

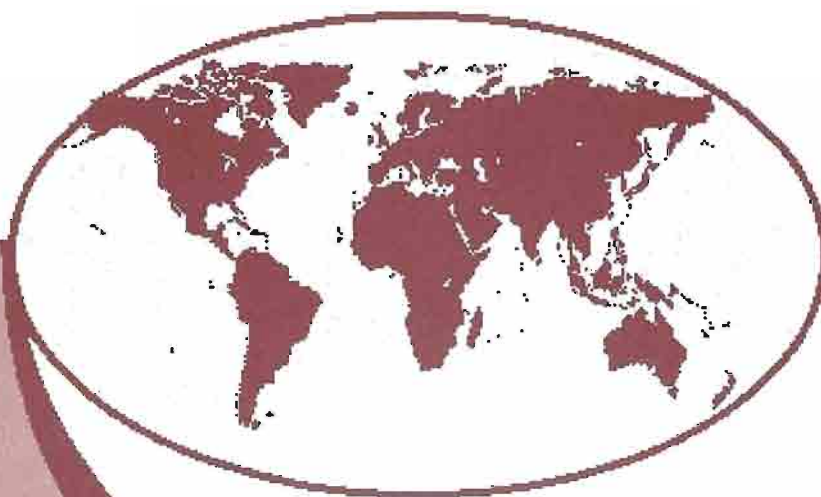
IUBS

UNESCO

SOIL FERTILITY AND GLOBAL CHANGE

The Role of TSBF Studies in the IGBP

Edited by M. J. Swift



**Biology
International**

Special Issue N° 25

SOIL FERTILITY AND GLOBAL CHANGE

The Role of TSBF Studies in the IGBP

Edited by M. J. Swift

Special Issue N°25
BIOLOGY INTERNATIONAL
THE INTERNATIONAL UNION OF BIOLOGICAL SCIENCES
NEWS MAGAZINE

TABLE OF CONTENTS

PREFACE	ii
SUMMARY	iii
1 INTRODUCTION	1
1.1 The IGBP	1
1.2 The TSBF Programme	1
1.3 Scope of the Report	2
2 THE IGBP SCIENTIFIC PROGRAMME	4
2.1 Global Atmospheric Change	4
2.2 IGBP Research Priorities	5
2.3 IGBP Research Implementation	6
3 THE TSBF SCIENTIFIC PROGRAMME	7
3.1 Scientific Principles	7
3.2 The TSBF Programme Sites	10
4 TSBF AND IGBP	14
4.1 Process and Population Studies	15
4.2 Ecosystem Studies	17
4.3 Ameliorative Actions	19
4.4 Monitoring of environmental change	20
4.5 Regional Research Centres (RRC)	21
5 RECOMMENDATIONS	22
6 REFERENCES	23

PREFACE

This report was prepared in fulfilment of a contract between UNESCO and the Tropical Soil Biology and Fertility Programme (TSBF) of IUBS. The objective of the report is to assess the possible significance of the studies being carried out by the TSBF programme to the development of a research agenda for studying Global Climate Change.

International Council of Scientific Unions (ICSU) has given responsibility for development of that agenda to the Special Committee for the International Geosphere-Biosphere Programme (IGBP). The particular target of this report is to propose ways in which TSBF and IGBP can collaborate in research on the interaction between soil and atmosphere.

The report was edited by Mike Swift from contributions made by Jo Anderson, Sandra Brown, Bill Heal, Hans Scharpenseel, and Bob Scholes.

Graphics and page lay out were designed by TSBF Headquarters staff, Nairobi.

SUMMARY

Soil is the largest terrestrial pool of carbon, nitrogen and sulphur, and is intimately involved in the main fluxes of these important greenhouse elements between land and atmosphere. Soil is also a fundamental resource on which human populations are dependent for food, fuel and fibre. Land use shifts and their sustainability are an important part of Global Change, and it is through the response of the plant-soil system that climate change will have its main impact on humankind. Furthermore, it is in the tropics that the demands of developing human populations are most tightly linked to climate- and soil-determined limits. Paradoxically, it is in this zone and on these topics that our capacity to respond scientifically is weakest.

2. The Tropical Soil Biology and Fertility Programme (TSBF) was initiated in 1984 by the International Union of Biological Sciences and the UNESCO *Man and the Biosphere Programme* in order to stimulate research in the tropics, and in particular on the poorly-understood topic of the role of biological processes in the maintenance of soil fertility. The TSBF strategy includes focus on the paths of carbon, nitrogen and water through the soil-plant-atmosphere system, and the key factors which regulate them. These concepts are being developed by a network of researchers at sites spread throughout the humid, sub-humid and semi-arid tropics.
3. The International Geosphere-Biosphere Programme (IGBP) aims to describe and understand the interactive physical, chemical and biological processes that regulate the total Earth system, the changes that are occurring in this system, and the manner in which they are influenced by human activities. Process-orientated research, modelling and the monitoring and documentation of environmental change are the central elements of the proposed programme. The IGBP planning process has highlighted the fragmented and geographically uneven distribution of the ecological research community; the inadequacy of the databases for predictive purposes; the limited understanding of soil processes in element fluxes; and the lack of coordination in this type of study. The TSBF programme is able to offer its experience, data, site network, models and conceptual framework towards the solution of these problems.
4. The key elements of the TSBF programme of direct relevance to the IGBP are:
 - a) The TSBF programme includes detailed study of the pool sizes, fluxes and controlling factors of carbon and nitrogen in tropical ecosystems. The main "greenhouse" gases (CO_2 , CH_4 and NO_x) are all generated and consumed as part of the transformations of these elements in the soil-plant system. Sulphur has not been considered by TSBF, but would be relatively easy to include since it is controlled by similar processes. Soil contains the largest terrestrial biospheric carbon pool, and is susceptible to major changes

through management and climate shifts at the timescale of decades to centuries. It therefore has substantial potential to act as either a source or a sink of atmospheric carbon.

- b) The controlling effect of climate on soil biological processes has been explicitly considered by TSBF. In conjunction with a process-orientated and model-based research philosophy, this forms a basis for the prediction of the consequences of climate change on carbon and nitrogen compound fluxes to and from both natural and derived tropical terrestrial ecosystems. The influence of feedback effects controlled by soil biological processes, and lags induced by the range of turnover times in soil carbon pools, will be especially critical in assessing the nett consequences of climate change.
- c) The CENTURY terrestrial ecosystem model has been the main tool for conceptual, formalization, data synthesis and extrapolation within the TSBF programme. This model has been identified by the SCOPE terrestrial ecosystem modelling group as a contender for interfacing with Global Climate Models (GCM) in the IGBP. The process of parameterisation of the CENTURY model for the TSBF research sites has contributed to its current structure and validation in tropical ecosystems.
- d) The TSBF Programme is located in the tropics, where scientific knowledge, expertise and data are least available. The programme has an established network of sites which have been characterized in detail, and a core of experienced personnel.
- e) The TSBF programme has designed and implemented a minimum data set for studying terrestrial ecosystem carbon and nitrogen fluxes. Site characterization and calibration has been completed at the ten major Programme Centres. The documentation and testing of a standardized set of methods, parameters and units has been a key activity. These tried-and-tested techniques are disseminated in the form of a methods handbook.
- f) One of the major potential effects of Global Change on human societies is through its impact on agriculture, in particular in those areas of the world where the population is heavily dependent on local food production. TSBF is targeted at the development of sustainable tropical agriculture.
- g) The spectrum of TSBF sites spans the wet and dry tropics, and the transition between them. Some of the sites are located in the marginal lands near the tropical-temperate transition. This is particularly important, since it is near such climatically-determined margins that Global Change has, and will continue to have, its greatest impact.
- h) The TSBF programme has had experience of the problems inherent in the interaction between biophysical and social scientists in collaborative programmes. This experience could help the IGBP efforts in this respect.

5. On the basis of the above the following are recommended:

- a) That the IGBP should initiate a detailed study of the consequences of CO₂ and climate change on soil biological processes, including elemental and water fluxes between soil and atmosphere, utilizing the TSBF concepts and expertise as captured in the CENTURY model.**
- b) The IGBP and TSBF collaborate to develop a programme to examine the effects of global change on the diversity, populations levels, distribution and behaviour patterns of key functional groups of soil organisms with particular reference to effects in marginal distribution zones.**
- c) The IGBP and TSBF work together to develop ecosystem models depicting the synchronization of vegetational and soil processes and examine the effects of differential rates of change in response to global change with respect to vegetational distribution and use potential particularly in marginal or transitional environments.**
- d) The IGBP and TSBF develop a joint study, by means of modelling and field experimentation, of the influences of change in land use and climate change on the long term storage of carbon and other nutrients in soil, and in particular seek means of increasing the sequestration of carbon in soil by suitable ameliorative action.**
- e) The IGBP should assist in incorporating studies of sulphur dynamics and denitrification into the TSBF programme.**
- f) The IGBP should consider the development of selected TSBF intensive study sites as part of their network of Regional Research Centres and Regional Research Sites.**

1.2 The TSBF Programme

TSBF was launched at a workshop held in 1984 (Swift, 1984) under the sponsorship of the International Union of Biological Sciences (IUBS), and with the support of the UNESCO Man and the Biosphere (MAB) Programme. It is one component of the collaborative research programme entitled "The Decade of the Tropics", the objective of which is to **"increase our knowledge and understanding of the biology of the tropics from the point of view of the various biological subdisciplines"** (Solbrig and Golley, 1983).

The major justification for the launching of the Decade programme was the recognition of the critical necessity for improved management of the natural resources of the tropical zone. It was thus recognized, *inter alia*, that intensified study of biologically mediated soil processes would not only be scientifically interesting but could also make a significant practical contribution to agricultural development in the tropical zone. The continuing high rate of population increase in many tropical countries and the coincident pressure on land has led both to food shortages and environmental degradation. One crucial component of the solution to these problems lies in the development of sustainable agriculture and forestry systems which are ecologically viable as well as economically productive. With this in mind the overall objective of TSBF was stated as **"the determination of the management options for improving tropical soil fertility through biological processes"** (Swift, 1984). TSBF aims to meet this objective by research which leads to the development of management practices which promote and sustain fertility by manipulating soil biological processes.

The TSBF strategy includes focus on the paths of carbon, nitrogen and water through the soil-plant-atmosphere system, and the key factors which regulate them. The practical targets are to synchronise plant demand with nutrient and water availability, and to manipulate and conserve soil organic matter pools. The tools with which this can be achieved are the management of the quantity, quality and timing of organic inputs, and the manipulation of soil organisms. A key tactic is the comparison of managed systems with the natural ecosystems from which they were derived. These concepts are being developed by a network of researchers at sites throughout the humid, sub-humid and semi-arid tropics.

The prospect of climatic change adds a further dimension to this research. Plans for the management of tropical soils for sustainable production must include the capacity for response to changing environment. This report addresses the issue of how the research priorities in the TSBF Programme (Swift, 1984, 1987; Ingram & Swift, 1989) can be utilized or adapted to the needs of the IGBP.

1.3 Scope of the Report

The short description above clearly establishes that TSBF is a programme targeted on agroecosystems of the tropical zone. IGBP however is concerned with the global impact of climatic change on both natural and managed ecosystems. These apparent differences in target are not however important. The scientific principles on which TSBF is based are globally applicable; indeed, the bulk of the scientific evidence underpinning them still derives largely from research conducted in ecosystems of the

higher latitudes. A key approach of TSBF has been to apply these principles, modified where necessary, to the study of tropical ecosystems. A second approach has been to utilize the information and insight gained in the study of natural ecosystems in the study of agroecosystems; in short an ecological approach to soil investigation and management.

The contribution that TSBF seeks to make by this report is thus threefold: first to propose, on the basis of the working principles developed within TSBF, certain of the priorities and methodologies for soil fertility research within IGBP; second to provide a particular focus for agroecological work in IGBP; third to provide a means of facilitating work in the tropical zone where there is a risk that the intensity of scientific participation in IGBP may be low.

SOIL FERTILITY AND GLOBAL CHANGE: THE ROLE OF TSBF STUDIES IN THE IGBP

FINAL REPORT

1 INTRODUCTION

1.1 The IGBP

The last three decades have seen a rate of change in the global environment unprecedented in human history. Most of this change has been induced by human activity of both industrial and agricultural origin. The International Geosphere-Biosphere Programme (IGBP) was initiated to investigate these changes and propose possible solutions to the potential impact on the human population and its environment.

The IGBP is an interdisciplinary research endeavour carried out within the framework of the International Council of Scientific Unions (ICSU). Along with the World Climate Research Programme (WCRP) and other international research efforts it addresses critical research questions related to global environmental change. The extent of inter-governmental endorsement of the programme is reflected in the UN General Assembly resolution of 17 December 1989, which "Recommends that Governments, with due consideration of the need for increased scientific knowledge of the sources, causes and impact of climate change and of global, regional and local climates, continue and, wherever possible, increase their activities in support of the World Climate Research Programme and International Geosphere-Biosphere Programme, including the monitoring of atmospheric composition and climate conditions, and further recommends that the international community supports efforts by developing countries to participate in these scientific activities".

The research focus of the IGBP is on the biogeochemical aspects of global change phenomena, on Earth system modelling and the recovery and interpretation of data dealing with global changes of the past; the WCRP addresses the physical aspects of the climate system. The ICSU initiated detailed preparation for the IGBP in late 1986 and appointed a Special Committee to guide the planning and implementation of the programme. Detailed development of the initial research priorities into core projects has been conducted by a number of planning groups that draw upon the expertise of the international scientific community. Many other ICSU bodies are participating in this process.

THE IGBP SCIENTIFIC PROGRAMME

2.1 Global Atmospheric Change

The International Geosphere-Biosphere Programme aims to describe and understand the interactive physical, chemical and biological processes that regulate the total Earth system, the changes that are occurring in this system, and the manner in which they are influenced by human activities. Process-oriented research, modelling and the monitoring and documentation of environmental planning processes has highlighted the fragmented and geographically uneven distribution of the ecological research community; the inadequacy of the databases for predictive purposes; the limited understanding of soil processes in element fluxes; and the lack of coordination in this type of study (IGBP, 1990).

The chemical composition of the atmosphere is to a large degree determined by the uptake and release of a large variety of trace gases by the biosphere. In turn, the Earth's climate and the deposition of chemical compounds containing essential nutrient elements (such as C, N, P and S), are of critical importance for the sustainability of the biosphere. Climate, biospheric conditions and atmospheric chemical composition together thus form a strongly interactive system. The biospheric production of relatively small amounts of trace gases such as CO₂, CH₄, and N₂O are of special interest, as these greenhouse gases trap terrestrial infrared radiation, thus warming the Earth's surface. In addition, CH₄, N₂O and a large variety of other biogenic trace gases, such as CO, NO_x and a range of volatile organic compounds (VOC), play a key role in atmospheric chemistry by affecting tropospheric and stratospheric concentrations of ozone, the penetration of photochemically and biologically active solar ultraviolet radiation to the Earth's surface, and the production of hydroxyl (OH) radicals. These are responsible for the removal of almost all trace gases that are emitted by biological or anthropogenic processes into the atmosphere.

The chemical composition of the atmosphere has for the past few centuries been changing, initially under the influence of agricultural, and more recently by industrial activities. As a consequence, the atmospheric volume mixing ratio of CO₂ has increased from 280 to 350 ppm and for CH₄ from 0.7 to 1.7 ppm over the past two centuries. Currently, the measured annual increases of these gases are equal to 0.4 - 0.5% and 0.7 - 1.1% respectively. In addition, the atmospheric concentrations of several other trace gases are increasing. The most important among these are the industrially produced chlorofluorocarbon gases (CFCl₃ and CF₂Cl₂) and N₂O, with annual atmospheric growth rates of about 4%, 0.2% and 0.3%, respectively. All these gases have long atmospheric residence times, ranging between about 10 years for CH₄ and about 200 years for N₂O. The observed increases in the above mentioned gases have caused great concern for a rapid climate warming by several degrees in the next century.

The rapid rate of land use changes that accompany human population growth is contributing to the perturbation of biosphere-atmosphere interactions. This is particularly significant in the tropical zone. For example, the emissions of hydrocarbons, carbon monoxide and nitrogen oxides by biomass burning during the dry

season result in the photochemical production of large amounts of ozone. Increased rice production also probably contributes significantly to increasing CH₄ concentrations. Enhanced N₂O releases may well result from increased application of N-fertilizers and tropical deforestation activities.

2.2 IGBP Research Priorities

Bearing in mind the nature of the above changes, IGBP has devised a research programme with the objective of describing and understanding the interactive physical, chemical, and biological processes that regulate the total Earth system, the unique environment that it provides for life, the changes that are occurring in this system, and the manner in which they are influenced by human activities.

IGBP is concerned in particular with the changes that are most susceptible to human perturbation. The primary goal of IGBP is thence to develop a predictive understanding of the Earth system, especially in relation to changes that affect the biosphere. To make this goal achievable, emphasis is placed on a time scale of decades to centuries. Thus the IGBP planning project (IGBP, 1990) has focused on seven key questions:

1. How is the chemistry of the global atmosphere regulated and what is the role of biological processes in producing and consuming trace gases?
2. How do ocean biogeochemical processes influence and respond to climate change?
3. How do changes in land use affect the resources of the coastal zone, and how do changes in sea level and climate alter coastal ecosystems?
4. How does vegetation interact with the physical processes of the hydrological cycle?
5. How will global changes affect terrestrial ecosystems?
6. What significant climatic and environmental changes have occurred in the past, and what were their causes?
7. How can our knowledge of components of the Earth system be integrated and synthesized in a numerical framework that provides predictive capability?

The questions will be addressed through activities of observation, process studies and modelling in the context of a limited set of Core Projects. The project of particular significance to TSBF is that entitled Global Change and Terrestrial Ecosystems (GCTE). The project, which is targeted at question 5, has the objective of **"developing the capability to predict the effects of changes in climate, atmospheric CO₂ and land use on terrestrial ecosystems, and how these effects can lead to feedbacks to the physical climate system."**

2.3 IGBP Research Implementation

Collectively, it is the national IGBP programmes that will have the resources required to implement the Core Projects. Thus a close partnership between the national and international planning efforts has been established. To facilitate this, a Scientific Advisory Council for the IGBP has been established. This body consists of representatives from national IGBP committees and ICSU's scientific members with interest in global change research. The council advises on the development of the research programme.

In order to implement IGBP, a network of about ten Regional Research Centres (RRC) and associated networks of research sites for global change studies is being proposed for establishment in developing countries (IGBP, 1991). They will facilitate regional collaboration and research on global change issues, with special emphasis on aspects of processes that manifest distinctly in tropical regions. These centres will assimilate, synthesize, and interpret regional data sets for integration into global-scale synthesis and modelling efforts. They will also extract the relevant regional component from global model output. In this way, these centres will provide information for resource managers and decision makers of particular importance to the region. These centres will also ensure that scientists from less developed countries have an equal opportunity to contribute to the research activities of the IGBP.

THE TSBF SCIENTIFIC PROGRAMME

3.1 Scientific Principles

As stated above, the overall objective of TSBF is to determine the management options for improving tropical soil fertility through the manipulation of biological processes. Research directed at this objective has now been initiated in a number of sites around the tropical zone, with a particular concentration in Africa. Whilst research at any one site is unique in content, all experimental designs are guided by five research themes, those of *Synchrony*, *Soil Organic Matter*, *Soil Fauna*, *Soil Water* and the *Integration of Biological Processes*.

In the earliest discussions the scientists advising TSBF decided that the programme, whilst serving to encourage soil biological research in general, should nonetheless be selective in terms of its own targets. The criteria for the selection of programme components included the potential for management as well as intrinsic scientific interest. For the small-scale farmer such management potential primarily exists in relation to control over what he plants, what inputs he utilizes and the type of tillage he practices. All three of these activities may be utilized to manipulate the biological processes of soil, particularly those concerned with decomposition and nutrient mineralization. For instance the composition, timing and location of organic inputs within the soil may influence the pattern of nutrient availability (Swift & Sanchez, 1984; Sanchez *et al.*, 1989); the type (quality) of the organic input may influence the amount and quality of humus formed in the soil (Young, 1987); the activity of the soil fauna strongly influence the physical structure of the soil (Lavelle, 1984). Manipulation of soil biological activities by means of the type of plant cover, input regulation and tillage were thus seen as having three important targets in terms of soil fertility: improvement of the efficiency of nutrient cycling and fertilizer use; maintenance of optimal levels of soil organic matter; management of soil biota to improve soil physical structure and water regimes.

Other areas of soil biology, such as N-fixation and mycorrhiza, can also be utilized to improve farming system efficiency, but it was agreed that as there are already well-established programmes concerned with these specific aspects of soil biology, TSBF would not attempt to duplicate them but seek instead to work in collaboration with other networks wherever possible.

TSBF research is thus guided by the following five principles:

SYNCHRONY

The release of nutrients from above-ground inputs and roots can be synchronized with plant growth demands.

The availability of nutrient to plants is controlled by a complex set of interactions. A dynamic equilibrium exists between nutrient supply from mineralisation (or addition of inorganic fertilizer and its control by immobilization on organic

materials) and losses through volatilization, nitrification and leaching. Biological processes regulate this balance, and, as they are open to potential manipulation, the interaction with competing process of plant uptake can be optimised. The hypothesis is that the potential for such manipulation will be greatest when there is a diversity of resources available, and when management options are relatively flexible.

SOIL ORGANIC MATTER

Soil Organic Matter (SOM) can be separated into functional pools each of which plays a particular role in nutrient release, cation exchange and soil aggregation.

Soil organic matter plays key roles in crop sustainability, primarily through its interactions with soil chemical and physical properties in relation to nutrient release, cation retention and soil structure. The value of soil organic matter (as distinct from the value of organic inputs described in the *Synchrony* Principle) is well recognized, but little is known about the processes that contribute to its three key roles. This is in sharp contrast with the well understood processes underlying the use of chemical fertilizers. As low-input systems regain importance in the tropics it is essential to better understand the functioning of soil organic matter.

Soil organic matter can differ in both quantity and quality (composition) resulting in differing patterns of nutrient release and availability. The quality of organic inputs may affect both the composition, and long-term and the short-term nutrient release rates from soil organic matter. TSBF proposes to identify the quantitative parameters that define the size of SOM fractions in relation to their functional significance and to determine the response of these pools to climate, soil type and management practice.

SOIL WATER

Availability of soil water to plants can be improved by the management of surface litter and SOM.

All soil biological and chemical activity is dependent on an adequate level of soil water. This includes the processes of decomposition, mineralization, nutrient uptake and plant growth. Many of these processes are inhibited by excessive soil water, and some major avenues of nutrient loss, such as leaching and denitrification, are associated with wet soils. The duration for which water is available within the tolerance range of a particular process therefore has an overall controlling influence on the degree to which it can operate.

The quantity of water penetrating the soil, and the amount subsequently lost through evaporation are both strongly influenced by the nature and amount of litter on the soil surface. The relationship between the soil water content and soil water potential (the soil water retention curve) is influenced by several factors, including the SOM content. This relationship determines the availability of water to plants and soil micro organisms. In conjunction with soil depth it determines the soil water storage capacity and thus the amount of water lost to deep drainage.

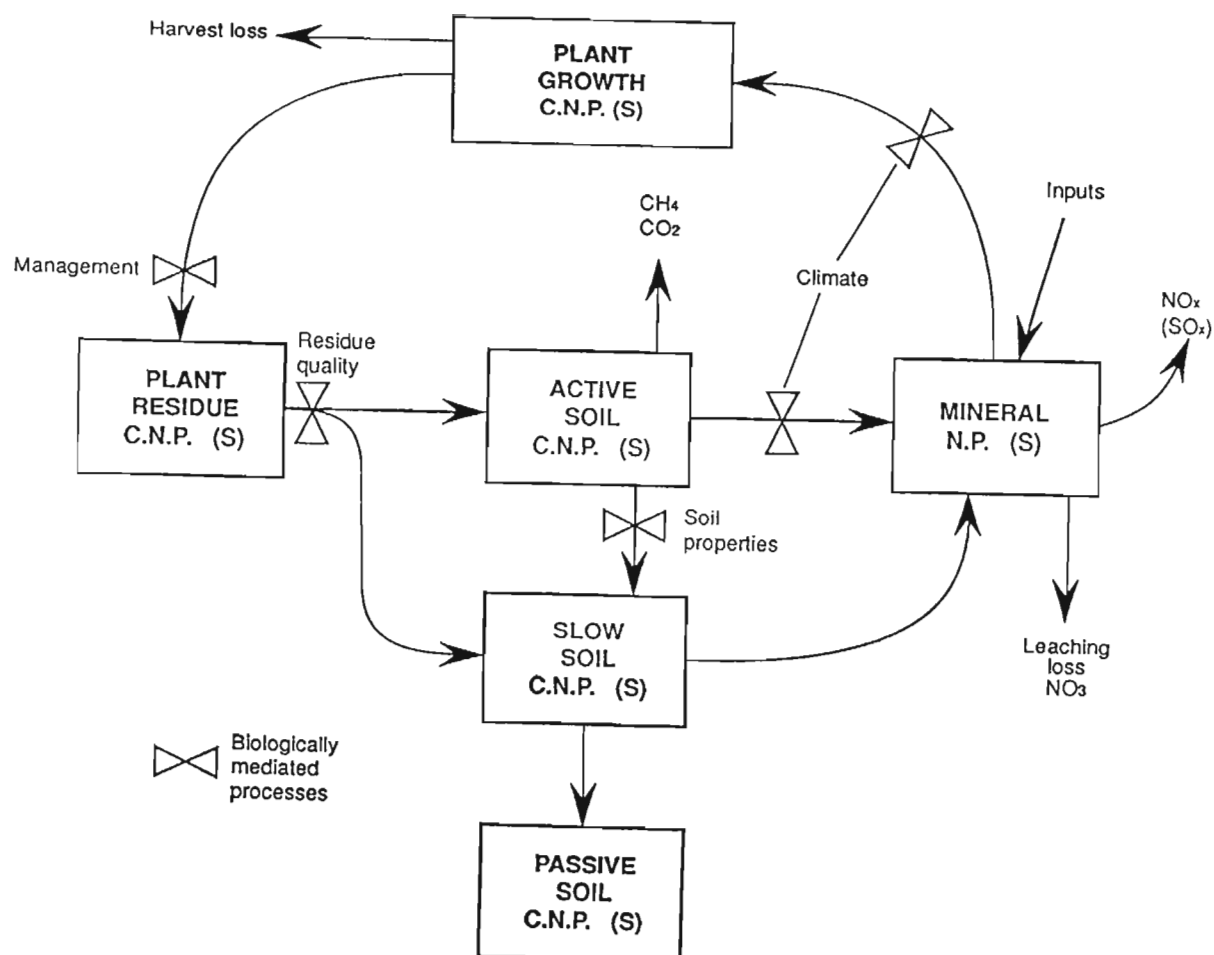


Figure 1 Diagram of the major biologically regulated fluxes of C, N, P and S associated with soil organic matter (SOM). The SOM fractions are those defined in the CENTURY model (Parton *et al.*, 1987).

The potential therefore exists to increase the soil water content, and its availability and duration, by the management of SOM and surface litter (mulches). Mineralization, nutrient uptake and plant growth could thereby be enhanced, provided that the soil does not become excessively wet.

SOIL FAUNA

Soil fauna can be manipulated to improve the physical properties of soil and regulate decomposition processes.

Soil fauna are important as regulators of decomposition, nutrient cycling, soil organic matter formation, and soil structure. Soil fauna can be classified into ecological groups, based on their feeding habits and habitats, and this helps to understand their role in nutrient regulation and SOM formation.

Although there is basic information on the role of soil fauna in soil processes such as nutrient cycling and soil aggregation it is now necessary to quantify the relative importance of soil fauna to such processes. Applied research will emerge from the understanding of the function and dynamics of soil fauna; this could involve the manipulations, such as introduction of soil fauna to biologically poor systems, in order to re-establish the valuable biological processes that maintain soil fertility and structure.

INTEGRATION OF BIOLOGICAL PROCESSES

The biological control of soil fertility is the integration of plant nutrient demand, root distribution, decomposition processes, soil fauna activities and their interaction with soil chemical and physical properties.

The TSBF Principles have evolved from careful study of natural ecosystems. The ability of plant communities to efficiently conserve nutrients and moisture through the effects of canopy, litter and soil organic carbon, soil water and soil fauna cannot however be separated in the context of overall soil fertility. By linking these basic principles, the fifth TSBF Principle, Integration provides a framework for research leading to sustainable soil fertility.

The TSBF Programme has adopted the CENTURY model (Parton *et al.*, 1987; Swift, 1987) to stimulate plant production, nutrient cycling and soil organic matter dynamics for TSBF sites. A central feature of CENTURY is the division of soil organic carbon into functional pools based on the residence time in soils (Figure 1, page 9).

3.2 The TSBF Programme Sites

These five principles give guidelines for experimental research within the TSBF Programme. Experiments conducted by participants have their own detailed objectives and hypotheses dependent on site characteristics, research priorities and institutional

constraints. Examples of specific hypotheses and experimental designs are detailed in the report of the third TSBF Workshop (Swift, 1987). Inter-site comparability is maintained by agreement to use the standard methods as outlined in the TSBF Handbook of Methods (Anderson and Ingram, 1989), and to carry out a standard package of measurements of site characterization (Table I, page 12) designed to define environmental and land management conditions. This permits the sites to be placed in a regional and global context of soil and climatic regimes (Table II, page 13).

The Handbook also defines measurements of key variables which are considered to be informative and sensitive in relation to soil properties and processes as well as plant responses. The definition of methods is designed to enhance comparability of information across the widely distributed sites and incorporation of main variables into the general model (CENTURY). The model is being used to explore the response of different systems to varying environmental and management conditions both within and between sites.

The initial research sites in the TSBF programme comprised ten Programme Centres, where comparative studies have been carried out on the structure and functioning of natural and derived systems (Figure 2, below). These were later supplemented by a network of research sites in Africa concerned with more specific aspects of agroecological soils research. Most recently a "theme" network investigating soil organic matter dynamics has been initiated. Site characteristics for the ten Programme Centres are given in Table II, page 13.

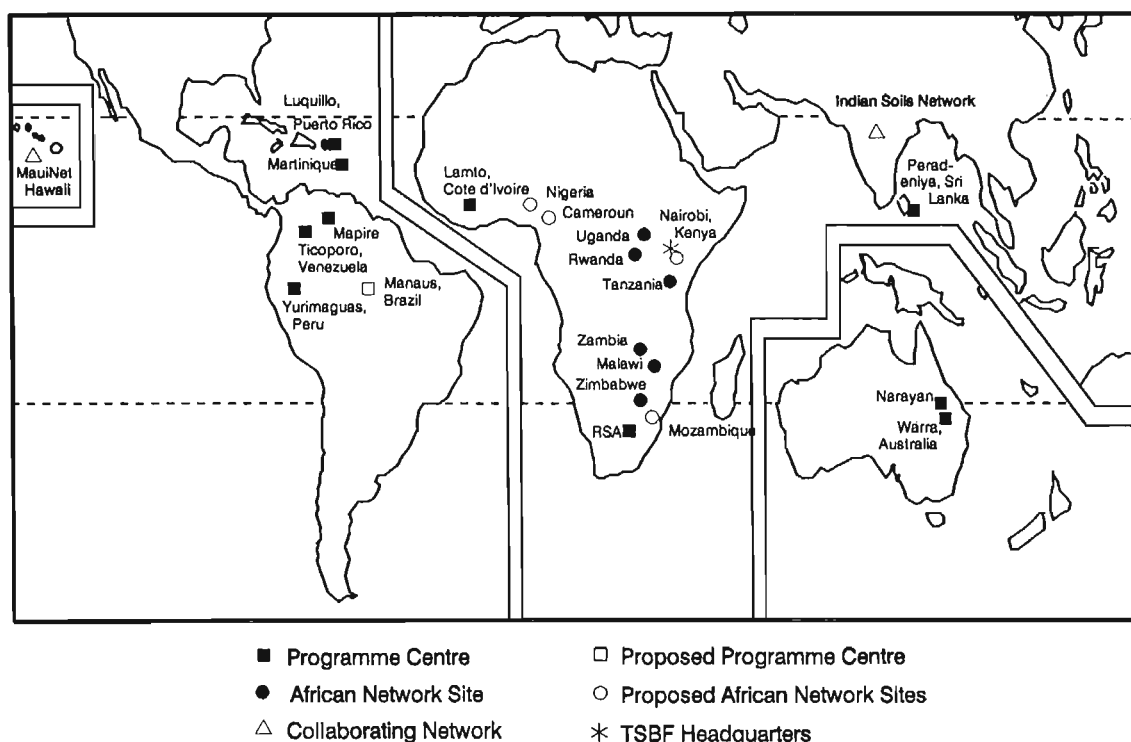


Figure 2 TSBF worldwide activities.

Table I *The TSBF "minimum package" site characterisation data set.*

Site description

Location; altitude; slope; topographical position; aspect; socioeconomic context.

Climate

Monthly means for rainfall; minimum and maximum air temperatures.

Soils

USDA Soil Taxonomy family; profile description; for main horizons to 1.5 m: pH; particle size distribution; bulk density; field capacity and wilting point water contents; organic carbon, light fraction and microbial biomass; total nitrogen and N-mineralisation potential; major extractable cations and acidity; total, organic and resin-extractable phosphorus.

Vegetation

Density, basal area and total biomass by species for woody plants; peak and trough biomass by species for herbaceous plants.

Soil fauna

Density and biomass by major functional groups.

Organic fluxes

Annual tree litter-fall; fine root and grass production; nitrogen, phosphorus and lignin contents for all components.

Decomposition

Half-lives of a decomposition standard and major litter types in standard litter bags.

Fire and herbivory

Frequency; intensity; type.

Table II *Selected environmental data for TSBF Programme Centres comparing natural and managed ecosystems.*

COUNTRY (Site)	elevation ¹	MAR ²	----- soil ----- carbon ³ nitrogen ⁴ pH ⁵
SRI LANKA (Sinharaja/RRI)			
Rainforest	470	503	4.9 0.34 4.6
Rubber	30	200	4.3 0.24 4.9
PUERTO RICO (Luquillo)			
Montane forest	500	381	4.0 0.47 5.4
Pine forest	500	381	3.6 0.42 4.5
PERU (Yurimaguas)			
Rainforest	184	220	2.7 0.12 4.3
Field crop ⁶	184	220	2.8 0.10 4.4
Agroforestry	184	220	2.6 0.11 4.5
VENEZUELA (Ticoporo)			
Montane forest	185	215	6.0 0.34 5.6
Teak	185	215	4.4 0.17 6.2
Pine	185	215	3.3 0.23 5.6
VENEZUELA (Mapire)			
Sediment plain	56	149	3.2 0.33 4.6
Field crop ⁷	56	149	2.2 0.25 4.5
COTE d'IVOIRE (Lamto)			
Guinean savanna	100	121	2.3 0.10 6.5
ZIMBABWE (Marondera)			
Woodland savanna	1640	91	2.8 0.09 6.6
Field crop ⁸	1640	91	1.2 0.05 5.3
AUSTRALIA (Narayen)			
Dryland forest	255	72	7.8 0.65 8.0
Pasture	255	72	5.6 0.45 6.9
AUSTRALIA (Warra)			
Dryland forest	300	63	4.5 0.90 7.1
Pasture	300	63	2.0 0.32 7.6
Field crop ⁹	300	63	1.6 0.25 8.2
RSA (Nylsvley)			
Rich savanna	1100	62	3.8 0.06 6.6
Poor savanna	1100	62	2.5 0.06 4.9

¹ meters above sea level; ² mean annual rainfall (cm yr⁻¹); ³ soil organic C (kg m⁻², 0-20 cm); ⁴ total soil N (kg m⁻², 0-20 cm); ⁵ 1:2.5 in water, 0-20 cm; ⁶ low input culture of rice/rice/cowpea; ⁷ sampled after low-input cotton cultivation in the dry season; ⁸ continuous maize, zero N fertiliser; ⁹ intensive wheat cultivation.

TSBF AND IGBP

Soil is the largest terrestrial pool of carbon, nitrogen and sulphur, and is intimately involved in the main terrestrial fluxes of these important greenhouse elements (Mooney *et al.*, 1987). Soil is also the fundamental resource on which human populations are dependent for food, fuel and fibre. Land use shifts and their sustainability are an important part of global change. These changes include shifts in the patterns of arable pastoral and plantation agriculture and forestry. It is through the response of the plant-soil complex in the production systems that global change will have its greatest impact on humankind. Furthermore it is in the tropics that the demands of developing human populations are most tightly linked to climate and soil-determined limits. Paradoxically, it is in these regions and topics that our capacity to respond scientifically is weakest.

A number of key elements of the TSBF programme are of direct relevance to IGBP:

- a) The TSBF programme includes detailed study of the pool sizes, fluxes and controlling factors of carbon and nitrogen in tropical ecosystems. The main "greenhouse" gases (CO_2 , CH_4 , and NO_x) are all generated and consumed as part of the transformations of these elements in the soil-plant system (Figure 1, page 9). Sulphur has not been considered by TSBF, but would be relatively easy to include since it is controlled by similar processes. Soil contains the largest terrestrial biospheric carbon pool, and is susceptible to major changes through management and climate shifts at the time-scale of decades to centuries. It therefore has substantial potential to act as either a source or a sink of atmospheric carbon.
- b) The controlling effect of climate on soil biological processes has been explicitly considered by TSBF (Swift, 1984; Swift, Heal & Anderson, 1979; Anderson, 1989). In conjunction with the process-oriented and model-based research philosophy, this forms a basis for the prediction of the consequences of climate change on carbon and nitrogen compound fluxes to and from both natural and derived tropical terrestrial ecosystems. The influence of feedback effects controlled by soil biological processes, and lags induced by the range of turnover times in soil carbon pools, will be especially critical in assessing the net consequences of climate change.
- c) The CENTURY terrestrial ecosystem model has been the main tool for conceptual formalization, data synthesis and exploration within the TSBF programme. This model has been identified by the SCOPE terrestrial ecosystem modelling group as a contender for interfacing with GCM's in the IGBP programme. The process of parameterisation of the CENTURY model for the TSBF research sites has contributed to its current structure and validation in tropical ecosystems. The possession of soil and vegetation information, such as maps and computer databases, is not by itself sufficient for the prediction and extrapolation of the consequences of Global Change at a regional scale. When used in conjunction with the understanding of dynamics which is the focus of

TSBF, and linked to models such as CENTURY, however, they provide a rigorous foundation for large-scale prediction.

- d) The TSBF programme is located in the tropics, where scientific knowledge, expertise and data are least available. The programme has an established network of sites which have been characterized in detail, and a core of experienced personnel.
- e) The TSBF programme has designed and implemented a minimum data set for characterizing terrestrial ecosystem carbon and nitrogen fluxes. Site characterization and calibration has been completed at the ten major Programme Centres. The documentation and testing of a standardized set of methods, parameters and units has been a key activity. These tried-and-tested techniques are disseminated in the form of a methods handbook.
- f) One of the major potential effects of Global Change on human societies is through its impact on agriculture. This is particularly true of those areas of the world where the population is heavily dependent on local food production. TSBF is targeted at the development of sustainable tropical agriculture.
- g) The spectrum of TSBF sites spans the humid and semi-arid tropics, and the transition between them. Some of the sites are located in the marginal lands, near the tropical-temperate transition. This is particularly important, since it is near such climatically-determined margins that Global Change has, and will continue to have, its greatest impact.
- h) The TSBF programme has had experience of the problems inherent in interactions between biophysical and social scientists in planning collaborative research programmes. This experience could help the IGBP efforts in this respect.

On the basis of the above it is proposed that there are three main areas of scientific activity on which joint IGBP and TSBF collaborative projects could be built: Population and Process Studies; Ecosystem Studies; and Ameliorative Actions. Furthermore it is proposed that TSBF could contribute in an advisory role to the area of Monitoring Global Change and that the network of TSBF sites could be considered within the context of the Regional Research Centres of IGBP.

4.1 Process and Population Studies

The fauna and flora of soil are influenced, both directly and indirectly, by the environmental factors envisaged as being prominent in global change (the CO₂ content of the atmosphere, ambient temperature, the intensity and pattern of rainfall). In addition soil biological activity may also be affected by other changes such as the concentration of minor gases (methane, nitrous oxides) or in the distribution of materials (e.g. lead, mercury) which are either a component of the climate change scenario or of industrial pollution. All these factors are influenced most strongly of all

by changes in type and intensity of land use. Significant changes in all these factors may influence the activities of the soil organisms, leading to changes in the rates of processes which they mediate. Population levels will also be affected.

At the fringe of vegetational and faunal distribution ranges these effects will be more severe resulting in contraction or expansion of colonized areas. In extreme cases and/or where species are already existing under precarious circumstances, extinctions will occur. Conversely, however, opportunities will arise for species to colonize previously inhospitable regions. The TSBF research network of Programme Centres and Project Sites covers a wide range of tropical environments (Table II, page 13) and includes sites in marginal or transitional climates. It is in these areas that some of the greatest and most significant impacts of global climate change may be felt.

TSBF research has focused on exploring the relationship between soil biological processes and the fertility of the soil as expressed in terms of plant, particularly crop, growth. The rationale for this has lain in the hypothesis that improvement in understanding of the mechanisms regulating biological activity in soil will enhance our capacity to manage soil fertility. In so far as that TSBF is thus engaged in research on soil processes then its studies have clear direct relevance to the concerns of the IGBP. Elucidation of the mechanisms controlling soil fertility will contribute to the development of the functional, process-based, generic models of the carbon and nutrient cycles which form part of the IGBP core project on Global Change and Terrestrial Ecosystems (GCTE). Studies of soil populations are relevant to the potential core project Global Change and Ecological Complexity (GCEC).

This level of interaction could be at the very general level of exchange of information of common interest. A more deliberate collaboration could be developed by a decision to work directly on the effect of the global change factors on soil processes and populations. Examples of processes of particular interest to TSBF and of relevance to global change are as follows:

- a) Changes in the amount, resource quality and timing of litter inputs. These would result from the changed phenological patterns of plants (in response to climate change) and in the carbon:nutrient ratios of plants in response to higher CO₂ levels.
- b) Changes in the rate of decomposition of plant litters and crop residues, and in particular in the patterns of nutrient release. This will be influenced by changes in both environment and resource quality. The length of the "decomposition season" may be of particular importance among the climatic variables.
- c) Changes in the equilibrium quantity and resource quality of the soil organic matter. Both the rate of synthesis and of decomposition of SOM are likely to be influenced directly by climate change. Indirectly these processes will also be influenced by changes in the population structure and chemical composition of the vegetation. SOM composition may also change in relation to these factors.
- d) Changes in populations of key organisms. Soil temperature, moisture (though probably not CO₂) regimes may all influence the population levels, distribution patterns and behaviour of key groups of soil fauna (e.g. earthworms and termites) or microflora (e.g. N-fixing bacteria and mycorrhiza).

Codicil: It should be recognized that intensive process level studies of this type are under way in the advanced laboratories of the temperate zones many of which are better equipped to carry out such investigations. The comparative advantage of TSBF is threefold: the focus on tropical systems; the links between tropical country and temperate country scientists which the programme has developed; and the links between ecologists and agriculturalists that have been nurtured by TSBF.

If a process-level programme is mounted by collaboration between TSBF and IGBP it should have a clearly defined mission targeted at the tropics and at the practical implications of process-level change as outlined in the section below on system-level studies.

4.2 Ecosystem Studies

From its inception IGBP has shown an awareness of the influence of the scale of observation on the conclusion that will be drawn concerning the significance of global change (Rosswall, Woodmansee & Risser, 1988). In discussing the effects on terrestrial biota it is recognized that the vegetational (and faunal) patterns must be matched to a scale commensurate with the functioning of the Global Circulation Models which predict climate change. At present the meeting level is that of a grid cell of about 200 x 200 km. For the ecologist this focuses at the scale of the whole landscape. Appropriate subjects for description and measurement are thus the vegetational units comprising these landscapes, described at the ecosystem level of functioning and in terms of change over periods of a decade to a century.

These scales of measurement are, at first sight, removed from the specific process-focused studies which are the main concern of TSBF (section 3.1). The point of contact lies however in Principle 5 of the TSBF programme, the *Integration of Biological Processes*. In advocating study at this level, TSBF scientists have recognized that whilst soil management may be targeted on specific processes (e.g. manipulation of soil fauna) the outcome, in terms of the effect on soil fertility, is on the overall interaction of all the constituent processes which contribute to fertility. Change in the rate of any process will have positive and negative feedback effects on all, or most of, the other processes. The integrative influence on soil fertility coincides with the lower scale of interest of the IGBP - that of the mechanisms regulating ecosystem function.

Both programmes have also recognized that simulation modelling is the appropriate tool for scaling up of research results. Thus for instance the IGBP-GCTE Project has proposed the development of "an efficient hierarchical structure of inter-linked statistical and mechanistic models, which together predict changes in vegetation structure, dynamics and composition in response to climate change" (IGBP, 1989). TSBF has set itself a very similar task: "[TSBF] research should contain a substantial strategic component. The use of the model described in the [TSBF III] report provides a powerful tool for developing an integrated view of soil biological processes. Development of the model for application to a wide range of tropical environments and farming systems is an important target for the next phase of TSBF research". The development of models for the integrated functioning of the plant-litter-soil system is thus potentially the most significant area for interaction between TSBF and IGBP.

A number of areas of ecosystem-level study which could be of joint interest to TSBF and IGBP include:

- a) The synchrony theme is focused on the feedback between vegetation and decomposition subsystems, relating in time and space the opposing pathways of nutrient demand and uptake and those of nutrient release and availability. At the ecosystem level this presupposes an equilibrium between vegetational and soil biotic processes which optimises homeostasis and tightness in nutrient cycles.

Both plant and decomposition processes are influenced by the spectrum of factors implicated in climate change scenarios. The hypothesized homeostasis of nutrient cycles is a product of co-adaptation to the ecosystem environment. Changes in environmental factors may however have differential effects on the vegetation and decomposition subsystems. At a within-season scale of time the influence may either act in the same direction (promoting synchrony) or in opposite directions (asynchrony). For instance, increased CO₂ will promote the rate of primary production leading to increased nutrient demand. The effect of the CO₂ in widening the carbon to nutrient ratio of litter may however result in slowed litter decomposition rates and an increased proportion of nutrient immobilized in the microbial biomass and SOM. The potential interactive effects, even with one example such as this, are complex. The overall effect however is the possibility of uncoupling nutrient cycles with consequent risk of increased losses of nutrients from hitherto tight systems.

At larger time scales the rate of change, and of adaptation to change, may be different in the vegetation and decomposition subsystems. This would result in a trend of increasing asynchrony and leakiness over time until compensatory mechanism come into play.

This type of scenario, because of its complexity, is best explored by the use of models. Validation of predictions would require long term investigation of ecosystem level vegetation dynamics and patterns of nutrient turnover, immobilization and nutrient loss parameters. Shorter term data might be obtained by transplantation experiments across climatic zones.

- b) The equilibrium level of SOM affects a wide spectrum of soil fertility determinants. Possible differential effects of the direct and indirect influence of changing climatic factors on synthesis and decomposition could result in increases or decreases in the total equilibrium level of SOM. In addition these factors may produce differential effects on the various SOM fractions. Once again soil fertility-global change models (SFGCM) provide the optimum means of exploring future scenarios and their soil fertility consequences for different environments. Validation will require long term studies of soil organic matter change under rigorous condition of estimation over a spectrum of environments. Valuable short term data could be obtained by suitable modifications of the type of experiment which has been proposed for a wide range of TSBF sites. Known as KILLSOM the aims of the experiment are to measure the size of the slow SOM pool in a variety of soils, determine the rate of turnover of the various SOM pools in relation to a variety of soil management practices (such as tillage) and derive site specific SOM-decomposition coefficients for a wide environmental range.

This experiment could provide valuable information on the responses of SOM to potential Global Climatic and Land Use Change.

- c) Climatic change may result in alterations in the absolute and relative abundance of soil fauna groups including potential extinctions and modified distribution ranges. There may also be significant changes in behaviour patterns such as the patterns in time and space of vertical and horizontal movement in litter or soil, and in feeding activities.

The integrative consequences of such changes will be seen in altered rates of litter decomposition and nutrient cycling, modifications of the equilibrium level of SOM and litter standing crop, changes in soil porosity and other physical features and modified levels of below-ground herbivory.

Prediction of these effects would require models that are more organism-based than those currently included in the TSBF programme. Such models would however be relevant to the concerns of the potential GCEC project and joint development could comprise a collaborative activity of considerable attraction. Validation would require long term population and behavioural studies. Information might be gained in the shorter term by transplantation experiments.

- d) Soil water regimes are influenced by a number of factors that are biologically mediated. The moisture available to plants in the context of climate change will be directly affected (by the changing evapotranspirative environment) and indirectly (by the changed character of the soil). The latter will be influenced by such features as modifications in the litter cover, altered organic matter content and changed porosity. The biological processes leading to such modifications need to be modelled with the objective of predicting changes in soil water regime.

4.3 Ameliorative Actions

The soil contains about 15×10^{14} kg of carbon (Buringh, 1984) in comparison with the terrestrial biomass sequestration of about 5×10^{14} kg. Both these stores are major sources of fluxes of carbon to the atmosphere. A major feature promoting this exchange is the conversion of land from forest in the tropical region, which is thought to be proceeding at a rate of about 7 million hectares per year. The burning of biomass taken for fuel and the loss of carbon from the soil store on conversion to agricultural land both contribute to the transfer of C (and N and S) to the atmosphere. The change in the quantity and type of plant cover essentially removes the control mechanism for replenishing the store and regulation of elemental exchange.

The objective of IGBP is not only to study and monitor these changes but also to seek ameliorative action. TSBF has an equal concern which is focused particularly on the development of sustainable methods of soil management for tropical agriculture. Whilst the TSBF target is essentially aimed at specific practices at the cropping system level, consideration should also be given to the scaling up of these effects to the landscape level using the techniques envisaged in the previous section on ecosystem studies.

The study of sustainable agriculture involves management at various scales; those of the cropping system, the farming system and the local, national and regional agricultural system. The latter three scales embrace questions of policy with regard to

land use. It is at these levels that impact may be made on changing the balance of carbon storage and loss. This involves decisions in relation to tree planting and policy concerning soil conservation. These decisions need to be guided however, by scientific advice concerning the optimum choices of species, sites and management practices for maximising elemental storage. This advice in its turn depends on insight into the relationships of plants with soil - the major topic of concern to TSBF.

TSBF and IGBP could therefore collaborate fruitfully both in the area of study of land use implications for elemental storage and exchange, and in that of ameliorative soil management, with the particular objective of seeking means of sequestering carbon in soil. Mechanisms for achieving this have been recently reviewed by Grantham (1989).

4.4 Monitoring of environmental change

Whilst detection of changes in the environment, for example in the response of soil conditions to changing climate, are an important focus of both IGBP and UNESCO-MAB, they are not presently within the objectives of TSBF. TSBF could however play some role in this aspect by:

- a) Advising in the use of site characterization packages. The baseline information incorporated in site characterization is critical to any monitoring programme. TSBF now has considerable experience in such activities. The TSBF characterisation package includes dynamic components (e.g. N mineralisation) as well as static properties (Table I, page 12).
- b) Advising on the selection and measurement of soil parameters which respond to environmental change. Selection criteria should include sensitivity, simplicity and interpretability. Parameters must be capable of consistent standardized measurement across a range of site conditions.
- c) Interpretation of results, in particular to distinguish between the effects of past environment (including past land use) and current change.
- d) Provision of sites, with known management and site conditions in which global environmental monitoring could be established as part of any wider network.

Experience within TSBF and in other programmes has highlighted the importance of very careful consideration of each these four aspects in monitoring. Monitoring, (i.e. detection of change) is a rigorous science which requires good statistical design and analysis as well as the collection of comprehensive data. The normal practice is to overemphasize the latter at the expense of the former which results in an ineffective and sometimes uninterpretable outcome. Monitoring is most effective when it is linked to the testing of prediction. This combination helps in interpretation of mechanisms causing change and also improves predictive compatibility. It is in this area that there is the opportunity for unique collaboration between TSBF and IGBP, particularly because the TSBF strength in soil biological processes and their impact on agricultural ecosystems corresponds with probably the weakest area in the IGBP GCTE programme.

4.5 Regional Research Centres (RRC)

The welcome momentum, stimulated by IGBP, in developing research on the analysis and interpretation of global change has exposed the fragmented and dispersed nature of the ecological and environmental research community, particularly that in terrestrial research. Worldwide or even regional comparative studies are not well developed and IGBP has identified the need to organize such studies. IGBP have thus formulated the concept of Regional Research Centres (IGBP, 1990; 1991), focused on comprehensive and intensive measurements at a global network of sites, such as could be provided by the UNESCO-MAB Biosphere Reserves. The RRC concept envisages a series of centres with coordination, communication and information functions developed at a major institution or university but with research and field site capability. In both approaches an hierarchy of sites or centres would be considered to provide a network giving regional and global coverage.

The RRC concept has a parallel in the TSBF structure of Programme Centres (PCs) and Regional Networks. This is an hierarchical structure in which the PCs are intensive study sites, currently 10 in number distributed throughout the tropics (Figure 2, page 11). At all PCs a standard set of climate, vegetation, soil, fauna and management data are collected which allow cross-site calibration and standardization. The PCs also undertake detailed research with field experiments, to explore the key TSBF themes. Through the CENTURY model holistic analysis of the system dynamics is explored for each site. Of even greater importance however is the between site comparisons that are possible with this approach. The PC sites are, in all cases, well established research centres supported by Universities or other institutions. They have in most cases well developed computer communication systems and associated organization and administration. Some, such as Yurimaguas in Peru, have excellent comprehensive long-term field experiments. Many of these tropical sites have well established links between the national agricultural organization and institutions in the so called developed countries, e.g. North Carolina State University in the case of Yurimaguas. As potential RRCs, the TSBF PCs have many of the relevant required characteristics although they are not always geographically close to major research institutions and international airports. The PC in Zimbabwe has many of the RRC attributes although the intensity of TSBF research there is currently small.

The conclusion from this assessment is that the primary value of TSBF to IGBP is in the provision of a small but coherent set of sites at which Global Change measurements could be incorporated. In any selection of tropical RRCs consultation with TSBF is recommended both because of the potential of its network and the experience of the scientists with tropical research, and also to take into account the availability of soil biological expertise which should be a competent of research at any RRC.

5 *RECOMMENDATIONS*

There is considerable communality between the objectives and research programme of IGBP and TSBF. The potential for further interaction should be directed towards six areas of action:

1. That IGBP should initiate a detailed study of the consequences of CO₂ and climate change on soil biological processes, including elemental and water fluxes between soil and atmosphere, in the tropical region, utilizing the TSBF concepts and expertise as captured in the CENTURY model.
2. IGBP and TSBF collaborate to develop a programme to examine the effects of global change on the diversity, populations levels, distribution and behaviour patterns of key functional groups of soil organisms with particular reference to effects in marginal distribution zone.
3. IGBP and TSBF work together to develop ecosystem models depicting the synchronization of vegetational and soil processes and examine the effects of differential rates of change in response to global change with respect to vegetational distribution and use potential particularly in marginal or transitional environments.
4. IGBP and TSBF develop a joint study, by means of modelling and field experimentation, of the influences of change in land use and climatic change on the long term storage of carbon and other nutrients in soil, and in particular seek means of increasing the sequestration of carbon in soil by suitable ameliorative action.
5. IGBP should assist in incorporating studies of sulphur dynamics and denitrification into the TSBF programme.
6. IGBP should consider the development of selected TSBF intensive study sites as part of their network of Regional Research Centres and Regional Research Sites.

6 REFERENCES

- Anderson, J.M. 1989. The effects of climate change on decomposition processes in grassland, tundra and coniferous forests. In: *Proceedings of the workshop "The effects of climate change on production and decomposition in coniferous forests and grasslands"*, SCOPE, (in press).
- Anderson, J.M. & Ingram, J.S.I. (Eds.) 1989. *Tropical Soil Biology and Fertility: A Handbook of Methods*. C.A.B. International, Wallingford, England.
- Buringh, P. 1984. Organic carbon in soils of the world. In: G.M. Woodwell (Ed.) *The role of terrestrial vegetation in the global carbon cycle: Measurement by remote sensing*. SCOPE 23, John Wiley, Chichester.
- Grantham, R. 1989. Approaches to correcting the global greenhouse drift by managing tropical ecosystems. *Tropical Ecology* 30, 157-174.
- IGBP 1989. *Effects of atmospheric and climate change on terrestrial ecosystems*. IGBP Report, 5, Canberra.
- IGBP 1990. *The International Geosphere - Biosphere Programme: a study of global change. The initial core projects*. IGBP Report, 12, Stockholm.
- IGBP 1991. *Global change system for analysis, research and training (START)*. IGBP Report, 15, Boulder.
- Ingram, J.S.I. & Swift, M.J. (Eds.) 1989. Tropical Soil Biology and Fertility Programme: report of the Fourth International Workshop, Harare. *Biology International Special Issue* 20, 1-64.
- Lavelle, P. 1984. The soil system in the humid tropics *Biology International* 9, 2-17.
- Mooney, H.A., Vitousek, P.M. & Matson, P.A. 1987. Exchange of materials between terrestrial ecosystems and the atmosphere. *Science* 238, 928-932.
- Parton, W.J., Schimel, D.S., Cole, C.V. & Ojima, D.S. 1987. Analysis of factors controlling soil organic matter levels in the Great Plains grasslands. *Soil Science Society of American Journal* 51, 1173-1179.
- Rosswall, T., Woodmansee, R.G. & Risser, P.G. 1988. *Scales and Global Change: Spatial and temporal variability in biospheric and geospheric processes*. SCOPE 35, John Wiley, Chichester.
- Sanchez, P.A., Palm, C.A., Szott, L.T., Cuevas, E. & Lal, R. 1989. Organic input management in tropical agroecosystems In: D.C. Coleman, J.M. Oades & G. Uehara (Eds.). *Dynamics of soil organic matter in tropical ecosystems*. pp. 125-152, Niftal, Hawaii.

- Solbrig, O.T. & Golley, F.B. 1983. A decade of the tropics, *Biology International Special Issue 2*, 1-15.
- Swift, M.J. (Ed.) 1984. Soil biological processes and tropical soil fertility (TSBF): planning for research *Biology International Special Issue 9*, 1-24.
- Swift, M.J. (Ed.) 1987. Tropical Soil Biology and Fertility: Inter-regional research planning workshop, Yurimaguas. *Biology International Special Issue 13*, 1-68.
- Swift, M.J., Heal, O.W. & Anderson, J.M. 1979. *Decomposition in terrestrial ecosystems*. Blackwell Scientific Publications, Oxford.
- Swift, M.J. & Sanchez, P.A. 1984. Biological management of tropical soil fertility for sustained productivity. *Nature & Resources 20*, 1-9.
- Young, A. 1987. *The potential of agroforestry for soil conservation: III. Soil changes under agroforestry (SCUAF): a predictive model*. ICRAF Working Paper 44, 1-190.

Biology International
is the News Magazine of the
INTERNATIONAL UNION
of
BIOLOGICAL SCIENCES

President: J. SALANKI (Hungary)
Vice-Presidents: F. di CASTRI (France)
W.D.L. RIDE (Australia)

Past-President: O.T. SOLBRIG (U.S.A.)
Secretary General: G. NICOLIS (Belgium)
Treasurer: D.F. ROBERTS (U.K.)

Executive Secretary: T. YOUNES

IUBS SECRETARIAT

51, Boulevard de Montmorency, 75016 Paris, France.
Tel: 33 (1) 45.25.00.09 - Telex: c/o ICSU 630 553 F
Telefax: 33 (1) 42.88.94.31

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 the IUBS presently consists of 41 Ordinary Members, adhering through Academies of Science, National Research Councils, national science associations or similar organizations, and of 72 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 Tecnicas
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 Biología de Chile
CHINA- Association for Science and Technology, Beijing
CHINA- Academia Sinica, Taipei
CUBA- Academia de Ciencias
CZECHOSLOVAKIA- Czechoslovak Academy of Sciences
DENMARK- Det Kongelige Dansk Videnskabernes Selskab
EGYPT- Academy of Scientific Research and Technology
FINLAND- Societas Scientiarum Fennica
FRANCE- Académie des Sciences
GERMANY F.R - Deutsche Forschungsgemeinschaft
HUNGARY- Academy of Sciences
INDIA- Indian National Science Academy
IRAQ- Scientific Research Council
IRELAND- Royal Irish Academy
ISRAEL- Academy of Sciences and Humanities
ITALY- Consiglio Nazionale delle Ricerche

JAPAN- Science Council of Japan
JORDAN- Yarmuk University, Irbid, Jordan
MONACO- Centre Scientifique de Monaco
NETHERLANDS- Koninklijke Nederlandse Akademie van Wetenschappen
NEW ZEALAND- The Royal Society of New Zealand
NORWAY- Det Norske Videnskaps Akademi
PHILIPPINES- National Research Council of the Philippines
POLAND- Academy of Sciences
SAUDI ARABIA- King Abdul Aziz City for Science & Technology
SOUTH AFRICA- Council for Scientific & Industrial Research
SPAIN- Consejo Superior de Investigaciones Cientificas
SWEDEN- Kungliga Vetenskapsakademien
SWITZERLAND- Swiss Academy of Sciences
UNITED KINGDOM- The Royal Society
U.S.A.- National Academy of Sciences- National Research Council
U.S.S.R.- Academy of Sciences
VENEZUELA- Consejo Nacional de Investigaciones Cientificas y Tecnicas
YUGOSLAVIA- Union of Biological Sciences