SPECIAL ISSUE - 5

Biology International

The News Magazine of the International Union of Biological Sciences (IUBS)

SOIL BIOLOGICAL PROCESSES AND TROPICAL SOIL FERTILITY

A PROPOSAL FOR A COLLABORATIVE PROGRAMME OF RESEARCH

Edited by
Professor M.J. Swift

SOIL BIOLOGICAL PROCESSES

AND

TROPICAL SOIL FERTILITY:

A PROPOSAL FOR A COLLABORATIVE PROGRAMME OF RESEARCH

Report of the meeting of the IUBS Working Group
on Soil Biology /Decade of the Tropics Programme
co-sponsored with
the UNESCO Man and Biosphere Programme
and the
Institute of Terrestrial Ecology, U.K.

January 9-13, 1984
Lancaster, United Kingdom

Edited by

Professor M.J. Swift
University of Zimbabwe
Harare, Zimbabwe

SPECIAL ISSUE - 5

BIOLOGY INTERNATIONAL

The International Union of Biological Sciences
News Magazine

T A B L E   O F   C O N T E N T S

SOIL BIOLOGICAL PROCESSES AND TROPICAL SOIL FERTILITY:

A PROPOSAL FOR A COLLABORATIVE PROGRAMME OF RESEARCH

SUMMARY

An international programme of collaborative research is proposed, to clarify the links between biological processes and tropical soil fertility. The major objective of this programme is:

- <u>to determine the management options for improving tropical soil fertility through biological processes</u>.

The proposal was drawn up by a group of fifteen scientists (agriculturalists, biologists, ecologists and soil scientists) from ten countries, at a workshop held in the UK in January 1984 under the sponsorship of IUBS 'Decade of the Tropics' and Unesco 'Man and the Biosphere' programmes. The workshop was arranged because of the recognition by these bodies of the urgent need to consider biological approaches to improved management of tropical soils in the face of the widening gap between productivity and demand for food in the tropics. This approach was visualized as being a complement to the current developments in high-input agriculture that are already massive contributions to this problem but which are limited by both socio-economic and ecological factors. It was equally recognized that the current level of understanding of how biological processes contribute to soil fertility was inadequate. Revision of this situation thus requires investigation not only of agricultural systems but also of the integrative functioning of the natural ecosystems from which they are derived.

The workshop set itself the initial task of evaluating the current understanding of the link between the biological processes of soil and its fertility. This has been presented in the form of a 'General Hypothesis' - a succinct and abbreviated statement of current concepts.

On the basis of this evaluation a research proposal has been constructed. Within this proposal two broad themes of research have been identified:

Synchrony (SYNCH) - to investigate the mechanisms of transfer of nutrients from decomposing organic materials in soils to uptake by plant roots with the aim of manipulating plants and plant residues to optimize the efficiency of the transfer.

Soil Organic Matter (SOM) - to investigate the relationship between the organic (and inorganic) inputs to soil and the quality and quantity of soil organic matter formed. This programme also aims to determine more precisely than is presently understood, the contribution to soil fertility of the quantity and quality of organic matter present on a soil.

These two themes provide a basis for a coordinated international research study.

Within the study a minimum package of research methods has been identified, designed to clarify the potential for manipulation of soil biological processes under a wide range of conditions. The package allows rigorous comparison of results from a wide range of sites, but it can also be expanded to incorporate more sophisticated techniques and more sensitive variation in management. It is envisaged that a single or small range of agricultural practices would be examined at a network of Project Sites which would be linked to a few Programme Centres. These centres would undertake comparison of a wider range of management practices and would also act as a focus for the provision of services, training and communication. Inclusion of natural (undisturbed) vegetation will provide an important baseline comparison with agricultural management options.

To implement the programme a Coordinating Committee has been established under the auspices of IUBS. A Scientific Advisory Group embracing all relevant scientific disciplines has also been established to assist in the further planning of the project.

The next stage in the planning of the programme will be to formulate a more explicit set of hypotheses which can be tested through the experimental programme. Full details of the approach and methods will be provided in a handbook. The programme will, however, also generate new hypotheses during its implementation and will additionally provide new ideas and general understanding of the relationships of soil biological processes and soil fertility.

It is a major aim of the project that there should be a rapid transfer of information from the fundamental research projects to 'farm-trial' programmes by encouraging a close association, from the very start, between scientists and extension workers.

WORKSHOP PARTICIPANTS

J M ANDERSON	Exeter University, UK
Y R DOMMERGUES	Office de la Recherche Scientifique et Technique Outre Mer, Dakar, SENEGAL
M HADLEY	Unesco, Paris, FRANCE
O W HEAL	Institute of Terrestrial Ecology, Grange-over-Sands, UK
P LAVELLE	Ecole Normale Superieure, Paris, FRANCE
T ROSSWALL	Swedish University of Agricultural Sciences, Uppsala, SWEDEN
P SAJISE	University of the Philippines at Los Banos, Laguna, PHILIPPINES
P A SANCHEZ	North Carolina Mission to Peru, Lima, PERU
F E SANDERS	University of Leeds, UK
M J SWIFT	University of Zimbabwe, Harare, ZIMBABWE
B H WALKER	University of Witwatersrand, Johannesburg, SOUTH AFRICA
W G WIELEMAKER	Agricultural University, Wageningen, NETHERLANDS
A YOUNG	International Council for Research in Agroforestry, Nairobi, KENYA

Correspondents

R LAL	International Institute of Tropical Agriculture, Ibadan, NIGERIA
R HERRERA	Instituto Venezolano de Investigaciones Cientifica, Caracas, VENEZUELA

Rapporteurs

J DIGHTON	Institute of Terrestrial Ecology, Grange-over-Sands, UK
P INESON	Institute of Terrestrial Ecology, Grange-over-Sands, UK

SOIL BIOLOGICAL PROCESSES AND TROPICAL SOIL FERTILITY:

A PROPOSAL FOR A COLLABORATIVE PROGRAMME OF RESEARCH

1 INTRODUCTION

1.1 BACKGROUND

This document constitutes a proposal for a programme of collaborative research into the role of the biological processes of soil in sustaining soil fertility. The objective of this programme may be stated thus:

> <u>to determine the management options for improving tropical soil fertility through biological processes.</u>

The impetus for the programme comes from the recognition of the urgent requirement to improve the efficiency of food production in the tropical zone. The crises created by a burgeoning human population and attendant land shortage are widely recognized and no further detail is required (3, 14). The context for this programme has however been succinctly stated by the International Union of Biological Sciences (IUBS) when initiating its 'Decade of the Tropics' programme: (39) '......whatever the reasons, the discrepancy between the rich temperate zone and the poorer tropics represents probably the largest global problem that mankind faces today... In biological terms, the problem is that of a fast growing population, living in an area of present low productivity and low income, threatened with famine because of low agricultural productivity and increasing world-wide food demand.'

Thus, demand for increased productivity puts man's ingenuity to the test. Great advances have been made, through the 'Green Revolution' and other programmes, to apply scientific principles to farming in the tropics. This spread of high-input farming systems is clearly one direct path to solving the problem. It is also apparent that there are economic, ecological and social limits to the extent to which such high technology systems can be extended. Further, the various types of low-input agriculture (eg shifting cultivation systems) that support the major part of the tropical zone population cannot be indefinitely sustained. As population pressures force the shortening of the fallow cycle and eventually impose the practice of continuous cultivation on low fertility soils unable to sustain it (11).

Solutions must be found to raise this fertility which do not lean entirely on the same economic and social base as the high-subsidy, high technology farming characteristic of the temperate zones. Some mix of high-input and low-input systems should be sought, appropriate to improving and/or sustaining fertility in each ecological zone adapted to the particular soil types within the zones. One approach to this is to improve the management of the natural resources of soil.

In natural ecosystems productivity is sustained by the tight integration of the vegetative system with the biological system of soil. Yet these crucially important biological processes of soil are poorly understood by ecologists, even in natural ecosystems, and are rarely investigated by agriculturalists. One of the reasons for this is the success of high-input farming, which effectively bypasses soil biological processes through its use of fertilizers, pesticides and mechanized preparation of soil. This success leaves little apparent reason why soil processes should be taken seriously. But, it is noticeable that the adoption of minimum tillage systems in temperate regions is refocussing attention on soil ecology. Such systems can provide economically viable options which may be particularly applicable to the sensitive soils of certain parts of the tropics (35). Moreover, much of our current knowledge of these soil biological processes has been achieved through pure research just as the understanding of the consequences of perturbing nutrient cycles has largely come from manipulative studies of natural ecosystems (5). It is therefore necessary to retain and develop an interface between natural and agroecosystems as a context for integrating and building on the knowledge of ecologists and agricultural scientists.

It is the deep conviction of the scientists involved in this programme that we can no longer afford to ignore the potential which soil processes offer as a means of regulating productivity. Furthermore it is evident that there are fundamental as well as practical scientific problems to be solved; here problems are not unique to the tropics but it is the particular problems of the tropics that demand their solution.

1.2 PROGRAMME PHILOSOPHY

It was with the above objective and rationale in mind that IUBS and the Unesco 'Man and the Biosphere' (MAB) programme jointly sponsored a workshop held in the United Kingdom in January 1984 in which thirteen scientists (soil biologists, soil scientists, agriculturalists and ecologists) from ten different countries participated. The purpose of the workshop was not to conduct an academic review but to take the first step towards defining a plan of action. The workshop set itself the following targets:

1) to prepare and publicize a reasoned evaluation of the importance of soil biological processes to the functioning of natural and managed ecosystems;

2) to identify the most significant gaps in our present knowledge and understanding, with particular respect to tropical soils;

3) to recommend priorities for research into the relationships between soil biological processes and soil fertility in tropical areas;

4) to evaluate the methods available for these investigations;

5) to promote the establishment of a network of research sites within the tropical zone where research of this kind may be simultaneously tackled;

6) to make recommendations for standardization of methods and experimental design so that comparability of results is attained and general principles more clearly defined.

The following sections of this document address these targets:

The General Hypothesis is an evaluation of the way in which soil biological processes contribute to soil fertility (ecosystem productivity) and of the manner in which agricultural management may modify them. It is not a comprehensive review nor does it lack areas which many experts would regard as speculative. It is intended to focus attention on processes which the workshop scientists judged to be of importance in the regulation of soil fertility.

The Research Proposal: the workshop identified priorities for research and produced a broad outline of the way in which an international programme of collaborative research could be initiated to tackle them. It was felt neither necessary nor feasible at this stage to make proposals in terms of detailed testable hypotheses nor to make specific recommendations for methods. These essential aspects will form part of the next phase of the programme, should it go forward, and will be guided by the response of the scientific community of the tropical zone to the proposals.

In making the proposals a number of general principles guided the decisions of the workshop. These should be evident on reading the document but it may be of value briefly to state them in advance:

that it is crucial to bridge the lack of common experience and understanding between biologists, soil scientists and agriculturalists. The composition of the workshop was designed to attack this and the general hypothesis and proposals reflect a first step in this direction;

that to understand how to manage an agricultural ecosystem it is profitable to learn from a natural ecosystem;

that compatibility of data at a global level is essential; hence the concept of a 'minimum package' of research;

that the implementation of the research proposal should not be dependent on the availability of expensive facilities or equipment or large teams of personnel;

that as management recommendations are one of the major long-term objectives of the programme, the socio-economic aspects of land use practice must be taken into account right from the onset of the programme;

that even if clarity demands that statements be made in general terms, the climatic, edaphic and sociological diversity of the tropical zone be constantly remembered: to talk of 'the tropics' is naive - it is of greater value to remember that many important physical, biological and sociological properties show as much variation within the range of their tropical distribution as exists between the tropical mean and the temperate mean.

2 THE ROLE OF SOIL BIOLOGIOCAL PROCESSES IN SOIL FERTILITY: A GENERAL HYPOTHESIS

A primary objective of the programme is to prepare a reasoned evaluation of the role of soil biological processes in the fertility of natural and managed ecosystems in the tropics. There is a small, but significant, body of published information on soil biology but a wealth of published and practical experience on the management of tropical soils. In addition there is a body of research on soil processes in temperate and other regions which indicates some of the methods and general principles which, with modification, may be applicable to the tropics. The knowledge from these various sources are combined in the following general statement of current understanding of the dynamics of biological processes in tropical soils, their relationship to the soil environment, to plant growth and to management. Although many of the relationships given in this model of the system can be substantiated by data, many others are more speculative and are based on general experience or are deduced from general principles. A bibliography relevant to the subject is given at the end of the document and some references to this are made within the text.

The tropical regions of the world encompass considerable variation in climate nnd vegetation as well as soil type. For the purposes of this analysis three broad 'zones' have been recognized:

1) the humid tropics, dominated by rain forests;
2) the sub-humid tropics dominated by broad leaf tree savannas (cerrado); and
3) the semi-arid tropics characterized by thorn or other xeromorphic bush savannas.

It is within these systems that biological processes are considered to be of particular importance to soil fertility and plant growth and it is in these regions that there are significant opportunities for manipulation of soils by agricultural practices. In the other systems such as the arid zone and in tropical highlands and wetlands, physical factors, particularly water and/or temperature, are the primary determinants of fertility and management is determined by manipulation of hydrological features.

2.1 THE SOIL SYSTEM

The structure of all ecosystems may be pictured in terms of the flux of matter between the biotic and abiotic components (Figure 1). Within this structure the soil may be regarded as a major sub-system,

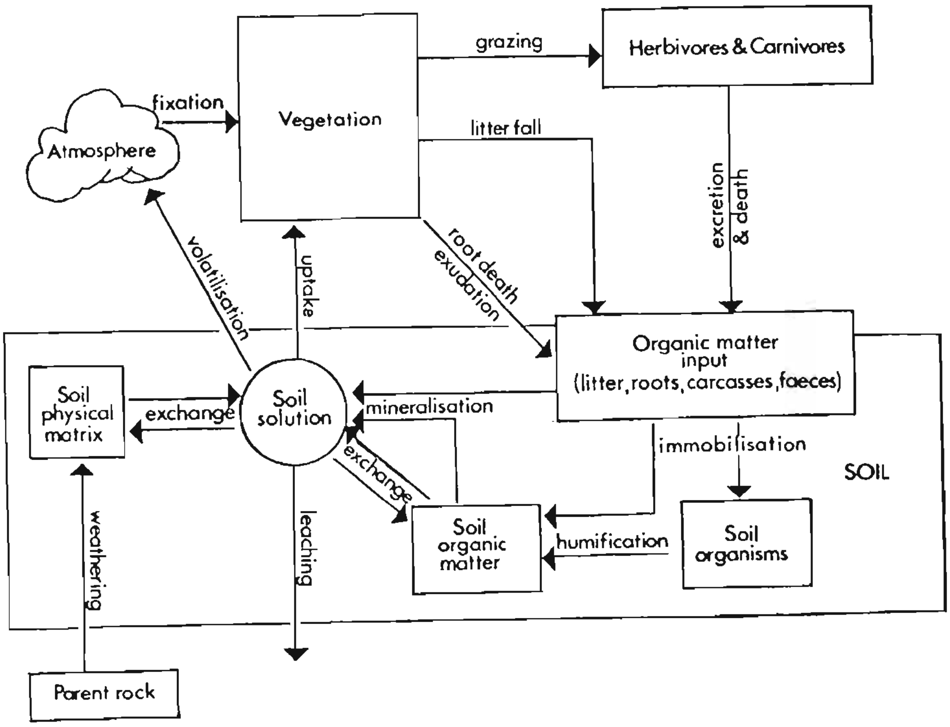

FIGURE 1. Major pathways of nutrient flux within ecosystems.

functionally integrated with the vegetation sub-system and the grazing sub-system. The transfers are controlled by factors of supply and demand and by environmental factors such as temperature, moisture or acidity. Of central importance to plant (and animal) productivity is the control of soil fertility, particularly by the regulation of the nutrient supply to the plants and by the influence of the physico-chemical properties of soil. Three facets can be identified within the concept of soil biological processes.

2.1.1 Plant requirements

Plant growth depends on the ability of the soil to provide a physical environment suitable for root growth and function and adequately to supply water and nutrients (4). This ability is greatly influenced by soil biological processes.

The demand upon the soil varies between different species of plant. In natural vegetation, with diverse composition, a variety of patterns of demand will exist, adapted to the capacity of the soil to meet the demand, both in quantitative terms and in terms of the synchrony in time and space between supply and demand.

In ecosystems producing crops for human or animal consumption, the crop species usually have high rates of growth, and high concentrations of protein, fat or soluble carbohydrate are allocated to vegetative or reproductive parts. These characteristics are deliberately selected for and are often associated, in annuals, with a high demand over a relatively short period of time for mineral nutrients. Perennial crops, often with slower rates of growth and a high proportion of structural carbohydrate, tend to have a lower demand for nutrients, spread over a longer time period.

2.1.2 Soil physico-chemical complex

The physico-chemical environment of soil contributes to soil fertility both by its direct influence on root growth and by its regulation of the composition, abundance and activities of soil organisms (4, 16). At the same time the physico-chemical structure is itself modified by the soil organisms. The major soil groups of the tropics (Table 1) reflect the variation in general physico-chemical properties resulting from the interaction of differing parent materials, climate, topography, vegetation, biological processes and time. These inherent soil characteristics are modified by the imposition of management practices.

For instance, although the original particle size and composition is determined by parent material, the degree of aggregation and the spatial distribution (both vertical and horizontal) of size fractions are strongly influenced by the vegetation and soil organisms (eg earthworms and termites) and by management. In turn, changes in the aggregation and size distribution of soil particles affect water content and movement, pore space, aeration and hence the retention and supply of nutrients, water and oxygen to the plants and to the soil biota.

The amount, type and distribution of the clay fraction of the soil is particularly important in determining nutrient availability through exchange phenomena. The proportion of different clay minerals can be modified by the activity of specific microbial groups, while the adsorption characteristics can be masked by organic complexing. These processes are slow relative to most biological processes, but unlike most other processes the weathering is irreversible.

Organic matter is maintained both on the surface and within the soil. Its distribution and rate of decomposition is under the primary control of the soil biota and is critical in the recycling of nutrients. The organic matter also has essential properties which influence soil physical structure.

TABLE 1. Approximate distribution of soil orders[a] in the tropical regions of the world[b].

Soil associations dominated by	Tropics (mha)	(%)
Oxisols	833	23
Ultisols	749	20
Alfisols	559	15
Mollisols	74	2
Entisols	574	16
Inceptisols	532	14
Vertisols	163	5
Aridisols	87	2
Andisols	43	1
Histosols	36	1
Spodosols	20	1
Total	3670	100

[a] See Appendix for brief descriptions of the main characteristics of these soils.

[b] From (36). Latitudes below 23 1/2^{o}.

2.1.3 Soil biological processes

Within the soil a diverse series of biological processes occur, the rate and type of which control plant growth both directly and indirectly. A soil biological process of central importance is that of the decomposition of the organic matter input from plants in the form of litter, dead roots or crop residues (42). Additional inputs resulting from management practice may take the form of mulches or manures. Decomposition results in the release of inorganic nutrients which may be recycled within the soil biota, retained within the soil matrix by exchange or other phenomena, absorbed by plant roots or lost from the soil by leaching, gaseous or aerosol outputs or erosion. Removal by harvest can also be an important loss from the system. The regulation of decomposition and the varying pathways of nutrient flux under its control thus determine the long-term nutrient capital of an ecosystem and the rates of

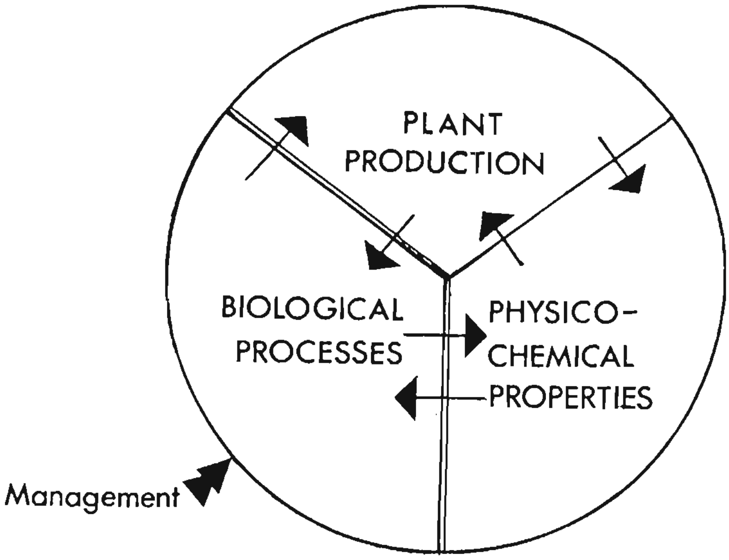

FIGURE 2. The interactive contribution of biological processes and soil physico-chemical structure to soil fertility. The arrow outside the circle represents the aim of the programme in targeting management on biological processes and influencing soil fertility through the interface between them and the other components.

supply of nutrients to the plants. These regulatory controls vary with differing vegetation and soil types. Soil micro-organisms are also responsible for specific processes (9) such as nitrogen fixation, a variety of transformations of inorganic elements and for facilitating nutrient uptake by plants. Soil biological processes (particularly microbial) are also responsible for the formation and decomposition of humus fractions (1).

Faunal activities may furthermore be important in the distribution of organic and mineral material within the soil profile (27). The activities of micro-organisms, fauna and roots also modify the physical structure of soil and hence regulate the rates of movement of nutrients, water and gases. Soil micro-organisms may play important roles in controlling plant pathogens and degrading phytotoxic substances in the soil.

Soil biological processes, mediated by roots, micro-organisms and fauna, are thus an intimate part of the function of natural and managed systems (Figure 2). Current understanding of the functioning of these processes is now outlined in greater detail within two main contexts - their influence on nutrient cycling and on modification of the physico-chemical properties of soil.

2.2 NUTRIENT CYCLING

The role of biological processes in nutrient cycling is first considered in relation to the factors determining nutrient retention and release by organic matter; second, a brief account is given of some specific microbial transformations of nutrient elements; and third the biological influence on the uptake of nutrients by plants is discussed.

2.2.1 Decomposition and mineralization

The rate of decomposition of any resource,(ie any individual unit of organic matter available to the decomposer organisms such as a leaf, fruit, twig, root or faecal pellet) is controlled by the physico-chemical environment and by its intrinsic properties (resource quality). Both environment and resource quality act through the soil micro-organisms and fauna. The climate of the region and the microclimatic regime of the resource, combined with soil properties such as moisture holding capacity, clay mineral composition and acidity, constitute the physico-chemical environment for decomposition. The term resource quality embraces those intrinsic properties of a resource which determine the activities of decomposer organisms: carbon and energy sources, nutrients, and certain substances which modify the activity of organisms in a specific way (eg phenolics). Lignin can act both as a carbon and energy source and as a modifier. Consequently, together with nutrient concentration, it is a key component of resource quality.

During decomposition the physical structure of the resource is changed through comminution, complex organic molecules are enzymatically degraded and soluble fractions may be leached. Concurrently, new organic matter components are synthesized in the production of animal and microbial tissues and in the formation of amorphous soil organic fractions (humification). In their turn, these components are themselves decomposed. Thus there is a cascade in which the original plant material is physically and chemically changed and redistributed (Figure 3). In all cases the rate of decomposition of a fraction is determined by its quality and by the immediate physico-chemical environment.

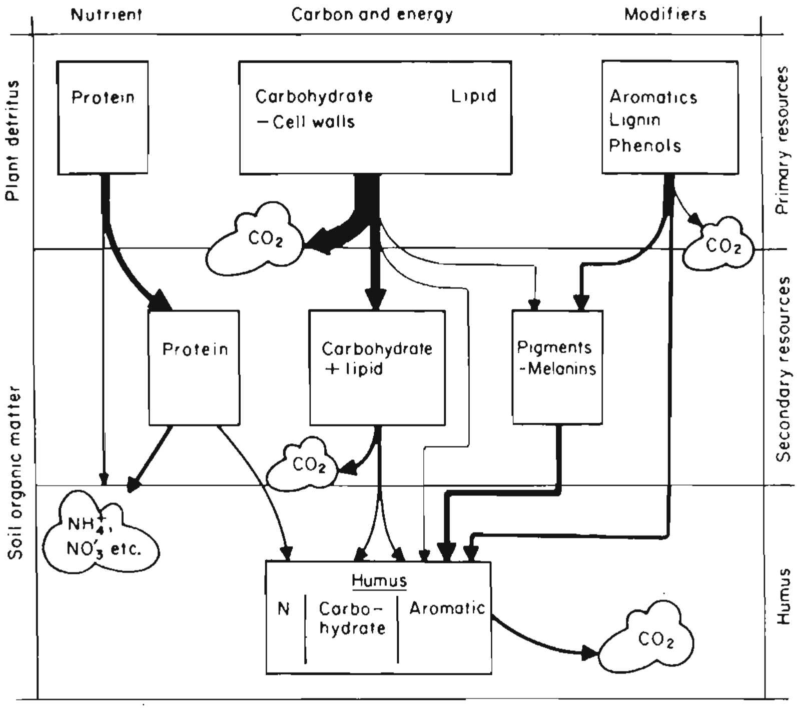

FIGURE 3. The major chemical pathways of decomposition processes. A double-cascade structure for decomposition is indicated. In the first cascade microbial cells (= secondary resources) are synthesized during the decomposition of plant litter or crop residues (= primary resources). In the second cascade the more recalcitrant components of soil organic matter (lumped together here as 'humus') are synthesized. Mineralization takes place during both steps (and also of course during subsequent decomposition of humus) (42).

The accumulation of surface and soil organic matter in tropical ecosystems is a balance of the rates of inputs and decomposition (2). The potentially high rate of decomposition associated with high temperature and rainfall is modified locally by resource quality as well as by seasonal drought, moisture holding characteristics of the soils and soil chemistry. The quality and quantity of input also varies. Hence surface and soil organic accumulation varies considerably within the tropics (36). Management practices may modify the accumulation by manipulation of either input variables or by directly influencing the rates of decomposition.

The time during which mineral nutrients are released from a resource occurs is regulated by its rate of decomposition. The efficiency of transfer of nutrients from the organic matter of soil to the plants is at a maximum when the timing of nutrient release is synchronized with that of plant uptake. Variation of any of the factors that affect decomposition rate (eg the spectrum of quality in mixed litter or climatic change) may cause an uncoupling of decomposition and plant nutrient uptake.

Management practices which may result in uncoupling include stimulating the decomposition rate by selection of high quality crop monocultures, burying crop residues by ploughing, and fertilization with inorganic nutrients. The introduction of pesticides or low quality mulches may, however, delay the onset of nutrient release. Alternatively, any mixed cropping practice will spread the period of plant demand as well as widening the spectrum of resource quality in the input.

Soil organic matter is an important source of nutrients in addition to these released by the decomposition of plant litter or crop residues. Soil organic matter is not one well characterized soil component (38) but can be regarded as a series of more or less well defined fractions with different qualities. These fractions form a continuum which can be subdivided into three main fractions.

The first (Figure 3), which is the most easily decomposable, has a half life of less than two years. It consists of dead microbial and animal cells and their metabolites (eg mucus, exudates). The second fraction consists of stabilized organic matter and has a half life in the order of ten years. It is synthesized from fresh organic matter by soil organisms and extracellular chemical condensation reactions. Part of it becomes complexed with clay minerals, which makes it less susceptible to decomposition and mineralization. The third fraction is formed in a similar manner but is very recalcitrant to microbial attack with a half life typically more than a hundred years. Although the rate of nutrient release may be very slow this organic matter component can be quantitatively important, as a nutrient reservoir.

Deeper understanding of the quantitative aspects of the formation and decomposition of these fractions of soil organic matter would offer a powerful tool to predict and manipulate the mineralization capacity of different soils. Variables affecting these processes are the resource quality of materials from which the fractions are derived, and climate.

Thus, the manipulation of resource quality input, soil fauna and conventional management options can be used to influence the rate, location and timing of decomposition processes, the quantity and quality of soil organic matter and its susceptibility to biological attack, and the overall pattern of nutrient cycling.

2.2.2 Specific nutrient transformations

Fixation of atmospheric nitrogen by micro-organisms is an important pathway by which the soil nitrogen capital can be maintained or enhanced (7). The most active N_2-fixing systems are symbiotic, particularly the association of the bacterium *Rhizobium* with legumes. Examples of non-leguminous nitrogen fixation include associations with the Actinomycete *Frankia*. Fixed nitrogen is incorporated into the soil through plant litter, roots or crop residues. Green manuring is an obvious example of the deliberate manipulation of this process. In low input agriculture or in agroforestry, biological nitrogen fixation appears to be more effective and economic than the application of nitrogen fertilizers.

Management options include the choice of appropriate nitrogen fixing annuals or perennials and inoculation, where necessary, with strains of *Rhizobium* or *Frankia*. The amount of fixed nitrogen that is transferred to the soil is variable however and, with some crops such as grain legumes, may be so small as to produce a nett N deficit (8).

Fixation of N_2 by free-living prokaryotes also occurs in many tropical soils but appears to be of little quantitative significance except under particularly specific conditions.

Ammonium nitrogen is produced during mineralization of plant litter and soil organic matter and may be further oxidized to nitrate by certain micro-organisms (nitrification). The latter process is important in regulating nitrogen cycling at the ecosystem level (6), since nitrate can be lost from the system either through leaching by water from the soil rooting zone or reduction by micro-organisms to gaseous products which escape to the atmosphere (denitrification).

Nitrification rates in many tropical soils are low. Acidity, root exudates and inhibiting compounds leached from the plant canopy or produced during decomposition may retard the rates of ammonium oxidation. Denitrification is greatly influenced by the presence of labile energy compounds. Root exudation is one important source of organic carbon which can be used by denitrifiers, and plant roots may regulate this gaseous nitrogen loss. It is also possible that certain environments associated with animals (eg faecal pellets, guts, termite mounds) may favour high rates of denitrification.

Biological oxidation/reduction processes are important not only for regulating nitrogen cycling but also for sulphur (18). This can be especially important in certain acid soils and sulphate reduction has, for example, been shown to inhibit rice plant growth in paddy soils. Phosphorus does not take part in similar biological oxidation/reduction processes.

2.2.3 Nutrient uptake

The growth rates of crops are usually lower than those potentially attainable because of suboptimal supplies of water and nutrients. This is also true in many natural plant communities, where the members must often divert a considerable fraction of production to the acquisition of nutrients and rooting patterns are closely coupled to the distribution of nutrients and water within the soil profile. For example, in humid forest on acid soils, surface root mats often form in response to a tight internal nutrient cycle (40) and to the occurrence of inhibitory levels of aluminium in the upper mineral soil. In semi-arid conditions, where water is a major limiting factor, trees have deep water-seeking roots but also develop transient systems of feeder roots close to the surface of the soil (20).

In crop plants, with high growth rates and nutrient demands, higher rates of nutrient uptake per unit of root occur than in natural vegetation where root-shoot ratios are usually higher.

Mycorrhizal development, which is almost universal in the roots of plants in the tropics (24), is very important in increasing the efficiency with which root systems can acquire phosphorus, nitrogen and possibly water. This increase arises from the ability of the external hyphal system around the roots to exploit a very large proportion of the soil volume (19). In addition, in natural ecosystems significant associations between roots, mycorrhizal fungi and decomposing organic materials can be observed. By this means plants can achieve a very close contact with sites where nutrients are being released by the processes of decomposition.

There is some evidence that in certain cases, mycorrhizal fungi may directly recycle nitrogen and phosphorus from litter. In addition there is evidence that roots influence decay rates. It is therefore important to define both the magnitude of these effects and the circumstances under which they operate. It has become clear that many important crop plants such as cassava are completely dependent on their mycorrhizal association for adequate supplies of phosphorus when no phosphorus fertilizer is applied.

2.3 MODIFICATION OF SOIL PHYSICO-CHEMICAL PROPERTIES

The influence of the physico-chemical properties of soil on biological processes has already been referred to. This section considers the major effects of organisms on the physico-chemical properties of soil.

2.3.1. Surface properties and structure of soil

Fine textured soils have a tendency to develop soil caps or crusts, which reduce water infiltration. Plant litter prevents the development of soil caps and the accumulation or maintenance of a litter cover is of major significance in semi-arid regions (26). Infiltration is also promoted by the activities of soil fauna. A negative biotic effect is the development of microfloral crusts which become hydrophobic when dry (eg *Scytonema* sp.). The combination of clay and microfloral caps can cause a tenfold reduction in water infiltration on fine-textured soils in the sub-humid tropics.

Soil organic matter, particularly the short-lived fraction, increases soil particle aggregation, for example by the presence of binding molecules of mucopolysaccharides, which in turn increase porosity. Porosity is also increased by the activities of soil fauna (especially earthworms and termites (12, 28)) and by the growth and decomposition of plant roots. The effects of fauna and roots lead to macro-pore development, which has various consequences such as increased water absorption, and therefore reduced run-off and erosion; reduced water-logging; changes in the distribution of water in the soil profile, thus altering the competitive balance between plants with different rooting depths.

2.3.2 Soil water and chemistry

Water is essential for soil organisms, for plant growth, and as a medium for nutrient transport. In the humid tropics it is largely the movement of nutrients which is of concern, apart from soils where water-logging is a problem. In the drier tropics available soil water is generally the major determinant of ecosystem structure and function. For any particular rainfall pattern the soil water regime is determined by the infiltration rate, the water holding capacity of the soil, soil water conductance, and soil depth.

The indirect effects of soil biota on water dynamics operate mainly through the increase in water holding capacity associated with soil organic matter accumulation. This is of particular importance in sandy soils in the sub-humid tropics. The main direct biotic effect on the water dynamics is the uptake of water by plant roots. The greater the uptake the less the risk of leaching, or in soils with impeded drainage the less the likelihood of water-logging. Although most natural ecosystems show very little loss of nutrients through leaching, disturbance of the plant cover can lead to increased losses, particularly of nitrate, because this ion is not retained by the ion exchange complex in most soils (5). In agroecosystems the plant cover may be intermittent leading to increased risk of this type of loss.

Over much of the sub-humid tropics there is a hydrologically induced soil catena with high clay and nutrients in the lower (illuvial) horizons. Where there is a source of sodium (eg in granites containing albite) there is a tendency for these potentially very fertile illuvial soils to become saline. The tendency is enhanced by reduced evapotranspiration in the eluvial zone.

Uptake of water by roots in non-saturated soil is determined by the amount and distribution of roots and their ability to absorb water against the retention characteristics of the soil. Mycorrhizal hyphae extend root contact with soil and may increase water uptake. In very dry soil roots may exude water into the soil, which facilitates nutrient uptake.

In coarse-textured soils, or those in which the clays have a low cation exchange capacity, nutrient retention and availability to plants is strongly dependent on the maintenance of organic colloids. Conditions which favour the formation of soil organic matter, particularly the stable fractions, are thus an advantage. Seasonal hydrogen ion equilibria are also affected by both decomposition processes and plant nutrient uptake mechanisms.

Many biological processes affect the ionic balance of soil in the same way. This may result, under different circumstances, in changes in nutrient availability, including the creation of limiting conditions or the accumulation of toxic levels, for specific ions.

2.4 BIOLOGICAL PROCESSES IN RELATION TO MANAGEMENT

A number of key biological processes affecting soil fertility have been identified in the preceding paragraphs. Each of these processes is affected in some way by agricultural management practices whether of the low- or high-input variety (extensive/intensive; traditional/introduced, etc (32)). Some practices promote the biological contribution to soil fertility, others suppress or disrupt it. A selection of these processes with examples of the effects of agricultural management is given in Table 2.

Although there is considerable information on crop yields, there is a particular lack of empirical data which provide a basis for comparing different management options with respect to variations in

TABLE 2. The major soil biological processes with examples of management practices by which the process can be manipulated

Soil biological process -- management practice

1 Root turnover -- fertilizers increase root production
2 Root exudation -- crop species differ in the nature and amount of exudates
3 N_2-fixation -- legume fallows
4 Nutrient translocation -- tree fallows induce upward movement of nutrients
5 Litter decomposition (comminution) -- insecticides reduce detritivore populations
6 Litter decomposition (enzymatic catabolism) -- tillage increases biological oxidation
7 Humification -- incorporation of low quality residues promotes synthesis of organic colloids
8 Nutrient immobilization -- incorporation of low quality crop residues
9 Grazing by soil fauna -- insecticide treatments decrease faunal mobilization and increase microbial immobilization
10 Soil organic matter decomposition -- lime application increases rate of SOM decomposition
11 Mineralization and mobilization -- burning increases mobilization
12 Solubilization -- addition of S increases solubilization of rock phosphate by *Thiobacillus*
13 Nitrification -- drainage increases nitrification
14 Denitrification -- increased by nitrate fertilization in humid soils
15 Oxidation or reduction of S, F, Mn, etc -- incorporation of nutrient rich residues increases reduction processes
16 Nutrient uptake -- mycorrhizal inoculation increases nutrient uptake
17 Soil particle aggregation -- addition of crop residues (animal and microbial effects)
18 Soil surface capping -- heavy grazing bares the soil surface and increases microfloral capping
19 Soil pore development -- addition of organic residues maintains populations of macrofauna
20 Soil particle movement -- termites reverse clay illuviation; tillage or pesticides destroy termite nests
22 Toxification of soil -- reduced by crop rotation

vegetation, climate and soil type. There is therefore a limited appreciation as to how a particular traditional or low-input practice should be optimized, as well as the long term consequences of high intensity agriculture on soil properties.

High fertility soils (alfisols, mollisols and vertisols) which have no major physico-chemical or environmental limitations to continuous cropping, underly only a small proportion of the land available for food production in the humid and sub-humid tropics (Table 1). Most of the human populations in these regions practice shifting cultivation on low fertility, acid soils (oxisols and ultisols) which usually show a rapid decline in crop yields over two to three years and must remain fallow, usually under natural vegetation, for varying periods of time. Continuous cropping can be sustained on these soils under particular agro-economic circumstances (37) but with shortened fallows and traditional practices, shifting cultivation is often a guarantee of poverty and habitat destruction.

In the following section some of the consequences of shifting cultivation on low fertility soils are considered in terms of the processes identified in Table 2. This section emphasizes the integration of biological processes and is not a review of a practice which is widely variable in relation to soil types, vegetation, climate and socio-economic conditions (32). Shifting cultivation is ecologically sound under certain conditions but when these are altered the system may be destabilized, resulting in losses of plant nutrients, and the degradation of soil structure. Other management options involving different combinations of practices with or without fallows of natural or introduced wood species, also influence soil biological processes. The fallow option may not be feasible where there is land shortage. Whilst the effects of natural fallow is rather general, alternative practices may have similar but more specific influence on soil biological processes. For instance, practices such as composting, mulching or green manuring provide some of the same benefits of litter input that are gained from natural fallow (35).

2.5 SOIL BIOLOGICAL PROCESSES AND CULTIVATION

Shifting cultivation (29) involves two main phases, arable and fallow, with different balances between input and loss of carbon and nutrients.

The fallow system is generally <u>agrading</u>: accumulating carbon in plant biomass and soil organic matter until a degree of balance is reached in the mature forest between photosynthesis and community respiration. Potentially limiting nutrients, particularly N and P, are conserved in plant, microbial and animal tissues as well as in the more intractable components of soil organic matter. In base rich soils, cations mobilized by weathering in excess of demand are leached from the system. But in acid soils, where the rooting depth of plants is limited by high concentrations of exchangeable aluminium in the sub-soil, the biological cycling of elements, which sustains massively productive rain forests, is largely confined to the top 30 cm or so of the soil profile. Under these conditions most macronutrients are conserved and the small losses to ground water are balanced by atmospheric inputs. Consequently, recovery of these ecosystems may be extremely slow after the nutrient capital of some elements sequestered over decades, is lost in as many months following cutting.

The arable phase is generally degrading: losses of carbon and nutrients are greater than input as a consequence of the disruption of the relationships between the vegetation and soil subsystems, the development of imbalances between nutrient mineralization and demand and disturbance of the soil biological community through changes in environment to conditions to which most organisms are not adaptable.

The degrading system may plateau at a new lower level of sustained productivity where nutrient removal in crops is balanced by nitrogen fixation, manures and fertilizer appications. Nonetheless, under these circumstances nutrients may be more 'leaky' due to the disruption of regulatory mechanisms under biological control and 50% or more of fertilizer application may be lost through leaching and denitrification.

2.5.1 Cutting and site clearance

After cutting, bush and forest slash is either left to decompose *in situ* or is burned. In both cases the largest trees may be left standing. Alternatively, in more intensive continuous cropping systems vegetation may be clear felled and bulldozed from the site. This is a particularly destructive method of forest clearance, since most of the nutrient capital held in vegetation and even top soil is deposited outside the plot.

In the slash and burn system fire is used both for site clearance and to mobilize plant nutrients from vegetation and litter. Some of the nitrogen capital of the natural system is inevitably lost as smoke during burning. Losses of nitrogen associated with felling, and immediate post-fire leaching, may amount to 1000 kg ha^{-1} yr^{-1} when humid forests are cleared, but in West African savanna ecosystems, containing comparatively low nitrogen standing crops, losses of 12-15 kg N ha^{-1} yr^{-1} appear to be compensated by atmospheric inputs and nitrogen fixation in algal crusts (31). Under higher rainfall regimes, some of the potential benefits of N mineralization may be lost by leaching and denitrification prior to establishment of the root network of the crops. The commonly observed flush of nitrate in soils following clearing, with or without burning, is due to an increased rate of nitrification which may be promoted by one or more of a number of factors, eg microclimatic changes, increased inputs of high quality resources, increased ammonium concentrations in the absence of a root sink, or the removal of nitrifier inhibition, imposed by secondary compounds in tree vegetation (though unequivocal proof of this last phenomenon is still lacking).

The benefits of litter inputs to the soil, in terms of soil organic matter formation and associated soil physico-chemical properties, are also lost by burning. On the other hand, ash reduces exchangeable aluminium to below toxic levels in acid soils so that more extensive rooting systems of crop plants can develop (34).

Substantial nutrient loss may occur even if *in situ* decomposition of the slash is permitted. An important distinction between the natural processes of litter fall and clearance for agriculture is in the resource quality of the organic inputs to the soil. In clearance, the resource quality of leaves and twigs is higher than in natural vegetation where withdrawal of nutrients by the plant precedes litter fall (42). In consequence the decomposition rate of the litter is accelerated which may also lead to the loss of synchrony between nutrient release and plant uptake. This disruption may not however be as great as in burning, under some circumstances although recent evidence in humid forest has shown that decomposition results in greater mobilization of N than burning (25).

Low resource quality inputs to the decomposer system such as large roots and wood can reduce losses by providing a temporary sink for nitrogen and phosphorus. Thus low quality resources can be used to manipulate the microbial immobilization and release of nutrients. Termites may play an important role in decomposition and nutrient mobilization, particularly from wood (28), but this has not been quantified in relation to agricultural practices.

Exposure of the soil surface after vegetation clearance results in more extreme fluctuation in moisture and temperature, with consequences for soil organisms and associated processes in the surface horizons. Biological processes are also affected by soil compaction and increased surface evaporation if heavy machinery is used during forest or bush clearance and their subsequent cropping period.

2.5.2 Cultivation

It is well established that arable practices generally result in a reduction of soil organic matter content, with associated changes in cation exchange capacity, water holding capacity and aggregate stability (34), but there is little understanding of the biological processes involved, or the indirect biological consequences of these changes. Soil organic matter concentrations and distribution in arable soils will alter because of imbalances established between the formation of recalcitrant soil organic matter fractions, as a result of lower amounts and higher quality of inputs, and the enhancement of soil organic matter decomposition by tillage (increased aeration and disruption of aggregates) and the higher thermal regime of the soil. The exposure of surface litter to high intensity solar radiation also accelerates decay rates by initiating biochemical depolymerization of structural carbohydrates as well as by volatilization of simple aromatic molecules or inactivation of other modifiers of decomposition.

In a seasonal environment litter decay and plant growth are initiated by the onset of rain (43) and a major pulse of nutrient release may occur before the rooting system of the crop can respond. The timing of litter inputs to the soil in relation to climate or irrigation, and the manipulation of decay rates to coincide with crop demand, clearly requires an integrated knowledge of soil processes and crop phenology.

In extremely phosphorus-deficient soils, phosphate fertilizer is needed but the rate of application is reduced if crop roots are infected with mycorrhizae at the start of the growth cycle (15). The use of nitrogen fixing plant species for cropping, interplanting or as green manures is widely practised and, in providing organic matter inputs as well as nitrogen, reduces leaching losses even when supplemented with fertilizers. The accumulation of nitrate in soil can, however, inhibit root nodulation and the use of stem nodulated species provides a method of increasing inputs of biologically fixed nitrogen to soils even when the nitrogen content of the soils is high (10).

Pesticides have direct effect on the soil biota and indirectly modify rates of decomposition in a manner analogous to the anti-herbivore defence compounds of natural vegetation. The impacts on non-target organisms and associated processes include reduction of soil fauna, litter comminution and changes in soil physical structure, as well as the poorly quantified effects on soil micro-organisms. For example, there is evidence that persistent pesticides, such as DDT, can have long term effects on soil fertility (30).

The application of fertilizers may contribute to increased rates of soil organic matter decomposition, though this effect has not been clearly distinguished from those associated with tillage practices. Since humus is the main cation exchange site in acid soils, an understanding of this process is critical. Crop plants, particularly fertilized crops, have high resource quality characteristics and generally decompose faster than natural vegetation under comparable conditions. Grain crops differ from fodder or root and tuber crops in the distribution of resource qualities in different parts of the plants. Hence the consequences of harvest for the nutrient balance of the system are different for different crops.

In many traditional agricultural systems hoe-ridging is used to produce an earlier flush of mineral nitrogen for rapidly growing species than occurs using zero tillage or ploughing. However, ploughing may influence the spatial separation of the nutrient sources and sinks, by burying the litter below the rooting zone of the developing seedlings. An active worm population may counteract this effect by surface casting and promoting root proliferation as shown in temperate minimum tillage systems (13).

2.5.3 Fallow

In this phase there is regrowth of woody vegetation through natural succession. The introduction of an agroforestry option is analogous to the effect of trees on soils and soil biological processes (21). Particular processes can be manipulated through selection of tree species.

During the fallow succession there will be an increase in the litter input, particularly woody materials and roots. There is also increased diversity of plant species and phenologies. In consequence, the timing and quality of resource input becomes more variable. This leads to increased formation of soil organic matter (17). It is also interesting to speculate that the composition and properties of soil organic matter formed under natural vegetation are modified by the diverse resource quality and different physico-chemical and biotic characteristics.

During succession the depleted nutrient capital of the upper soil horizons is replenished through cycling of nutrients from deeper horizons, particularly calcium in acid soils. Surface replenishment occurs through surface litter inputs from deep rooted vegetation, nitrogen fixation by early successional herbs or wood species, and by increased ability to capture atmospheric sources of nitrogen, phosphorus and sulphur or other potentially limiting elements. The diversity of resources leads to a wide range of decomposition rates which spread nutrient release over a longer period of time than during cultivation. Uptake is stabilized by the development of a more or less continuous root mat of plant species with different requirements, mycorrhizal relationships and phenological characteristics (23). The overall consequences of all these features is an increased integration of the vegetation and soil subsystems leading to improved conservation of elements. The most critically limiting factor is the time taken for the recovery phase under natural fallow. Managed fallows can dramatically reduce the length of cultivation cycle and provide an intermediate practice between shifting agriculture and continuous cultivation. For instance, fallow under kudzu (Pueria phaseoloides), a nitrogen fixing creeper, for 1-2 years has the same restorative effect as 25 years of forest fallow (37). Similarly Chromolaena odorata, a composite shrub, has enabled shifting cultivators in the Philippines to shorten their fallow period from 7-15 years to only 3 years (33). But in many areas of the tropics the provision of fuel is only second in human needs to food and water (11) and attention is focussed on the potential of agroforestry techniques for optimizing multiple land use and the conservation of soils and soil fertility. (22).

It should also be remembered that the range of possible management practices is very different in the semi-arid regions of the tropics to that in the humid zone (44).

The end of the cultivation phase in low fertility soils generally results from a decline in crop yields as soil nutrient pools are depleted. One of the consequences of the rapid organic matter decomposition after forest clearance is that the production of hydrogen ions acidifies the soil and increases exchangeable aluminium to toxic levels, thus reversing the liming effects of the ash. On more fertile soils, however, a number of studies have shown that the regrowth vegetation has high nitrate-reductase activity suggesting that the abandonment of the plot was not due to the depletion of soil nitrogen (41). The build up of pests, diseases or weeds during cultivation are factors unassociated with soil fertility which may lead to decline in acceptable crop harvest. Crop losses due to weeds, insects and pathogens can be alleviated by crop rotation, selection of tolerant cultivars as well as the judicious use of insecticides and herbicides but pest control needs are likely to increase in the future. In many regions with acid, infertile soils plant protection becomes a major problem once soil fertility constraints are attenuated (35).

2.6 SUMMARY

The General Hypothesis described here identifies three major components of soil fertility: the plant requirement; the physico-chemical properties of soil; and the soil biological processes (Figure 2).

The basic physico-chemical characteristics of the soil are determined by soil genetic factors operating over a long time scale but are subject to short term modification by biological processes, particularly the formation and decomposition of soil organic matter.

In undisturbed natural ecosystems the biological processes regulate a variety of essential nutrient fluxes in such a way as to stabilize the nutrient cycling and maximize its efficiency (Figure 1).

Many agricultural practices, particularly those involving tillage and fertilizer application, tend to disrupt or bypass these regulatory biological processes. It is nonetheless apparent that it may be possible, with only minor modifications in practice, to utilize biological processes more effectively as a means of improving soil fertility in the tropics.

3 RESEARCH PROPOSAL

3.1 OBJECTIVES

The General Hypothesis identifies a variety of biological processes which, acting in an integrated manner, contribute to the fertility of the soil. The functioning of some of these processes is well documented but others, perhaps the majority, are poorly understood. The link between a management practice and a desired effect may be well established at an empirical level, but there is very little evidence or understanding of the linking mechanism which is usually one, or a set of, soil biological processes. Our ability to predict the biological consequences of management practices is therefore limited. In addition, the lack of standard experimental design and method precludes a general synthesis of results, let alone the possibility of accounting for variation in site-specific properties (eg differences in soil type, climate and management practices).

It is therefore proposed that a programme of collaborative research be mounted within the tropical zone to investigate what are perceived to be some of the major deficiencies in our current knowledge and understanding. The objective of this programme is:

> '<u>to determine the management options for improving tropical soil fertility through biological processes</u>.'

Where possible this will be explored by reference to natural ecosystems.

Two major themes have been identified within this programme:

<u>Synchrony (SYNCH)</u> - to describe the mechanisms determining the transfer of nutrients from decomposing organic matter to plant roots. The programme focusses on the potential to vary the timing and distribution of input of organic residues, recognizing that this controls the rate and time of release of nutrients and their availability to plants. It also recognizes that the quality of the resource influences when nutrients are released, and that soil fauna also affect the rate, the timing and the location of mineralization within the soil. While climatic factors, particularly rain, primarily determine the pattern of plant growth with time, there is nevertheless opportunity to influence the timing of crop growth so that it is more closely synchronized with the release of nutrients. Such manipulation will have the purpose not only of improved crop growth in the short-term, but also the sustaining of long-term fertility by maximum nutrient retention and maintenance of soil structure.

Soil organic matter (SOM) - to determine the relationship between the organic and inorganic inputs to soil and the quality and quantity of soil organic matter formed. The programme also aims to determine the significance to soil fertility of the quantity and quality of soil organic matter. These aims recognize that soil organic matter is an essential component of the capacity of the soil to retain and supply nutrients as well as in the maintenance of soil structure. It is also an objective to develop understanding of how to control the formation of the different fractions of soil organic matter each of which may have different functional roles in soil fertility.

Although these two themes provide the core of the proposed programme of research on tropical soil biology, a number of other research priorities have been identified within the programme which will both test and supplement the interpretation of the General Hypothesis.

3.2 APPROACH

The research programmes investigating SYNCH and SOM will contain a variety of component projects which have different requirements in terms of equipment, service facilities, land availability and personnel. It is therefore proposed that the studies be conducted at differing levels of resolution.

First, a 'minimum package' of investigations is suggested, embracing central features of both themes. It is hoped that these will be carried out at a large number of Project Sites throughout the major continents of the tropical zone. Although at many of these sites it might be possible to do more than just the minimum package, this package would constitute the sole requirement for definition of such a site. These projects could therefore be the responsibility of individual scientists with only limited facilities or, where larger projects are envisaged, be conducted by teams of scientists operating within an institutional framework.

Second, it is envisaged that more comprehensive programmes of research, embracing comparative studies of a wide variety of management practices, may be carried out at a small number of institutions with the appropriate facilities. These Programme Centres would, in addition to their own programme, assist in the coordination of the network of project sites in their region and also might provide certain scientific services (eg analytical facilities) lacking at the project sites. The interchange of expertise and information between programme centres and project sites is also envisaged.

A third type of participation that is recognized is that of the specialist in a particular discipline. Some of the processes described in the General Hypothesis (eg N-fixation or mycorrhizal infection) require specialized facilities for their study. It is hoped to involve scientists from laboratories or institutions which have such facilities in the programme. These scientists will be involved in advisory and service capacities, as well as in a participatory role. The specialized projects developing beyond the minimum package, would be very dependent on the input from these disciplines.

Within the programme two important design principles have been identified which should be included in all projects. First, wherever possible, comparisons should be made between agricultural systems and the natural systems from which they are derived. Such comparisons will help in the understanding of the soil processes which have been naturally selected in response to the particular environmental conditions in the area. This should help to identify mechanisms and species which may be of benefit in agricultural management. Improved understanding of natural ecosystems will also be of value in their management, regeneration and conservation.

The second design principle is the involvement of extension officers and/or researchers interested in socio-economic aspects of farming and land use, in research teams from the outset of the planning of projects. As one of the ultimate objectives of the programme is to make recommendations for incorporation to local and regional farming systems, the presence of such scientists throughout the project should ensure that recommendations are realistic in relation to current practices within locally perceived constraints.

3.3 METHODS

A brief outline of the range of methods considered applicable to the minimum programme is given here, with indications of possible ways in which the minimum programme can be developed. No attempt is made at this stage to detail the techniques to be employed, but it is a principle of the programme that a standarized set of such methods be used. Details of these will be presented in a handbook which will be distributed during the project planning phase of the programme. At the same time the provision of central services and the availability of specialist personnel and facilities will be identified.

3.3.1 The minimum package

The minimum package can be carried out within a single type of agricultural practice appropriate to the geographical area or within an area of natural (undisturbed) or fallow (secondary) vegetation. Wherever possible a comparison should be made between the agricultural practice and the natural vegetation. The general features of the minimal package are as follows.

Site characteristics: A simple description of the general features of geology, climate, soil topography and vegetation of the area.

Resource input: Measurement of the quantity and quality of litter and/or residue input. This provides a baseline for the timing, quantity and quality of entry of resources and nutrients to the soil.

Soil biological processes:

1) Decomposition and mineralization of litter: A range of decomposition experiments carried out with standard methods. Decomposition would be measured on or in the soil depending on local management practice and would be used to distinguish climate and quality controlled nutrient release. Comparison will be enhanced by use of standard materials in addition to the locally important litter(s) and residue(s);

2) Decomposition and mineralization of soil organic matter: Soil organic matter decomposition will be assayed by measurement of CO_2 output using simple field soil respirometers. Inorganic nitrogen release will be determined by repeated field incubation of soil samples. In both measurements, sampling times will be related to climatic and management regimes;

3) Soil organic matter content: Annual and long-term monitoring of the content and distribution of soil organic matter under various regimes of organic amendment;

4) Soil organisms: An investigation of key soil organism groups, particularly fauna, to indicate their influence on the timing and location of nutrient release.

Plant response: A limited study of certain plant growth parameters to assess the amount and timing of plant response to the availability of nutrients.

Environment:

1) Physico-chemical soil properties: Simple physical and chemical measurements which characterize the soil environment in which the biological processes take place and which may be altered by the biological processes and influence soil fertility;

2) Climate: Simple macroclimate and microclimate measurements made during the course of the experiments.

3.3.2 Development of the minimum package

The minimum package can be developed by introducing one or more manipulations associated with any of the package components or with variations in agricultural practice.

Alternatively, the minimum package can be developed by increasing the range and/or complexity of measurements. Such developments within the SYNCH theme would include: analysis of spatial and temporal patterns of nutrient availability (eg lysimetry); features of plant root growth and nutrient uptake including mycorrhizal infection, phenology and turnover; analysis of various processes within the nitrogen cycle; and the influence of specific faunal groups. Development of the programme on soil organic matter would include characterization of the different fractions of soil organic matter and their formation from litter of different quality; nutrient immobilization and release by different fractions of soil organic matter.

3.4 LOCATION

To provide comparisons within and between the range of managed and natural systems characteristic of a particular area, the project sites and programme centres would be encouraged to establish new, or maintain existing, sets of experimental plots. Programme centres would be sited ideally in at least three separate geographical regions within each of the zones defined in the General Hypothesis, ie the humid tropics, the sub-humid tropics and the semi-arid tropics. The programme centres would act as co-ordinating centres for a network of sites in their region.

Within the humid and sub-humid tropics the main systems, one or more of which will provide the focus for research, are:

1) an undisturbed forest or savanna woodland;
2) shifting cultivation, including both crop and fallow periods;
3) a low input cropping system (with managed fallows), including traditional methods where applicable;
4) a high input crop rotation;
5) a pasture system.

Any of the above managed systems may include trees as an agroforestry option.

Within the semi-arid areas there are two main agricultural systems each of which may also incorporate agroforestry options:

1) subsistence agriculture, equivalent to low input cropping, with either crop rotation or mixed cropping;

2) livestock production, which includes main variations in the form of i) cattle grazing and browsing in natural vegetation (free ranging or penned at night), ii) grazing on bush-cleared land, and iii) mixed stock farming (cattle, goats, game).

An underlying rationale is that comparative studies at a site will be carried out on soils of the same type and employing the same methods of site preparation. Details of this and other aspects of experimental design will be given in the handbook.

3.5 SUMMARY AND CONCLUSION

The General Hypothesis provided a succinct statement of the current understanding of the role of soil biological processes in soil fertility and their relationships to management practices. Within the research proposal, two broad research themes (SYNCH and SOM) have been identified, derived from the propositions of the General Hypothesis. These two themes provide a basis for the implementation of a broadly described programme of collaborative international research.

Within the study a minimum package of research methods is identified, designed to clarify the potential for manipulation of soil biological processes under a wide range of conditions. The package also allows rigorous comparison of results from a wide range of sites, but it can also be developed to incorporate more sophisticated techniques and more sensitive variations in management. It is envisaged that a single or small range of agricultural practices would be examined at a network of project sites which would be linked to a few programme centres. These centres would undertake comparison of a wide range of management practices and would also act as a focus for provision of services, training and communication. Inclusion of natural (undisturbed) vegetation will provide an important baseline comparison with agricultural management options.

The next stage in the planning of the programme must be to formulate a more explicit set of hypotheses which can be tested through the experimental programme. Full details of the approach and methods will be provided in a handbook. The programme will, however, also generate new hypotheses during its implementation and will additionally provide new ideas and general understanding of the relationships between soil biological processes and soil fertility.

4 IMPLEMENTATION

4.1 SUMMARY

1982-1986	Preparation and Project Initiation	
	- 1985:	Workshop 2
	- 1985/1986:	Regional Meetings
1986-1996	Research, Synthesis and Extension	
	- 1989:	Review
	- 1991:	First Synthesis
		Extension Trials
	- 1996:	Second Synthesis

4.2 PHASE 1: 1982-1983, PREPARATION

This proposal document, prepared through the Lancaster workshop, has been distributed and publicized widely within the scientific community of the tropics. It has also been sent to institutions, organizations and societies associated with agricultural and ecological research in the tropics.

Responses have been requested from scientists, institutions or organizations interested in particpating in, or contributing to the proposed programme.

4.3 PHASE 2: 1984-1985, PLANNING & PROJECT INITIATION

4.3.1 Administration

The second phase of the project will commence with the receipt during 1984 of the responses to the workshop documents. This phase of the project will be administered by a Coordinating Committee which came into operation immediately after the Lancaster workshop and which will receive and reply to the letters of response.

The following have agreed to serve on this committee:

Professor Michael J Swift (Chairman), Zimbabwe
Dr Francesco di Castri, France
Dr Frank B Golley, USA
Dr Pedro A Sanchez, Peru
Dr Thomas Rosswall, Sweden
Dr Jonathan M Anderson, UK

The committee has the following brief:

1) to oversee the preparation and distribution of the workshop document;

2) to liaise with the IUBS 'Decade of the Tropics' and the Unesco 'Man and Biosphere' programmes;

3) to establish and promote contact with other relevant research programmes;

4) to coordinate the evaluation of responses to the workshop documents;

5) to submit applications for funding of the Core Budget to appropriate agencies;

6) to establish a programme secretariat:

7) to be responsible for the planning and preparation of the second programme workshop to be held in 1985;

8) to be responsible for the planning and preparation of the regional meetings to be held in 1985;

9) to be responsible for the appointment of staff;

10) to be responsible for the planning and preparation for the initiation of Phase 3.

A Scientific Advisory Group has also been established to assist the Coordinating Committee during Phase 2 of the project. This committee will consist of about twelve scientists embracing a range of relevant disciplines and geographical locations.

The brief of the Scientific Advisory Group will be as follows:

1) to advise the Coordinating Committee on scientific matters;

2) in collaboration with the Coordinating Committee, to identify potential project sites and programme centres for Phase 3;

3) to act as on-site advisers on behalf of the Coordinating Committee;

4) to be responsible for the preparation of the detailed Handbook of Methods for use in Phase 3 of the project;

5) together with the Coordinating Committee, to prepare the detailed guidelines for the administration of Phase 3 of the programme.

4.3.2 Research sites

As indicated in the research proposal, the programme will be carried out at a series of sites throughout the defined ecological zones of the tropics. The Coordinating Committee will be initially responsible for identifying the sites where projects included in the programme might be established and will report on this to the second workshop. Two different types of sites are envisaged to be termed Programme Centres and Project Sites respectively.

There will be a limited number of Programme Centres as defined in the research proposal document. The centres will be institutions capable of supporting a comprehensive programme of research and with facilities for relatively sophisticated research. At least one centre in each region should be able to provide analytical and other scientific services and database services for project sites in the area. It is intended that research at these centres be initiated early in Phase 3 or even in Phase 2. One responsibility of the centres will be to test the methods recommended in the handbook.

The regional meetings in 1985 will be held at appropriate programme centres and regional assistants may eventually be based at selected centres.

The establishment of a substantial number of project sites is essential to the functioning of the programme, for it is at these that the main replicated research studies will be conducted.

Project sites will be institutions where specific research projects are carried out by individuals or small groups of collaborating scientists. It is hoped that each region will eventually support a network of such sites.

4.3.3 Second workshop

A second workshop will be held on 27-31 May 1985, probably in Paris. This will be attended by the members of the Coordinating Committee, the Scientific Advisory Group and other scientists identifed from the responses to the proposal document. One or more independent 'Assessors' will also be invited.

The objectives of this workshop will be:

1) to evaluate the current status of the programme;

2) to make any adjustment to the broad objectives, proposals and strategies if necessary;

3) to refine the hypotheses for the experimental programme into testable form;

4) to consider and modify the draft Handbook of Standard Methods prepared by the Scientific Advisory Group;

5) to make specific proposals for the initiation of research projects at sites and centres identified by the Coordinating Committee and evaluated by the Scientific Advisory Group.

4.4 PHASE 3: 1986-1996, RESEARCH, SYNTHESIS, EXTENSION

Phase 3 begins immediately after the regional meetings (1985) and constitutes the main research phase, intended to last for approximately ten years. After about three years it is intended to hold either one major meeting or a series of regional meetings at which researchers will report on their progress and the direction and content of the programme will be reviewed. One objective at this stage will be to fill in gaps which have emerged.

4.4.1 Programme output

Individual scientists will be encouraged to publish their results in the normal way. In addition, the information emerging from the programme will be channelled in two directions. One will be a comparative analysis of biological processes in tropical soil systems and will lead to a scientific synthesis, emphasizing principles and possibly leading to recommendations for policy decisions in tropical land use. The other will be a regional interpretation of the information in which socio-economic considerations will play an important part, aimed at agricultural extension workers and the development of improved recommendations for local farming systems.

A first attempt at synthesis will be initiated five years after the start of the research (c. 1991), possibly at an international workshop, although incorporation of farm-trials may be possible for certain projects at an earlier date.

4.5 FUNDING

Funding of the programme will have two components:

1) a core budget which embraces administrative and travel costs for the coordinating and advisory groups, staff salaries, funds for regional meetings and second workshop, and a fund for providing small priming grants to project sites. This core budget will be sought for the 1984-86 period from appropriate international sources;

2) local research funds: individual projects will be funded from locally derived funds. The programme may provide small inputs of priming grants. The programme will also, where appropriate, provide support for applications for funds made by participating groups.

5 SELECTED BIBLIOGRAPHY

1. ALLISON, F.E. 1973. Soil organic matter and its role in crop production. Elsevier, Amsterdam.
2. ANDERSON, J.M. & SWIFT, M.J. 1983. Decomposition in tropical forests. In: Tropical rain forest: ecology and management, S.L. Sutton, T.C. Whitmore and A.C. Chadwick (eds). 287-309. Blackwell Scientific, Oxford.
3. BARNEY, G.O. 1980. The global 2000 report to the President of the U.S. Pergamon Press, New York.
4. BLACK, C.A. 1968. Plant-soil relationships (2nd edition). Wiley, London.
5. BORMANN, F..H. & LIKENS, G.E. 1979. Pattern and process in a forested ecosystem. Springer-Verlag, New York.
6. CLARK, F.E. & ROSSWALL, T. (eds). 1981. Terrestrial nitrogen cycles: Processes, ecosystem strategies and management impacts. Ecological Bulletins (Stockholm) 33.
7. DOBEREINER, J., BURRIS, R.H. & HOLLAENDER, A. (eds). 1978. Limitations and potentials for biological nitrogen fixation in the tropics. Plenum Press, New York.
8. DOMMERGUES, Y.R. 1982. Scarcely explored means of increasing the soil N pool through biological N_2 fixation. 138-149. Proceedings, 12th International Congress of Soil Science, New Delhi.
9. DOMMERGUES, Y.R. & DIEM, H.G. (eds). 1982. Microbiology of tropical soils and plant productivity. Nijhoff/Junk, The Hague.
10. DREYFUS, B. & DOMMERGUES, Y.R. 1980. Non-inhibition de la fixation d'azote atmospherique chez une legumineuse a nodules caulinaires, Sesbania rostrata. C.R. hebdomaire des Seances de L'Academie des Sciences (Paris), 291, 767-770.
11. ECKHOLM, E.P. 1976. Losing ground: environmental stress and world food prospects. Norton, New York
12. EDWARDS, C.A., LOFTY, J.R. 1977. Biology of earthworms (2nd edition). Chapman & Hall, London.
13. EDWARDS, C.A. & LOFTY, J.R. 1980. Effects of earthworm inoculation upon the root growth of direct drilled cereals. Journal of Applied Ecology, 17, 533-543.
14. FAO. 1981. Agriculture: Towards 2000. Food and Agriculture Organisation, Rome.
15. GANRY, F., DIEM, H.G. & DOMMERGUES, Y.R. 1982. Effect of inoculation with Glomus mossae on nitrogen fixation by field-grown soybeans. Plant and Soil, 68, 321-329.
16. GREENLAND, D.J. & LAL, R. 1983. Soil physical conditions and crop production in the tropics. Wiley, Chichester.
17. GREEENLAND, D.J. & NYE, P.H. 1959. Increases in the carbon and nitrogen contents of tropical soils under natural fallows. Journal of Soil Science, 10, 284-299.
18. HALLBERG, R. (ed.). 1983. Environmental biogeochemistry. Ecological Bulletins (Stockholm) 35.
19. Harley, J.L. & Smith, S.E. 1983. Mycorrhizal symbiosis. Academic Press, London.

20. HUNTLEY, B.J. & WALKER, B.H. (eds). 1982. Ecology of tropical savannas. Springer-Verlag, Berlin.
21. ICRAF. 1979. Soils in agroforestry. International Council for Research in Agroforestry, Nairobi.
22. ICRAF. 1983. Agroforestry systems for small-scale farmers. International Council for Research in Agroforestry, Nairobi.
23. JANOS, D. P. 1980 Mycorrhizae influence tropical succession. Biotropica, 12 (Suppl.), 56-64.
24. JANOS, D.P. 1983. Tropical mycorrhizas, nutrient cycles and plant growth. In: Tropical rain forests: ecology and management, S.L. Sutton, T.C. Whitmore and A.C. Chadwick (eds). 327-345. Blackwell Scientific, Oxford.
25. JORDAN, C., CASKEY, W., ESCALANTE, G., HERRERA, R., MONTAGNINI, F., TODD, R. & UHL, C. 1983. Nitrogen dynamics during conversion of Amazonian rain forest to slash and burn agriculture. Oikos, 40, 131-139.
26. KELLY, R.D. & WALKER, B.H. 1976. The effects of different forms of land use on the ecology of a semi-arid region in south-eastern Rhodesia. Journal of Ecology, 64, 553-576.
27. LAVELLE, P. 1933. The soil fauna of tropical savannas. I The community structure, II The earthworms. In: Tropical savannas, F. Bourliere (ed.). 478-484, 485-504. Elsevier, Amsterdam.
28. LEE, K.E. & WOOD, T.G. 1971. Termites and soils. Academic Press, London.
29. NYE, P.H. & GREENLAND, D.J. 1960. The soil under shifting cultivation. Technical Communication 51. Commonwealth Bureau of Soils, Farnham Royal, England.
30. PERFECT, J.T., COOK, A.G., CRITCHLEY, B.R., CRITCHLEY, U., DAVIES, A.L., RUSSELL-SMITH, A., SWIFT, M.J. & YEADON, R. 1979. The effect of DDT contamination on the productivity of a cultivated forest soil in the sub-humid tropics. Journal of Applied Ecology, 16, 705-719.
31. ROSSWALL, T. 1980. Nitrogen cycling in West African ecosystems. SCOPE/UNEP International Nitrogen Unit, Royal Swedish Academy of Sciences, Stockholm.
32. RUTHENBERG, H. 1980. Farming systems in the tropics (3rd edition). Clarendon Press, Oxford.
33. SAJISE, P.E., PALIS, R.K., NORCIO, N.V. & LALES, J.S. 1974. The biology of hagonoy (<u>Chromolaena odorata</u> (L.), R.M. King and H. Robinson.) I patterns of growth, flowering behaviour and nitrate accumulation. Philippine Agriculturist, 57, 364-373.
34. SANCHEZ, P.A. 1976. Properties and management of soils in the tropics. Wiley, New York.
35. SANCHEZ, P.A. & SALINAS, J.G. 1983. Low input technology for managing oxisols and ultisols in tropical America. Advances in Agronomy, 34, 279-405.
36. SANCHEZ, P.A., GICHURU, M.P. & KATZ, L.B. 1982. Organic matter in major soils of the tropical and temperate regions. 99-114. Proceedings, 12th International Congress of Soil Science, New Delhi.
37. SANCHEZ, P.A., BANDY, D.E., VILLACHEA, J.H. & NICHOLAIDES, J.J. 1982. Amazon basin soils: management for continuous crop production. Science, 16, 821-827.

38. SCHNITZER, M. & KHAN., S.U. 1972. Humic substances in the environment. Marcel Dekker, New York.
39. SOLBRIG, O.T. & GOLLEY, F.B. 1983. A decade of the tropics. Biology International, Special Issue 2, 1-15.
40. STARK, N.M. & JORDAN, C.F. 1978. Nutrient retention by the root mat of an Amazonian rain forest. Ecology, 59, 434-437.
41. STEWART, G.R. & OREMBAMJO, T.O. 1983. Studies of nitrate utilization by the dominant species of regrowth vegetation of tropical West Africa: a Nigerian example. In: Nitrogen as an ecological factor, J.A. Lee, S McNeill and I.H. Rorison (eds). 167-188. Blackwell Scientific, Oxford.
42. SWIFT, M.J., HEAL, O.W. & ANDERSON, J.M. 1978. Decomposition in terrestrial ecosystems. Blackwell Scientific, Oxford.
43. SWIFT, M.J., PERFECT, T.J. & RUSSELL-SMITH, A. 1981. Decomposition and mineral nutrient dynamics of plant litter in a regenerating bush-fallow in the sub-humid tropics. Journal of Ecology, 69, 981-995.
44. WALKER, B.H. (ed.). 1979. Management of semi-arid ecosystems. Elsevier, Amsterdam.

APPENDIX

Simplified definition of the major soil groups of the tropics

(The % of the tropics covered by each soil group is shown in parentheses.)

Soil order	Definition
Oxisols (23%)	Highly weathered, deep, reddish, well drained, acid low base status soils with generally excellent soil structure. Loamy or clayey textures; no important increases in clay with depth. Other names: Ferralsols (FAO), Sols ferralitiques fortement desaturees (French).
Ultisols (20%)	Similar to Oxisols except for a clay increase with depth. Similar chemical limitations. Textures range from sandy to clayey. Other names: Acrisols (FAO), Red Yellow Podzolics, Sols ferralitiques.

Note: For practical soil management purposes, Oxisols and Ultisols can be lumped together as acid, low base status soils. They are the stereotype 'tropical soils'.

Alfisols (15%)	Higher base status than Ultisols, but similar otherwise. Includes the more fertile tropical red soils. Dominant soils of West African sub-humid tropics and savannas. Other names: Luvisols (FAO), Sols ferrugineux (French), Red Earths (Australia)
Mollisols (2%)	Black soils derived from calcareous materials. Known as Chernozems and Rendzinas.
Entisols (16%)	Young soils without A-B-C horizon development. Generally high fertility except for sandy soils. Alluvial soils, Deep sands, Regosols.
Inceptisols (14%)	Young soils with A-B-C horizon development. Fertility highly variable. Other names: Brown tropical soils, many paddy soils.
Vertisols (5%)	Dark heavy clay soils that shrink, crack and swell. Other names: Grumusols, Dark cotton soils.
Aridisols (2%)	Desert soils.
Andisols (1%)	Volcanic soils. Known as Andosols, Andepts.
Histosols (1%)	Organic soils >20% organic matter.
Spodosols (1%)	Podzols.

Biology International

is the news magazine of the

INTERNATIONAL UNION of BIOLOGICAL SCIENCES

IUBS

Secretariat

51, boulevard de Montmorency - 75016 Paris (France)
Tél. : 525.00.09 - Telex : c/o ICSU 630 553 F

The International Union of Biological Sciences is a non-governmental, non-profit organization, established in 1919. Its objectives are to promote the study of biological sciences, to initiate, facilitate, and coordinate research and other scientific activities that require international cooperation, to ensure the discussion and dissemination of the results of cooperative research, to promote the organization of international conferences and to assist in the publication of their reports.

The membership of IUBS presently consists of **47 national members**, each country adhering through its Academy of Science, National Research Council, national science associations or similar organizations, and of **66 scientific members**, all of which are international scientific associations, societies or commissions in the various biological disciplines.

NATIONAL ADHERING ORGANIZATIONS

ARGENTINA - Consejo Nacional de Investigaciones Cientificas y Technicas
AUSTRALIA - Australian Academy of Science
AUSTRIA - Osterreichische Akademie der Wissenschaften
BELGIUM - Académie Royale de Belgique
BRAZIL - Conselho Nacional de Pesquisas
BULGARIA - Bulgarian Academy of Sciences
CANADA - National Research Council
CHILE - Sociedad de Biologia de Chile
COSTA RICA - Consejo Nacional de Investigaciones Cientificas y Tecnologicas
CUBA - Academia de Ciencias
CZECHOSLOVAKIA - Czechoslovak Academy of Sciences
DENMARK - Det Kongelige Danske Videnskabernes Selskab
EGYPT - Academy of Scientific Research and Technology
FINLAND - Societas Scientarum Fennica
FRANCE - Académie des Sciences
GERMAN DEMOCRATIC REPUBLIC - Deutsche Akademie der Wissenschaften
GERMANY (FEDERAL REPUBLIC) - Deutsche Forschungsgemeinschaft
GHANA - Ghana Science Association
HUNGARY - Academy of Sciences
INDIA - Indian National Science Academy
IRAQ - Scientific Research Foundation
IRELAND - Royal Irish Academy
ISRAEL - Academy of Sciences and Humanities
ITALY - Consiglio Nazionale delle Ricerche
JAPAN - Science Council of Japan
JORDAN - Yarmouk University, Amman
LEBANON - Conseil National de la Recherche Scientifique
MEXICO - Consejo Nacional de Ciencia y Technologia
MONACO - Centre Scientifique de Monaco
NETHERLANDS - Koninklijke Nederlandse Academie van Wetenschappen
NEW ZEALAND - The Royal Society of New Zealand
NORWAY - Det Norske Videnskaps-Academi
PHILIPPINES - National Research Council of the Philippines
POLAND - Academy of Sciences
ROMANIA - Academy of the Socialist Republic of Romania
SAUDI ARABIA - Saudi Biological Society
SOUTH AFRICA - Council for Scientific and Industrial Research
SPAIN - Consejo Superior de Investigaciones Cientificas
SUDAN - National Council for Research
SWEDEN - Kunglige Vetenskapsakademien
SWITZERLAND - Société Helvétique des Sciences Naturelles
TAIWAN - Academy of Sciences
THAILAND - National Research Council
UNITED KINGDOM - The Royal Society
U.S.A. - National Research Council
U.S.S.R. - Academy of Sciences
YUGOSLAVIA - Union of Biological Sciences