (*Reticulitermes, Cryptotermes, Coptotermes*) [15, 16]. Termites have the potential and do release large quantities of methane into the atmosphere. They are ubiquitous on the land surface; they process large quantities of biomass; their digestion is primarily dependent on anaerobic decomposition by symbiotic bacteria in the higher termites (family Termitidae) and by protozoans in the lower termites (all other families); and their digestion efficiency is high, usually greater than 60 percent [17]. In addition, human activities, including clearing of tropical forests and conversion of forests to grazing and agricultural land or road building, tend to initially decrease the number of termite species and increase the densities of one or two surviving species by about five fold [18]).

We have made both field and laboratory measurments of the emission of CH_4 and CO_2 from both higher and lower termite families (Macrotermes, mound building species, *Cubitermes*, soil feeders, *Trinervitermes*, *Reticulitermes*, lower termites, and *Gnathermitermes*). Similarly, we have made laboratory measurements of the emission of CH_4, CO_2, CO, H_2, C_2 to C_{10} hydrocarbons, and reduced sulphur species from *Reticulitermes* and *Gnathermitermes species.* In addition, emissions from arboreal nests of an unidentified species of Nasutitermitinae were sampled in the field in Guatemala and analyzed for CH_4 and C_2 to C_{10} hydrocarbons [9].

Table 1 shows the mean emission rates ($\bar{X}$) and standard errors ($s/\sqrt{n}$) for CH_4, CO_2, and CO from three *Reticulitermes* and two *Gnathermitermes* Colonies [19]; n is the number of days during which samples which were analyzed during the 55-day showed little variahility ($\pm 10\%$). The variability between days was sometimes much higher. These emission rates are about in the middle of methane production rates reported by

TABLE 1 - *Normalized emission rates per termite; R1, R2 and R3 represent three different colonies of* R. tibialis *Banks and G1 and G2 represent two different colonies of* G. perplexus *Banks.*

Colony	CH_4 (μg/day)			CO_2 (mg/day)			CO (μg/day)		
	X	$S/\sqrt{n}$	n	X	$S/\sqrt{n}$	n	X	$S/\sqrt{n}$	n
R1	0.447	0.023	21	0.091	0.005	10	0.006	0.003	11
R2	0.237	0.016	22	0.107	0.010	11	0.018	0.008	10
R3	0.592	0.031	22	0.137	0.010	11	0.060	0.014	10
G1	0.456	0.042	11	0.410	0.026	7	0.091	0.019	7
G2	0.338	0.034	11	0.210	0.023	7	0.053	0.017	7

Breznak [16]. This agreement is good considering the differences between the techniques used in the two investigations.

Similarly, Table 2 gives the same values for the higher termites representing the fungus combs feeders (*M. subhylanius* and *M. michaelsensi*), the soil feeders (*Cubitermes* sps.) and wood feeders (*Trinervitermes* sps) [20]. The *M. michaelsensi* nest was sampled by placing a teflon tube through a stainless steel pipe into the nest and sampling the gases coming out of the teflon tube.

We excavated the nest of a *Trinervitermes* species and *Cubitermes* species and took the nests to the laboratory for sampling using the teflon enclosure technique [19]. All the CO_2 measurements were done using the Matheson CO_2 detector tubes and Matheson pump. Table 3 gives the

TABLE 2 - *Methane and Carbon Dioxide content in the interior air samples from a* M. michaelsensi *nest in ppmv.*

Sample	$[CH_4]$	$[CO_2]$	$\frac{[CH_4]}{[CO_2]}$
Ambient	1.678	330	0.494
nest sample 1	14.59	26000	0.056
nest sample 2	16.41	26000	0.063

results of the CH_4 and CO_2 measured for the *Trinervitermes* species and *Cubitermes* species.

We also carried out measurements of gases emitted by termites when the *Trinervitermes* species nest and the *Cubitermes* species nest were broken down and the termites without the soil nest placed into a 1 litre Mason jar. The soils of the two species nests were also placed into another Mason jar and the air above each jar determined for CO_2 and CH_4. The number of *Cubitermes* termites placed into the Mason jar were as follows:

workers with dark, soil filled guts	2033
workers with pale bodies	160
larvae of all sizes	963
Soldiers	3
White soldiers	4
Last-instar nymph	37
next to last-instar nymph	16

The total number of *Trinervitermes* termites placed into the Mason jar were as follows:

major soldiers	343
minor soldiers	280
major worker soldiers	17
minor worker soldiers	60
major workers	1727
minor workers	1363
Larvae	290

The jars were sampled every five minutes for CH_4 and CO_2. Sampling was stopped after one hour. The amount of CH_4 concentration emitted by *Trinervitermes* termites rose from 1.793 ppmv, the ambient concentration, to 22.46 ppmv at the end of one hour. The *Ternervitermes* termites CO_2 concentration rose from 400 ppmv, the ambient concentration, to 2500 ppmv at the end of the hour. The air above the soil gave CH_4 and CO_2 concentrations that were not significantly different from the ambient air concentrations. The *Cubitermes* termites emitted CH_4 concentration which ranged from the ambient concentration of 1.749 ppmv to 27.26 ppmv at the end of the hour while the CO_2 concentration ranged from 400 ppmv in ambient sample to 2500 ppmv at the end of the experiment. The soil materials had identical result to that of the *Trinervitermes* soil.

TABLE 3 - *Measurements of CH_4 and CO_2 in a teflon bag enclosure air above a* Trinervitermes *species nest and a* Cubitermes *species nest in ppmv.*

SAMPLE	ELAPSED TIME (Hrs)	TRINERVITERMES				$\frac{[CH_4]}{[CO_2]}$ %	CUBITERMES				$\frac{[CH_4]}{[CO_2]}$ %
		$[CH_4]$		$[CO_2]$							
		X	σn	X	σn		X	σn	X	σn	
Ambient	0	1.724	0.033	400	—	0.431	1.724	0.033	400	—	0.431
Bag sample 1	1	5.999	0.096	1000	—	0.599	3.69	0.039	1000	—	0.369
Bag sample 2	2	10.65	0.181	1200	—	0.888	5.83	0.082	1100	—	0.530
Bag sample 3	17	59.19	1.258	6000	—	0.986	24.68	0.453	3600	—	0.686
Bag sample 4	18	53.41	0.370	6000	—	0.890	25.41	0.0	3000	—	0.847
Bag sample 5	19	53.9	2.610	5500	—	0.981	27.55	0.399	3500	—	0.787
Bag sample 6	20	54.71	0.619	6000	—	0.912	28.47	0.314	3700	—	0.769

In addition to *Macrotermes, michaelsensi* and *subhylinus Trinervitermes* and *Cubitermes* species we have also sampled gases emitted by *Odontotermes badius, Amitermes unidentatus,* and one *Syncanthotermes* species (grass feeding termites). All the termites sampled in the field and in the laboratory emitted large quantities of methane and carbon dioxide. The methane to carbon dioxide percent ratios were close to one for the *Trinervitermes* and *Cubitermes* species and slightly higher for *Amitermes unidentatus* and *M. Subhylinus* as shown in Table 4 for the *Amitermes* species. In some cases the ratio was about 0.3 to 0.4 percent.

Therefore, our original proposal that termites do emit large quantities of methane and carbon dioxide into the atmosphere is still valid given the field experiment we have undertaken to prove our original laboratory experiments.

2. *Climate Change*

It is now generally agreed that the amount of CO_2 in the atmosphere has increased and continues to rise. The major concern of increased CO_2 is the climatic change that may arise. In the excellent report [1] on "The Global 2000" the study group has proposed three environmental consequences of the changed climate. I intend to analyse each climate scenario and point out my views on the Africa region.

Scenario No. 1: No change. This scenario with a probability of 0.30 assumes that there will be no change in climate by the year 2000. The

TABLE 4 - *Concentrations of Methane and Carbon Dioxide in a Teflon bag enclosure air sample of an* Amitermes unidentatus *in ppmv.*

SAMPLE	ELAPSED TIME (Hrs)	$[CH_4]$ X	$[CH_4]$ σn	$[CO_2]$ X	$[CO_2]$ σn	$[CH_4]$ % $[CO_2]$
Ambient	0	1.663	0.007	400	—	0.4140
Bag sample 1	2	6.704	0.064	600	—	1.117
Bag sample 2	17.5	41.525	1.005	3700	—	1.122
Bag sample 3	18	43.755	0.305	3900	—	1.122
Bag sample 4	21.5	50.480	1.100	5000	—	1.010

warming effect of increasing CO_2 will be balanced by the cooling effects of a natural cycle of falling temperatures. Because of both population and livestock growth in Africa the environmental consequences of this scenario will not be minimal for the region. There will be increased demand for energy, increased shifting agricultural practices and decreased forest areas. The continent will find it hard to support its population and malnutrition may increase.

Scenario No. 2: Warming. The scenario with a probability of 0.25 assumes that due to the increased CO_2 in the atmosphere there will be by the year 2000 an increase of 1°C in global temperatures. Most of the warming will occur on the polar regions and the higher middle latitudes. Precipitation increases are predicted for the higher middle latitudes with little change elsewhere. Pressures on forests in Africa will be the same as in scenario No. 1 due to increased population growth and concomitant needs for food, fuelwood, building materials, and other forest products.

Scenario No. 3: Cooling. This scenario also with a probability of 0.25 assumes that cooling might occur if the global cooling trend that began in the 1940's were to continue. This would lead to a global temperature decrease of 0.5°C with 1°C cooling in the higher and middle latitudes and smaller changes near the Equator. Precipitation amounts will generally decrease, with month to month and year to year variability increases. Storm tracks shift Equatorward, bringing precipitation to the higher latitudes of deserts but causing Equatorward expansion of these deserts. Monsoon failures will become more frequent and severe and the Sahel will experience more frequent and severe droughts. In essence this scenario is the one that will affect Africa the most. Rainfall in Africa depends to a large extent on the Monsoons. Thus food production would decrease, forested areas would also decrease due to low rainfall. Human suffering and ecological changes in the magnitude of the Sahelian region experience or more would be expected. Massive irrigation projects in areas with fresh water or desalinated water would be expected to be undertaken in order to counteract the effect. There is no alternative which favours Africa.

3. *Strategies and Priorities for Research*

Some of the man-made changes taking place in Africa discussed in this paper may cause further ecological and climatic alterations. At present we do not have enough data to predict the actual changes. The scientific knowledge of atmospheric chemistry in Africa is sparse or non-existent. Furthermore, the unplanned, unmanaged development projects that have taken place in the region need re-directing and reorienting. It is clear that the supply of wood for energy occupies a major place in solving some of the ecological problems. In this respect, land use planning and policy should be embarked on by the respective governments as a priority. The planning will enable users to know areas suitable for agriculture, mining, urban and community development. It will also identify areas suitable for forestry and agroforestry.

Furthermore, greater efficiency in energy production and use should be achieved. At present there are several losses incurred in oil and gas production, electricity production and transmission. These losses worsen the pressure on natural forests as alternative replacement source. There is also a need to develop fuel-wood plantations instead of cropping natural forests. A study in ways and means of producing better kilns in the charcoal production, a process now experiencing 50-84 percent losses of the energy value, is long overdue. The wide use of such kilns will greatly help the situation.

The establishment of an Atmospheric Research Centre in Africa is long overdue. Given the commonality of research topics in this area for the region and the fact that atmosphere has no boundary, it becomes clear that the present University set up in Africa is incapable of handling all aspects of the atmospheric study. Such a centre can only be started with the help of UN bodies such as WMO, UNESCO, IOC, etc. with the co-operation of African Universities and the Organization of African States. The first goal of the centre should be to gather together a group of climate modellers, a community of scientists which must include meteorologists, oceanographers, glaciologists, biologists, geochemists, chemists, paleo-climatologists, and social scientists to draw up full scenarios of the future course of climate and its effects in each nation of the region. Such a detailed scenario should include description of the seasonal changes in temperature, precipitation, evaporation, and so forth on a regional and national scale, taking into account the rate of fossil-fuel burning and changing patterns of deforestation and reafforestation. The modellers should also anticipate the behaviour of ice-sheets, snow-covers, and sea-ice.

Complementary to the above, the scientists at the centre should develop for each state methods for assessing climate changes in human or economic terms. We in Africa need to predict the effect of a given change of weather conditions on: (a) the yields of staple foods such as maize, wheat and vegetables; (b) the important tropical plants such as coffee, tea, sisal and others; and (c) poultry and animal husbandry. All these may be difficult to quantify, but attempts must be made to reach the best possible estimates. Further energy demand and transportation/communication patterns will depend on climate change and a fair assessment of their implications should be taken into account.

There is a need to assess on a regional scale the economic (and institutional) interactions between various specific activities or sectors. The development of the economic system of a region or country and to show its sensitivity to a given scenario of climate change is essential. Although models cannot predict the future, they help to slow the relative economic response to a given situation, such as changes in agricultural productivity, price and sources of energy, shifts of trade etc.

The way people and social institutions will react to climate change will differ from region to region, country to country. Some countries will gain, some will lose. It is not too late for the African countries to involve in their future plans the alternatives to increased carbon dioxide, reduced fossil-fuel consumption, and a higher reafforestation rate.

One salient point which has been assumed in this paper is that the present high rate of population increase will be reduced and made steady. It will be almost impossible to effect a lasting land use planning and policy if the present rate of population growth is maintained. With the dwindling areable land and the increasing drought patterns in the region an increased population growth will not be sustained.

The chemistry of the ozone layer in the tropics has not been extensively studied. We do not know the level of the ozone concentration with exactitude. We have demonstrated that termites do emit large quantities of methane in the tropics. The emitted methane is transformed into CO which can affect the ozone layer. Therefore, studies of ozone layer profile in the tropics would be an essential component towards our understanding of the atmospheric chemistry.

Lastly, with the expected industrialization of Africa, there will be more industries and automobiles emitting NO_x, SO_x, particulates, PAN, etc. into the atmosphere. At present we do not have enough or complete background data on the concentrations of the above. The potential photochemical reactions that may take place in the tropics may be assumed. Although at present the region has relatively low level of oxides of nitrogen and sulphur, this does not negate the importance of their study. The effects of these compounds in causing acidic rains, which may adversely alter the pH of the lakes, is well documented. In addition, the oxides of sulphur are closely linked with photochemical smog. Studies of these gases should be initiated as soon as possible.

Acknowledgement

I wish to thank Mr. Patrick R. Zimmerman for the useful discussion and technical and equipment assistance given to us. I also wish to thank Mr. J.A.Z. Mugedo, who carried out most of this work under my supervision, for his M.Sc. thesis and Dr. J. Darlington for providing guidance in taxonomy.

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[19] Measurements were collected from three *Reticulitermes* and two *Gnathermitermes* colonies. Some gas samples were removed with a 10-ml gas tight syringe (Precision Sampling Co.) For others, the exhaust line of the jar was connected directly to the sampling loop of a six-pot Sampling value (Carle, Model MK-2). The samples were

analyzed chromatographically for CH_4, CO, and CO_2 by the method described by Rasmussen and Khalil [14]; for C_2 to C_{10} hydrocarbons by the method of P.R. Zimmerman [EPA 904/9-77-028, *appendix* C (Environmental Protection Agency Region IV Air and Hazardous Materials Division, Atlanta, 1979] and for reduced sulphur compounds by the method of S.O. Farwell, *et al.* [Anal. Chem., *51*, 609 (1976)].

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DISCUSSION

HARE

I would like to comment on both the Salati and Wandiga presentations. I think one should congratulate these two speakers on bringing forward the special environmental problems of the tropical countries. They have very much illuminated those special problems. This morning, as I understand the wishes of Prof. Marini-Bettòlo, we should be looking for general conclusions; and one general conclusion that I would hope that we would come to would be that the special environmental resource and human problems of the tropical world deserve as much attention from the scientific community as they can get. These two speakers should be assured of the full support of the scientific community. The thing that strikes you at once when you go to any Third World capital is the loneliness and the isolation of the small scientific community that tries to do its work in those areas.

May I make some specific remarks? First as regards the Amazonian rain forest, I was most interested in the data that our speaker gave us. In fact, the run-off data from the Amazon which he mentioned represents something like 85% of the total discharge of the streams of the United States, and about 40% of the discharge of the streams of Canada. So this is an enormous river system. Secondly, the finding that he presented that the precipitation is largely internally generated, that it is maintained at this high level by the re-evaporation of rainfall that has already fallen, and is not simply an abstraction from an oceanic source, that too is confirmed in Africa, where a very substantial proportion of the precipitation falling from the African monsoon is actually re-evaporated water. One can demonstrate this by simple applications of the continuity theorem. In fact, the rain that falls at the eastern end of the monsoonal thrust — actually the trajectory is turned from the southwest towards the west — comes from the southwest. The trajectory turns towards the west because as it rises it enters the Equatorial easterlies. But at the limit of the trajectory, about two-thirds of the precipitation has been on the average re-evaporated at least once. And so the point that our speaker made is certainly completely confirmed from the African continent.

The second point concerns the second paper, and has a bearing on the same point. It arises from the suggestions made by Prof. Wandiga about the role of termites and the possibility of climatic change in Africa. First of all, as far as climatic change in Africa is concerned, I recently chaired a meeting on behalf of the Economic Commission for Africa of the UN. We reviewed the status of the climatic change to which he referred. And it *is* true that the spatially averaged rainfall over inter-tropical Africa has been declining progressively since about 1958-59. Every year there are patches of good rainfall. Every year the size of those patches of good rainfall decreases. 1983 was probably the driest year in the history of the continent, judging from the recorded precipitation history. And so the continent has come through 22 years of desiccation. These happen to be the years of decolonization. The African republics achieved their independence just as the rainfall began its downward swing. In Mauretania in 1983 the raintall was so low and the exotic streams, coming from the south, from the rain forest belt, were so low that a state of national emergency was declared about six months ago. Something like one-third of all the territories of Mauretania are without resources of water and food. The population of Nouakchott has increased by tenfold in the last eight years. With the abandonment of territory, the people have come to the capital city. Now is this climatic change, or is it simply an extreme fluctuation? As a statistician I would say it is an extreme fluctuation; as you look at the record you can see other similar anomalies. Hence one could say that this is within the population expectation; this is what you might expect from the climate. But increasingly I wonder about this. There are two feedbacks that are tending to reduce the rainfall. One is the albedo feedback, to which Professor Wandiga referred. As the ground is bared, as the particle loads have increased, the reflectivity of the surface has increased. Possibly the induced mechanism of accelerated subsidence is at work. Secondly, if it is indeed true that the rainfall is derived near the end of the trajectory primarily from re-evaporated water, then reduced water-holding capacity in the soil provides a positive feedback that will tend to accentuate drought. It would appear that to some extent this is true. One of the things that will tend to reduce water-holding capacity is a sharp reduction in the organic content of the soil. It is my impression in those parts of Africa that I know that there is a rapid net loss, not only in mineral fine components, but in the organic content of the soil. There is a degradation of litter, and a consumption of soil humus. Both of these tend to reduce the water-holding capacity from which re-evaporated rain is derived. So that one can see the mechanism of which he spoke as part of a second feedback process.

The rôle of termites is comparable to the rôle of many other decomposers. The earth photosynthesizes that cellulose to the tune of maybe seventy gigatonnes a year. It respires an equivalent amount if the biomass is constant, but it looks as if in these very dry regions the net respiration, the net decomposition of organic material, is now exceeding the rate of photosynthesis. One of the processes whereby this would be done could be an acceleration of the work of the decomposers, such as the termites to which he refers.

So I have nothing optimistic to say either, Mr. Chairman; I was delighted to have these papers before us, and to express the personal view that the plight of the tropical countries and particularly Africa and Brazil (I did not say South America — I said Brazil — because of the enormous extent of desertified terrain in northeastern Brazil) absolutely need the attention of the scientific community. I hope they will get it, and that it will be among our recommendations that we support all the work that can be done.

Marini-Bettòlo

Thank you, Professor Hare, for giving us so much information, and for having drawn attention to the desertification.

Salati

I only want to add a comment on the water balance. The figures presented have been obtained from independent measurements and not by difference.

The discharge of the Amazon has been made by the U.S. Geological Survey during several months. Rainfall was measured in a large number of meteorological stations, and the evapotranspiration was calculated based on meteorological data obtained at the same stations.

Wandiga

I would agree with most of the comments that Professor Hare made, but I would like also to bring out one point which possibly I did not bring out yesterday. What I said is that we are proposing that termites may be accelerating the decomposition of the biomass in the Tropics, and we are not at this moment saying that the amount of CO_2 is affecting the climate. But as soon as I say that, I must also add that in Africa we have a lot of inefficient combustion engines; in other words, the automobiles that have been used in Africa right now are either those which were made 10 or 20 years ago or those which do not have efficient combustion engines, and these are, again, adding to the amount of carbon dioxide, which is already bigh, plus the fact that the creation of industries (and some of these industries are not really the modern type of industries that are being set up in the industrialized countries) is again another added aspect of the CO_2. So what I was trying to suggest is that, given the high concentration of CO_2 already present, which must have come from the biotic cycle, we are going to see even an additional higher concentration of CO_2 in Africa unless we reverse the trend. And this is the first thing I think I would like to make clear.

I would also like to agree with you that the last 20 years, as shown, were the period of decolonization. During colonial times most of the colonizers passed and enforced the land conservation laws, and when we became independent we thought that these were colonial laws and therefore abolished them, and we allowed our people to cut forests, to plow maybe up to a 45° angle on the hills. The result was an acceleration of the deforestation. This fact has had an effect in almost every country, and therefore we have seen less or fewer forests remaining because of the disregard of the colonial conservation laws. Regarding other things that you said, I think I would agree with you that certainly we are seeing reduced capacity of holding water in the continent and therefore we can expect less rainfall. Although in these twenty years there were fluctuations, I do not expect better conditions unless the African governments enter into a very massive reforestation program.

LAG

I should like to ask a question about water analysis in the Amazon regions. Have you any figures and calculations about the C/N ratio in the water? Is that somewhat like what you have in the terrestrial humus? Is it possible to give an answer to that?

SALATI

Yes, there are analyses and the data are available, especially published in *Acta Amazonica* and in the Max Planck Institute of Limnologie, Plön.

KNABE

I would like to make a comment from the point of view of my time in the Inter. Bureau of Forestry at Hamburg. The difference between the forest in the tropical zones and in the temperate zones is mainly that the lowest content of organic matter in the Tropics is in the living part of the ecosystem and not in the detritus or in the humus. So if you cut the most living part of the ecosystem, you at once lose the main part of the nutrient contents, i.e., the main part of the organic matter. Secondly, the decomposition of the rest of the organic material, as Professor Hare explained, will also be reduced, but third — that has not been mentioned — the soil under the cover of the rain forest is formed by a material able to retain water, whereas when the cover is removed, it changes its properties and is not able to hold the same amount of water as before. So it is really a great hazard to remove a shade tree cover from such soil types.

CRUTZEN

I wanted to support strongly what Dr. Hare said and also point to another problem. We have here two representatives from the tropical countries who are strongly interested in air chemistry and want to start up a program there. I want to emphasize how much they need our support, even moral support, because I found this out at the meeting in Africa to which Dr. Wandiga invited me in June and at which I gave a lecture on air chemistry. There was a lot of enthusiasm among the participants to get going, but immediately, after they showed a brief period of enthusiasm critical voices came up, saying is this really the major problem we have in Africa? We have such worse problems to deal with — should we really put resources into this basket? And of course one tries to defend atmospheric chemistry in that environment, but I do not really think it was up to me to do that allocation — I just wanted to indicate that these people have problems in their countries selling the issue and they need all our support to do that.

I have one specific question to Dr. Wandiga about the termite work. I was involved in that a little in the beginning, but one thing which still surprises me is the use of methane, compared to carbon dioxide: you obtained values just a little below 1%. Now if cellulosic material is decaying under totally anaerobic conditions, you would have really 50-50 would come out of it: of 100% cellulose, 50% of the carbon going into methane and 50% into CO_2. Now here it is only 1%, so somewhere on the way even 99% gets lost, or a large part of this environment anyhow is aerobic and methane is used. So then the problem comes up: where should one really measure the emissions? Should one go into the termite nest or should one collect methane and CO_2 outside the nest or put a bag over the system? I wonder if in the research which has been going on over the last years, with which I am not so acquainted, one has been looking at these factors, with a whole bunch of these common species.

WANDIGA

As you know, in the digestive system of the termite, the anaerobic part of it is only in the guts, and then from the guts it goes to the stomach, where the aerobic system does operate, and that is where most of the methane is being lost or utilized. We have looked both inside the mound and outside the mound, and the ratio of methane to CO_2 is very much the same, so we think it is being utilized within the animal itself.

CRUTZEN

So the conclusion is that the termite overall metabolism is still 99% aerobic and just 1% anaerobic?

WANDIGA

Yes.

REVELLE

I want to make a comment but I want to ask a question about the methane first. Would you conclude then that the methane is being used as a nutrient by the termites? That it is actually metabolized in the energy cycle of termites?

WANDIGA

Of all the literature, entomological literature, I have seen, nobody has invoked that, but from the fact that we have seen very low levels of methane being emitted we imply that it must be utilized somewhere, or never produced.

REVELLE

I would like to make a comment on something that a Brazilian colleague said about forest plantations. It seems to me that one of the most serious problems in the tropical countries is how to reforest the areas that have been deforested and to estahlish a steady state of equilibrium condition. The problems that he cited are very severe: the problems of disease, of pests that attack these newly planted trees, and the problems of nutrient cycling, which in the case of many trees result in the continuous reduction of the plant nutrients in the soil. But the problem really is how to make forest plantations in which none of these things happen. And nitrogen-fixing trees are clearly a major opportunity, but we also need fast growing trees, trees that are so-called pioneer species. And we need to find, by forest research, those that are disease — and pest-resistant. One example is the tree that has been widely talked about: Leucaena which seems to be quite pest — and disease-resistant. It is a very fast-growing and nitrogen-fixing tree.

But in more general terms it seems to me that one of the very important kinds of scientific research and development that are needed in the tropics is forestry research. In the past, forestry research has not attracted very good scientists or very many scientists, for the reason that the results come so slowly, because one result per generation, most scientists are not satisfied with that kind of scientific progress. In recent years, however, the new biology has made it possible to obtain results about once every six months, particularly with tissue culture of individual tree cells, which turn into little trees, and you can then do a lot with these very young individual trees.

And it may be that there are many other ways in which the new biology will be very applicable to forestry — it is certainly being pushed in the United States by the big forestry companies. In general, the scientific problems of forestry here cannot be over-estimated in terms of their human importance, because of the firewood problem which Wandiga spoke about and the general problem of substituting biomass energy for fossil fuel energy, which in the long run we will have to do anyhow, but the quicker we can do it, I think, the better off the world will be, certainly from the standpoint of the carbon dioxide problem, and from other standpoints too; I would urge that we not only think about atmospheric chemistry but of some of the implications of these chemical cycles that are so worrisome in the Tropics.

SALATI

Usually colonizers do not take into consideration the agricultural practices, but only the utilization of the land by the number of hectares. It is difficult to establish a relationship between the chemical aspects of the atmosphere and the forms of land management. When you consider the problem in terms of millions of square kilometers, it becomes regional and then it is possible to make a connection between them. It is therefore important to note that either chemical reactions and their consequences, or the amount of water vapor transported, the amount of dust or pollen, can have their values altered when forest areas are changed to agriculture. Amazon colonization is rather difficult. The Portuguese preferred to start colonization in southern regions where climate is more appropriate, while the Spanish chose especially higher altitudes. Even now the Amazon population does not reach 10 million inhabitants in over 6 million km^2. It would be important to study the rational and ecological utilization of the region.

CANUTO

I was telling you yesterday that there is a new financial system of the United Nations, called the United Nations Financial System for Science and Technology, which came up under the auspices of the 1979 Science and Technology Congress in Vienna. This Financial System has funds and the problem that you presented, in my understanding, fits perfectly in that program. So if that could be of any use, I think that I will be more than glad to give you more information about it.

HARE

I think that I should say that clearly what is being said around this table at the moment illustrates the basic principle on which this meeting is based, which is that all such studies are interdisciplinary. I have stopped calling myself a meteorologist, I call myself an atmospheric scientist because I know damn well I cannot get along without people like Crutzen and Rowland here, and I hope they feel they cannot get along without dynamicists and climatologists — none of us can get along without soil scientists and ecologists when it comes to this class of work. We will come back to that later on.

At this moment I only wanted to lay a further point before the meeting, that arises out of these two interesting papers, and that is that it is not merely that the so-called South politically, the tropical countries, have a lower living standard and are at a lower level of development, and have perhaps a more difficult physical environment than the middle latitude countries. It is that special stresses are now arising out of two circumstances, both of which were referred to by both speakers. The first is the population explosion, which is a matter for the scientist to concern himself with; and the other is that I must say that in the last two decades the tropical climate, rather climates in the plural, have behaved extraordinarily badly. The timing could not have been worse.

Now, may I bring that point home just by briefly looking back at Africa? The African drought, the Sahelian drought, even Professor Wandiga said it ran from 1968 to 1974. It did not, Professor Wandiga. It began before that and it continued. Drought has devastated the Sahel, the Sudano-Sahelian belt, every republic from the Atlantic right through to Ethiopia. Somalia, Kenya and

Tanzania have been somewhat more fortunate, especially lately, and Nigeria has been more fortunate. And this illustrates the biblical principle: "To him that hath shall be given and from him that hath not shall be taken away even that which he hath" because (for God's sake) it is the richest countries in Africa that have had the best time climatically. The most important event of the late 70's has been the extension of drought into southern Africa and even into the Union of South Africa. One began to think that only the Union of South Africa was immune from drought on the continent, but now even the Union is affected; the whole continent has undergone this extraordinary dessication. I cannot place too much emphasis on the fact that this is unprecedented and that it is imperative that the scientific community make itself heard about the matter. Discussions of economic affairs before the United Nations are almost entirely in terms of power-bloc politics, who will do what, whether the Soviet Union is intervening in that, whether the United States is intervening in that. This is all irrelevant to the problems of the continent, which are imposed and dictated by this deterioration of nature. It follows that it is in our laps, the scientists, to do and say something about this, and I never lose an opportunity, Mr. Chairman, which is why I butted in at that point.