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TROPICAL SOIL BIOLOGY AND FERTILITY (TSBF) PROGRAMME

REPORT OF THE FOURTH TSBF INTERREGIONAL WORKSHOP

Harare, Zimbabwe, May 31-June 8, 1988

Edited by
J.S.I. INGRAM and M.J. SWIFT

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This report was edited from text prepared both at, and subsequent to, TSBF IV. Special Thanks are due to Dr. Cheryl Palm and Dr. Bob Sholes.

"Of composts shall the sacred Muse descend to sing,
Nor soil her heavenly plumes? The sacred Muse
Naught sordid deems, but what is base; naught fair
Unless true Virtue stamp it with her seal.
Then planter, wouldst thou double thy estate
Never, ah, never be ashamed to tread
Thy dung-heaps."

James Grainger, MD
1721 - 1770

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Preface

The aim of this report is to combine the formal proceedings of the fourth TSBF Interregional Workshop with an updated statement of the TSBF Programme.

Several key papers presented at the Workshop are included in full, but the Programme Centre reports are summarised in table format for clarity and consistency. The Executive Summary includes a section derived from the evaluation conducted by Sir Charles Pereira, Dr. Anthony Young and Dr. Marc Latham. The KILLSOM experiment during the latter half of 1988; while the design remains the same, the number of variables to be measured has been decreased.

The section describing the TSBF Scientific Principles includes example experimental hypotheses. It is, however, expected that each research worker or group will in fact formulate their own hypotheses within the basic principles of the Programme. This offers a more flexible framework to that described in the TSBF III report of the 1986 Yurimaguas workshop.

The products of the working groups which reviewed standard methodology and the draft TSBF Methods Handbook are incorporated in the final version of the *Handbook*. This will be published as *TSBF: A Handbook of Methods*, in early 1989 by CAB International, Wallingford, Oxfordshire, U.K.

1.Opening Address

Dr. S.C. Muchena
Under Secretary for Technical Agriculture
Ministry of Lands, Agriculture and Rural Resettlement, Zimbabwe

Mr. Chairman, Professor Chetsanga, Sir Charles Pereira, Distinguished Delegates, Ladies and Gentlemen:

It gives me great pleasure to greet and welcome you to Zimbabwe and to this important workshop. Some of you have had to travel long distances to come to this workshop on the biological management of tropical soils.

As a way of introduction, Mr. Chairman, I would like to remind you that a large number of conferences, workshop, symposia and meetings have been held focusing on the sub-Saharan African food security crisis. Various proposals have been put forward to address the recurrent imbalance between food production and the ever growing population. To quote specific figures, food production increased approximately 1.9% per year between 1961 and 1980 in sub-Saharan Africa. Countering this progress is nearly 3% per year increase in population over the same period resulting in a decline of 1.1% in per capita food production. According to FAO figures, the sub-Saharan Africa scenario continues to deteriorate.

It has become fashionable to pin the blame for Africa's predicament on droughts, migrant pests, lack of appropriate technology, unjust international economic systems, the oppression of women, unwise government policies, the disarray of national economies and the continent's tumultuous politics. The reality is more complicated still. All these factors play a role in a much wider drama in which traditional societies and technologies interact on a stage set by the African environment and the world economic order.

Out of all the strategies that have been put forward to reverse Africa's decline there is one that deserves special mention here, is the one based on environmental or resource based goals. This strategy aims at restoring and preserving natural support systems - forests, grasslands, soils and the hydrological regime - rather than meeting a specified rate of economic return on investment in a particular project.

Mr. Chairman, I believe that this is compatible with the overall aim of the Tropical Soil Biology and Fertility Programme (TSBF) which has been stated thus: "To determine the management options for improving tropical soil fertility through biological processes".

The specific objectives of this workshop are:

to review progress of research at current Programme Centres;
to carry out the first syntheses of site characterisation and Level I studies;
to evaluate the progress of the programmes and to make necessary alterations and additions to the proposals and methods; and
4. to plan the next phase with particular emphasis on the transfer of information and technology from the researcher to the farmer.

The Tropical Soil Biology and Fertility Programme was launched under the sponsorship of the International Union of Biological Sciences and UNESCO at a workshop in 1984. Since then there have been two further planning workshops - in France in 1985, and Peru in 1986, when the research programme was officially initiated at ten centres in eight different tropical countries.

*This approach, the utilisation of the **natural biological** resources of soil for agricultural production is of particular importance for us here in Zimbabwe, and in Africa in general because agriculturalists and ecologists in Africa face two problems, both originating from the high rates of population growth characteristic of the continent:*

1. a need for an increase in food production both absolutely and in terms of yield per unit area; and
2. increased pressure on environment (timber for fuel, etc.) both associated with decreased availability of productive land.

In the past, with lower populations these problems were not as great.

"Traditional" farming systems were often "conservative" and "sustainable"; e.g., in the humid tropics where intensive arable cultivation is possible, replenishment of soil fertility was achieved by shifting cultivation.

In the semi-arid tropics agriculture was largely pastoral with a small arable component receiving a nutrient subsidy for the grazing area, provided via manure, leaf compost, etc.; replenishment was achieved by migration, either seasonally or over even longer cycles in response to drought, etc.

These traditional practices are now not possible because of pressure on land. What form should replacement take?

"Conventional" is intensive agriculture (e.g., Green Revolution) has been very successful under some conditions in some places, but has not met with the general success hoped for. Why have these methods proved unsustainable in Africa?

There are a great many interacting factors but two general statements can be made; one ecological and one economic.

1. Economically, the methods are too expensive in monetary terms as they require expensive inputs much as fertilisers, seeds, irrigation water, pesticides and machinery. In countries with an industrially based economy there is not a problem. In the majority of developing countries however, the inputs have to be imported using scarce foreign currency.

2. Ecologically, they are too expensive in natural resources, e.g., very high yield monoculture brings enormous pressure on capacity of the soil to support sustainable crop production.

TSBF is a programme designed to assist in developing the appropriate technology to combat these problems.

It is not a Farming Systems Research Programme but one which can provide some input to such programmes in the particular area of ***soil management.***

The underlying philosophy is that the most appropriate soil management practices (i.e., those most likely to lead to sustainable production) are those which manage the natural biological resources of soil, as well as, or as an alternative to, management by chemical inputs.

The development of appropriate farming systems for the Tropics depends on the exploration of all possible options for such systems rather than on any single recipe. Research must take into account socio-economic aspects of local requirements for food, fodder and fuel production and economic growth, as well as addressing technical questions. Farming systems should also be adapted to local climatic and edaphic conditions.

Considerable research with these aims is already underway in this country and elsewhere in the Tropics, and much progress has been made in developing appropriate farming systems.

The TSBF approach which is intended to supplement, not replace this research, differs from but complements other research programmes, e.g., CGIAR programmes, IBSRAM or IBSNAT, by recognising the potential for managing ***the biological component of the soil.***

The inherent fertility of natural ecosystems is maintained by biological processes which contribute to soil organic matter reserves, nutrient conservation, moisture retention and a good physical structure. The role and functioning of these biological processes, although discussed in a wide range of publications, are not clearly understood in many important respects.

TSBF aims to improve this understanding and to apply it to the management of soils in the troipcal zone.

The Research Programme

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 selection of programme components include 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:

a) what he plants;
b) what inputs he utilises;
c) the type of tillage he practices.

All three of these activities may be utilised to manipulate the biological processes of soil, particularly those concerned with decomposition and nutrient mineralisation. For instance the composition, timing and location of placement of organic inputs within the soil may influence the pattern of nutrient availability within the soil, the type (quality) of the organic input may influence the amount and quality of humus formed in the soil, the activity of the soil fauna strongly influence the physical structure of the soil. Manipulation of soil biological activities by means of the type of plant cover, input regulation and tillage were thus seen as having three important consequences in terms of soil fertility:

1) improvement of the efficiency of nutrient cycling and fertiliser use;
2) maintenance of optimal levels of soil organic matter;
3) 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 utilised to improve farming systems efficiency, but as we know there are already well-established programmes concerned with these specific aspects of soil biology. I understand the TSBF group have therefore decided not to duplicate these efforts but seek instead to work in collaboration with other networks wherever possible.

The three areas highlighted above are similar in that although the practical importance of the targets has long since been recognised, and forms part of generally desired farming practice, there are significant gaps in our current understanding of the biological, chemical and physical processes that regulate them. We hope very much that the work promoted by TSBF will go a long way towards improving this understanding and converting it into practical management practices that can be readily adopted by our farmers.

In this respect extension is as important as research. TSBF is a programme with a practical target. Although the present state of knowledge and understanding of the functioning of biological processes in tropical soils is such that much fundamental research is required, it is nonetheless essential that the gap between research and practice be kept as small as possible. Thus from the outset of TSBF, it was accepted that there should be close association between the research scientist, the farmers who represent his target population and, where appropriate, the local extension service. This will not only help to ensure rapid implementation of research findings but will also enhance the research itself, the experience of the farmer and extension officer being utilised by the scientists to identify priorities and constraints for research targets. Knowledge of use to the scientist may exist at any scale between the national and and the level of the practicing farmer. National and regional policies for land use and demographic development with the associated financial and logistic incentives, have strong influences on land management, including that of soil. These policies provide a structure for the design of TSBF research, but TSBF findings in their turn should influence such policies, e.g., by indicating which land use options are preferable in terms of soil fertility maintenance.

I understand that there are over sixty people at this workshop, representing research programmes in nearly thirty different countries. Also present are representatives of sponsoring and funding agencies and scientists from associated research networks such as IBSRAM and ICRAF.

I wish you all well in your deliberations and am sure of a productive output. I have thus great pleasure in declaring open this Fourth International TSBF Workshop.

2.The Tropical Soil Biology and Fertility Programme Executive Status Report

2.1. Summary

The overall objective of the TSBF Programme is to determine the management options for improving tropical soil fertility through the manipulation of biological processes. This will be achieved both by implementation of current expertise in soil biological processes within existing farming systems programmes, and by research to gain an improved understanding of these processes. Models of the relationship between soil biological processes and soil fertility can then be refined for predicting responses of tropical plant/soil systems to changing conditions of water, nutrient and organic matter inputs.

There is already extensive research into appropriate farming systems for sustainable food production in the tropics, including agroforestry systems and crop residue managment practices. There is not however, sufficient understanding of the role and functioning of the processes contributing to soil fertility in these systems. TSBF complements this research by carrying out integrated studies of the underlying biological, chemical and physical processes, in two main areas:

- the synchronisation of nutrient release with crop demand by the improved management of fertilisers and organic residues;
- the relationship between plant growth and the nature, and quantity, of soil organic matter derived from different organic residues.

TSBF research falls into two categories:

Target research, which investigates the soil biological aspects of specific management problems. Such research is designed within a socio-economic framework and carried out at TSBF Network Sites.

Strategic research, which is aimed at gaining a better mechanistic understanding of soil biological processes. This type of research is chiefly confined to TSBF Programme Centres, and underpins the target research.

To help ensure comparability of data throughout the Programme, a common methodology for site characterisation and variable measurement has been published.

At the fourth interregional TSBF workshop held in Harare in June 1988, priorities for research over the next two years were established, and the TSBF African Network was launched.

2.2. Programme History

TSBF was initiated in 1984, following a workshop held in Lancaster, U.K. A second Planning Workshop, TSBF II, held in Fontainbleu, France in 1985, was followed by the final planning at TSBF III in 1986, in Yurimaguas, Peru. These three workshops are reported as "Special Issues" N°s. 5, 9 and 13 of *Biology International,* International Union of Biological Sciences, Paris. This planning phase of TSBF was sponsored by IUBS, UNESCO, and the EEC. The first major Review Workshop, TSBF IV, was held at the University of Zimbabwe in May 1988.

TSBF Workshop IV

The Fourth Interregional Workshop of the Tropical Soil Biology and Fertility Programme, TSBF IV, was held at the University of Zimbabwe, Harare, from 31 May to 8 June, 1988. More than 60 participants from 23 countries were present including:

- representatives of current and potential Programme Centres;
- TSBF Steering Committee and Scientific Advisory Group;
- participants in the African TSBF Regional Network Development and Training Workshop, international and local scientists;
- representatives of IBSRAM and ICRAF, and authorities on tropical agricultural acting as evaluators of TSBF;

- representatives of Donor Agencies.

TSBF IV was sponsored by UNEP, UNESCO, the Rockefeller Foundation, IDRC and the Commonwealth Fund for Technical Cooperation. The task of TSBF IV constituted the first major review of the TSBF Programme, two years after initiation of the research programme at ten Programme Centres at the Yurimaguas workshop. The workshop participants thus addressed three main targets:

a) to review the progress of research at the current Programme Centres and on the basis of this experience to make any necessary alterations and additions to the principles, objectives and methods proposed by the Programme;

b) to evaluate the TSBF Programme as a practical contribution to the development of agriculture and natural resource management in the tropical zone; and

c) to establish a management plan for the next phase of the programme which would include consideration of the institutional status of TSBF, its relationship to other programmes and the extent of expansion to which it should aspire.

2.3. TSBF Rationale

Recent years have seen a dramatic increase in the per capita food production in much of the tropics. This improvement is largely based on the introduction of new crop varieties into farming programmes on fertile soils with good supplies of water, fertiliser and pesticide. In large parts of Africa however, and in many other less fertile parts of the tropics, the production trend is the opposite, and per capita production of food has actually been declining for twenty years.

The further spread of high-input farming systems is undoubtedly one answer to this situation, and one which is being pursued vigorously, including the development of new and appropriate technologies. It is apparent however, that the economic cost of such agriculture is often unacceptably high. These farming systems are also commonly of low efficiency in terms of resource use and may be accompanied by rapid environmental degradation. At the same time the more environmentally conservative traditional forms of agriculture practiced in much of the tropics are no longer sustainable because of increased population densities and pressures on land. The last two decades have therefore seen the great interest in the development of farming systems characterised by a relatively inexpensive level of input, a high efficiency of internal use, and hence more sustainable production in both economic and ecological terms.

Sustainable use of the soil resource is a primary goal of all such farming systems and it is towards this target that TSBF is directed. The stated general objective is to determine the management options for improving tropical soil fertility through biological processes. TSBF will differ from, and complement other research programmes in concentrating on research into the biological resources and processes of soil. In so doing, it will draw on expertise from both agricultural and ecological research.

In natural ecosystems productivity is sustained by the tight integration of the vegetative system with the biological system of soil in relation to key processes such as nutrient cycling and the formation and breakdown of soil organic matter. These crucially important biological processes of soil are still 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 fertilisers, pesticides and mechanised preparation of soil.

This success leaves little apparent reason why soil biological processes should be taken seriously. The focus on sustainable low-input agriculture described above does however, provide such a rationale. Furthermore, it is noticeable that the adoption of minimus tillage systems in temperate regions is refocusing 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. 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. It is therefore necessary to retain and develop an interface between natural and agro-ecosystems as a context for integrating and building upon the knowledge of ecologists and agricultural scientists.

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

2.4. TSBF Objectives and Principles

The overall objective of TSBF is to determine the management options for improving tropical soil fertility through the manipulation of biological processes. A programme of research to address this objective was defined in the reports of TSBF II and TSBF III.

The Programme has ten specific objectives within the five themes of Synchrony, Soil Organic Matter, Soil Water, Soil Fauna and the Integration of Biological Processes:

SYNCHRONY

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

1. To synchronise release of nutrients from organic inputs with plant demands for nutrients through the control of soil moisture.
2. To synchronise release of nutrients from organic inputs with plant demands for nutrients by the management of the timing and quality of inputs.

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.

3. To determine the best methods for quantifying the different SOM pools.
4. To determine the relative susceptibility to management of the SOM pools.
5. To manage SOM in relation to:

   (i) nutrient release;
   (ii) cation exchange;
   (iii) soil aggregation.

SOIL WATER

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

6. To gain a predictive understanding of the influence of surface organic inputs and soil organic matter on soil water balance.

SOIL FAUNA

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

7. To quantify the effect of soil fauna in the formation and maintenance of soil structure.

8. To quantify the effect of soil fauna in the regulation of decomposition.

9. To develop techniques for managing soil fauna to improve soil fertility.

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.

10. To develop an integrated approach to the maintenance of soil fertility.

These ten objectives 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 TSBF III, and are further discussed in section 3. Intersite comparability is maintained by agreement to use the standard methods as outlined in the *TSBF Handbook of Methods* (published by CAB International in 1988) and to carry out a standard package of measurements for site characterisation.

2.5. Types of Research

The experimental programme defined by the objectives given above recognises two distinct but interlinked types of research:

Target Research
Research originating from the recognition of a specific soil fertility problem. Experiments of this type would draw on present understanding of soil biological processes with objectives of divising suitable management practices over a short time frame. Examples of this type of research would be experimentation with crop residue management options to improve nutrient use efficiency within the objectives of the SYNCHRONY theme. Research at Network Sites will typically be of this type.

Strategic Research
Experimentation targeted at improving understanding of soil biological processes. Studies of this kind are exemplified by the objectives associated with the SOIL ORGANIC MATTER theme and that concerned with the fifth theme, INTEGRATION OF SOIL BIOLOGICAL PROCESSES. A substantial component of the research at Programme Centres is of this type.

2.6. Progress of Research at Programme Centres

Preliminary research reports for the 10 Programme Centres were presented at TSBF IV, and a synthesis of site characterisation data conducted. Although the research projects were officially instituted in July 1986, most sites had been conducting work in the field for less than 12 months; the minimum for site characterisation. Nonetheless, several Programme Centres had fulfilled much of the original minimum package of site characterisation. Logistic, financial and environmental constraints were experienced by all, and TSBF IV therefore recommended a reduction of the site characterisation workload. Most Programme Centres had established experiments designed at testing specific experimental hypotheses linked to the objectives listed above (formerly Level II experiments). Research directed at SYNCHRONY themes is now extensive, as is that into SOIL ORGANIC MATTER hypotheses. The two years' field work leading up to TSBF IV provided much discussion on methods, and the *TSBF Handbook of Methods* contains many revisions to the draft edition (May 1987).

Programme Centre research should contain a substantial strategic component. The use of the Century Model described in the TSBF III report provides a powerful tool for developing an integrated view of the functioning 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. It is also planned to develop an Expert System for assisting in crop residue management decision making.

Considerable stress has been placed in previous TSBF reports on the use of socio-economic surveys as a means of identifying research objectives. Whilst this approach had been successfully used at one Programme Centre, most others lacked the expertise for implementation of this programme component. TSBF in general will utilise the social survey and extension capacities of the other networks and agencies rather than attempt to build its own parallel socio-economic research programme. The minimum level of involvement would be a "Diagnosis and Design" or Rapid Rural Assessment type survey, with greater emphasis being given to Network Sites.

The TSBF Programme covers a wide range of ecosystems. It was however, recognised that there are gaps within the present range of Programme Centre sites both in terms of the environments and farming systems they cover. For instance, there are too few sites committed to agronomic development in comparision with the good cover of agro-pastoral and plantation systems; the absence of sites on Oxisols was also noted. It was agreed that the TSBF Board should seek to fill these gaps but that the number of new Programme Centres should be restricted to no more than three or four. The established TSBF African Network Sites help to cover a wider range of agronomic systems.

2.7. Initiation of Network Research

The organisational structure proposed for TSBF research in the first and subsequent reports envisaged a series of Regional Networks of research sites. Each network would consist of one or more Programme Centres where strategic research would be at a high priority, plus a range of Project Sites where less extensive TSBF research of a more target-orientated type would be conducted. The Programme Centres would act as coordination centres for the networks.

The evaluation team at TSBF IV counselled strongly against independent expansion of TSBF of this type. Accordingly no further network expansion is envisaged in the near future. It was also agreed that where ever possible, TSBF should utilise research sites established as components of other networks (e.g., IBSRAM) rather than seek to establish fresh sites.

The establishment of a network in Africa has always been recognised as having both the highest priority and also the greatest practicality in view of the TSBF office being located in Nairobi. Accordingly, 17 scientists from ten African countries had been invited to attend a Training and Planning Workshop in advance of TSBF IV in Harare and to then participate in the Interregional Workshop. On the basis of this participation it was agreed to initiate a TSBF African Regional Network during the 1988/89 period. Initial funding for this has been provided by the Rockefeller Foundation. The firm establishment and successful operation of this first TSBF network have been given top priority for TSBF activities in 1989.

The implications of establishment of further networks in India, Austral-Asia and South America require careful consideration. This will be a matter for discussion and decision by the TSBF Board. It was noted however, that a large number of contacts had been made in India, and the potential for a research network of a largely ecological character clearly exists. Two Indian scientists were present at TSBF IV as potential leaders in such a network. Whilst no Programme Centre exists in India, Professor P.S. Ramakrishnan, Director of the new G.B. Pant Institute for Himalayan Environment and Development, has agreed to assist in promoting and coordinating TSBF activities for the subcontinent.

2.8. Organisation and Operation

Senior representatives from the International Council for Research in Agroforestry (ICRAF) and the International Board for Soil Research and Management (IBSRAM) participated in TSBF IV. They both called for closer future cooperation between their programmes and TSBF. It was agreed that subject to the agreement of the IBSRAM Board, strong links could be developed with IBSRAM during the latter half of 1988 culminating in the signing of a formal agreement of cooperation. Initial linkage will be information networking and the "sharing" of research sites, especially in Africa, for mutual benefit. ICRAF sees TSBF as playing a crucial role in contributing to the mechanistic understanding of the success of many agroforestry practices.

A diagram of the proposed operational structure of TSBF is given in Figure 1. The Programme Centre Group and the African Network, the two major groupings of research institutions, are shown together with a management infrastructure. Overall policy is the responsibility of the Board of Management (to be formalised in March 1989) and implemented by the Scientific Director assisted by the Programme Officer and, in due course, a full-time African Network Coordinator. A diagram of the proposed scientific structure is given in Figure 2.

Where necessary, Joint Committees involving members of the Board, scientists from the Programme Centres and Network Sites and the TSBF Officers, will be established to plan and implement specific tasks.

In the initial years of the Programme, funding for international meetings was provided by IUBS, UNESCO/MAB and the EEC. IUBS also covered the costs of producing and distributing of the Proceedings. In March 1988, the Rockefeller Foundation approved a grant of US$100,000 to TSBF to hold the launching workshop for the TSBF African Network and for follow-up activities. IDRC, UNEP, the Commonwealth Foundation and ODA also contributed to the Workshop and to TSBF IV.

The post of Programme Officer was funded by ODA from March 1987 until March 1989, and budget was also secured for limited travel. The Rockefeller Foundation donated a further US$50,000 to fund the Programme Officer/African Coordinator and to provide secretarial support for the African Network development.

A major proposal is being drafted to seek funding for the next five years of the Programme.

Figures 1 and 2 - TSBF Operational and Scientific Structures

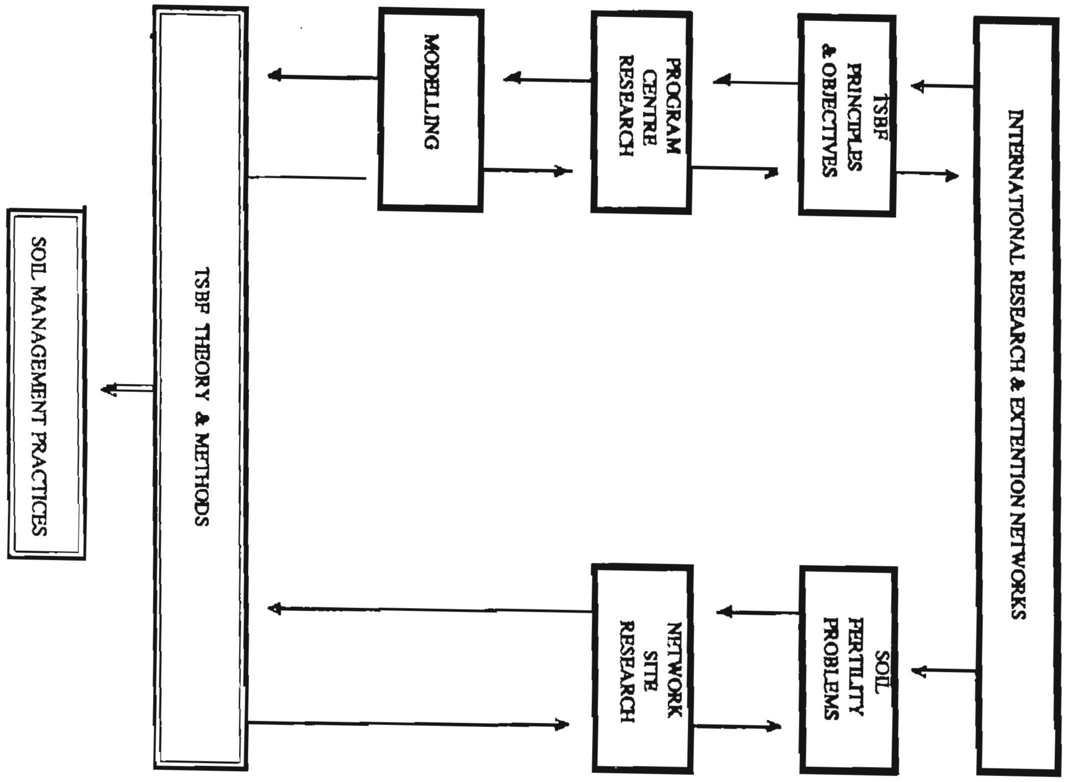

Fig. 2: Proposed TSBF Scientific Structure

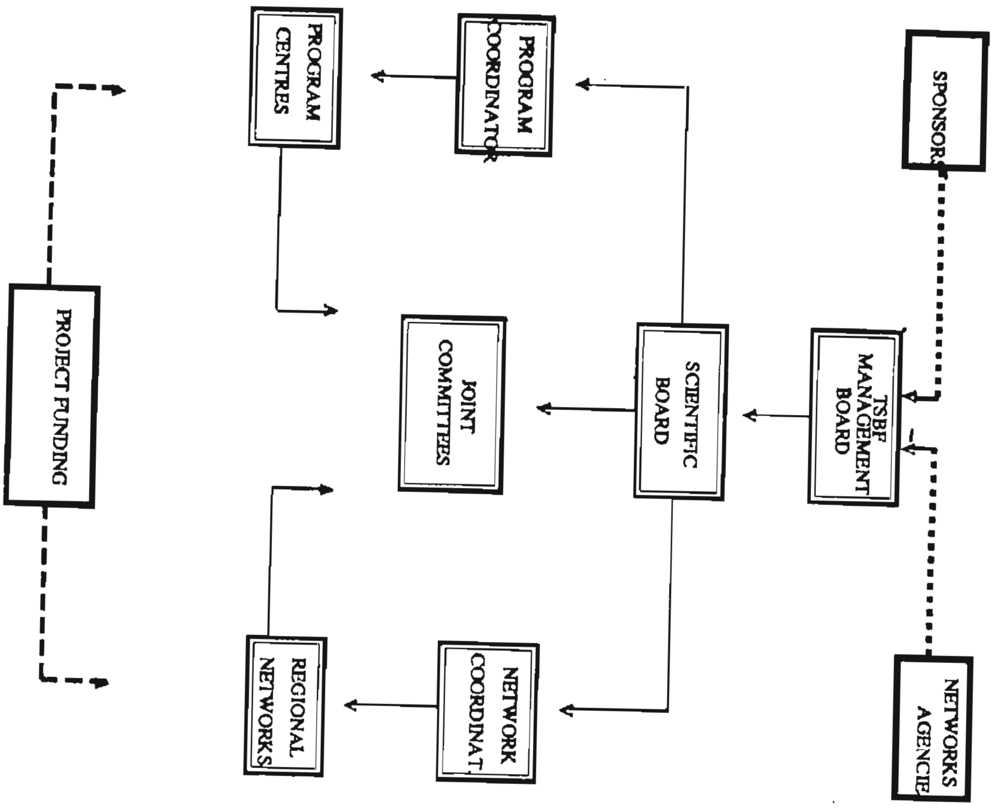

Fig. 1: Proposed TSBF Operational Structure

2.9. Evaluation

The evaluation given at TSBF IV by the international group of assessors (Sir Charles Pereira FRS, Dr. Marc Latham, Director-IBSRAM and Dr. Anthony Young, Senior Scientist-ICRAF) gave valuable criticism and guidelines to help plan the next phase of the Programme:

a) The target of the TSBF research programme, that of developing technologies for management of the organic resources of tropical soils, is recognised as a valid and essential contribution to the development of sustainable production in the humid and semi-arid tropics. The approaches and methods advocated by TSBF are also accepted as being scientifically valid, the emphasis on standardisation being particularly welcome.

b) TSBF is however, in danger of failing to gain necessary credibility both with potential sponsors and customers because:

i. much of the research is of a fundamental nature and perceived as being far removed from the urgency of immediate soil management problems;
ii. of poorly developed contact with the mainstream of tropical agronomic research and development at both national and international levels;
iii. of the possible counterproductivity of "overselling" an argument in favour of biological management without any concrete proposals despite the advocacy of a large body of established theory and information.

c) TSBF also runs the risk of outreaching its capacity in:

i. attempting too broad a scientific programme;
ii. expanding its participation beyond its coordinative ability.

2.10. Conclusions

The conclusions drawn from this evaluation establish the priorities for the work of the Board of Management over the next two-year phase (i.e., until Workshop V in 1990). One way of facilitating this is to devolve responsibility for development upon the Programme Centre Group, as represented by their Principal Investigators, with the Board members and the TSBF core staff concentrating on the administrative, operational and communication issues which are essential to financial viability.

The consolidation of the TSBF African Network holds top priority for 1989; the nature of further regional networks and the successful integration of TSBF target and strategic research largely depend on its success. This will be facilitated by strengthening the links already established with IBSRAM's African networks and ICRAF, and the introduction of a TSBF component into their management trials.

3. TSBF Scientific Principles

3.1. Summary

The TSBF Programme introduces an innovative philosophy to guide research into soil fertility. This philosophy leads to a set of general principles from which a larger number of research objectives, and a potentially infinite number of specific hypotheses and experiments arise.

The Programme aims to promote its research philosophy and principles, but the hypotheses that follow are provided as examples only; the experiments performed by individual participants will depend on the nature of their site, research priorities and institutional constraints. Between-site comparability is encouraged by a standard set of methods rather than a compulsory experimental programme, which would be inappropriate for greatly different sites.

There are five general principles that encompass the research objectives of TSBF. Of those five principles, four address specific aspects of soil biology and fertility. Some of the principles (e.g., SYNCHRONY) are well-founded by basic research and lead directly to applied/management type of research programmes. Other principles (e.g., SOIL ORGANIC MATTER) are newer disciplines or approaches and require more basic research before management type issues can be addressed. The fifth principle is intended to integrate the others and to stress TSBF's interdisciplinary approach to the understanding and management of soil fertility.

The five principles are:

P1 - SYNCHRONY
The release of nutrients from above-ground inputs and roots can be synchronised with plant growth demands.

P2 - SOIL ORGANIC MATTER
Soil organic matter can be separated into functional pools, each of which plays a particular role in nutrient release, ion exchange and soil aggregation.

P3 - SOIL WATER
Availability of soil water to plants can be increased by management of organic inputs and SOM.

P4 - SOIL FAUNA
Soil fauna can be manipluated to improve the physical properties of soil and regulate decomposition processes.

P5 - INTEGRATION OF BIOLOGICAL PROCESSES
The biological control of soil fertility is the integration of plant nutrient demand, root distribution, decomposition processes, soil faunal activities and their interaction with soil chemical and physical properties.

3.2. Principle Objectives and Selected Research Hypotheses

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

The synchrony principle is based on knowledge of the processes of decomposition and nutrient uptake by plants that lead to efficient nutrient cycling in tropical forest ecosystems; its aims are to improve the efficiency of nutrient cycling in agricultural systems by manipulation of these processes.

Numerous studies have shown that the decomposition of litter leads, over the course of time, to the release of nutrient elements, particularly N, P, in plant-available form. The rate of decomposition, and hence the time to nutrient release, is regulated by climate (P, particularly rainfall) and resource quality (Q).

The time course of current root growth determines the timing of nutrient uptake by plants and the spatial distribution of the roots determines the sources of nutrient that may be tapped. Definition of the relationship of P and Q to the time course of nutrient release, coupled with knowledge of the time course of demand by the plant for nutrients, provides a basis for maximising the efficiency of nutrient transfer.

Two applied research objectives follow directly from the rationale for SYNCHRONY, the first deals with the control by climate (P) on nutrient release through decomposition and nutrient uptake by plants and the second deals with control by manipulation of resources quality (Q).

Those objectives are:

0-1 To synchronise release of nutrients from organic inputs with plant demands for nutrients through the control of soil moisture.

0-2 To synchronise release of nutrients from organic inputs with plant demands for nutrients by the management of the quality and timing of inputs.

The value of SYNCHRONY - related research is evident in several agricultural subdisciplines as shown by the following examples and testable hypotheses related to continuous cultivation, plantation agriculture and pastures.

Continuous cultivation:
Fertiliser use efficiencies are often quite low in crop production systems in the humid tropics. This inefficiency is caused by applying fertilisers when crop uptake is low (e.g, before or at planting) resulting in losses by leaching or denitrification. Knowledge of nutrient mineralisation and immobilization patters as they relate to the quality of the organic inputs can lead to increased fertiliser use efficiency. A testable hypothesis addressing this problem could be as follows:

H - Fertiliser use efficiency increases through the temporary immobilisation of nutrients by application of low quality organic inputs, reducing leaching losses.

Plantation agriculture:

Tree crops, in general, have lower nutrient demands than row crops because of slower growth. Nutrient use efficiencies can be quite low if the nutrients applied are in a readily soluble form (inorganic fertiliser or high quality organic material). Nutrient use efficiencies might be improved if lower quality, as opposed to high quality, organic inputs were applied. Lower quality inputs release nutrients slower but over a longer time period than higher quality inputs and might therefore be more in synchrony to demand of nutrients by trees. A suitible hypothesis to test this idea could be:

H - application of low quality organic inputs to tree production systems results in higher nutrient use efficiency and higher production than application of high quality inputs.

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 yield sustainability, primarily through its interactions with soil chemical and physical properties. These in turn effect 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 recognised 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 fertilisers. As low-input systems become more important in the tropics it is essential to understand the functioning of soil organic matter.

Organic carbon and total nitrogen are the most commonly used parameters of SOM, although neither is directly correlated with plant growth; high SOM contents are often encountered in infertile soils. Inorganic soil fertility parameters (such as exchangeable K, available P and Al saturation) are effectively used to predict fertiliser reactions in soils. Total soil organic matter is in effect a "black box" which must be opened ane separated into different components in order to gain a similar predictive understanding about its regulatory roles of nutrient release, cation retention and soil aggregation.

Identification of the relative importance of measurable SOM pools would not only represent a major conceptual advance in soil science but also will provide much needed tools to agronomists for the management of this key component of sustainable production.

The recently developed Century Model proposes dividing SOM into functional pools (Structural, Metabolic, Active, Slow and Passive). These pools vary in their residence time and probably play different roles in relation to the functions of SOM. Active SOM, for example, may play a major role in nutrient availability but a minor one in cation retention. The passive pool may play a major role in soil aggregation but a negligible one in nutrient availability.

TSBF proposes to identify the viable quantitative parameters that estimate the size of the functional SOM pools and to identify the relevance of those fractions to the functions of SOM, and to see how these pools vary with climate, soil type and land use practice.

This strategic research is not likely to produce improved technologies in the short-term, but will provide major understandings on how to manage tropical soils in the medium term.

The specific objectives of the soil organic matter principle are:

0-3 To determine the best methods for quantifying the different SOM pools;
0-4 To determine the relative susceptibility to management of the SOM pools;
0-5 To manage SOM in relation to nutrient release, cation exchange and soil aggregation.

Some *specific hypotheses* relating to the SOM objectives are:

H - Clay mineralogy families affect the relative proportions of the SOM pools. Oxidic mineralogies have a higher proportion of the Slow C pool than layer-silicate mineralogies.

H - The Active SOM pool, although small, is relatively more important than the Slow and Passive pools in terms of nutrient release.

H - The Active SOM pool increases with additions of high quality organic inputs but the Slow Pool decreases.

SOIL WATER

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

All soil biological and chemical activities are dependent on an adequate level of soil water. These include the processes of decomposition, mineralisation, nutrient uptake and plant growth. Many of these processes are inhibited by too little or excessive soil wetness; 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 microorganisms. In conjunction with soil depth it determines the soil water storage capacity and thus the amount of water lost to deep drainage.

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

0-6 Quantify the influence of the amount and type of surface litter on the infiltration rate and evaporation rate for different soils and climates, with a view to developing a general predictive model of the influence of surface litter management on the soil water balance.

Key questions:

1. What is the diffusive resistance to water vapour of various types and amounts of surface litter?

2. How does the presence of litter alter the energy balance at the soil surface? In other words, how does litter alter the absorption of radiant energy and the thermal flux at the soil surface, thereby altering the energy available for evaporation of soil water?

3. Under what circumstances does the insulating effect of surface litter on soil temperatures retard rather than enhance plant growth?

4. Do the detrimental effects of pathogens harboured in the surface litter exceed the advantages of soil water conservation?

5. To what degree does the shielding of the mineral soil from direct raindrop impact by a layer of surface litter increase the infiltration rate?

6. Can the infiltration rate of a previously crusted soil be improved by covering it with surface litter? How long does this process take?

7. Does the interaction of surface litter and soil fauna modify the infiltration rate, for instance through the creation of macropores or the redistribution of soil?

8. Are any litter types or their decomposition products hydrophobic?

9. What is the interception capacity of various types and amounts of litter?

Example Experiments:

The above questions lend themselves to specific field experiments using various types and amounts of litter in conjunction with micrometeorological techniques, evaporimeters, lysimeters, runoff plots and rainfall simulators. The technological requirements can be as simple or sophisticated as the available resources will support. A water balance modelling approach is recommended to integrate the various data elements.

0-7 Quantify the interaction between SOM, soil particle size distribution, soil structure and bulk density as they jointly control the soil water retention curve, thereby enabling target limits for SOM content to be set with regard to soil water availability.

Key questions:

1. Are all SOM fractions equally effective in altering the soil water retention curve?

2. Is SOM itself responsible for increased water retention, or does it operate via its association with reduced soil bulk density and increase particle aggregation?

Example Experiments:

Since all of the factors which influence soil water retention show a high degree of mutual interdependence, a manipulative experiment is not appropriate for answering the above questions. A correlative approach is suggested, in which taxonomically, similar undisturbed soil samples are analysed for SOM content and fractions, texture, bulk density, aggregation and water retention, leading to an empirical predictive model. Such a model cannot prove causality but can lead to the rejection of some possibilities.

0-8 Quantify the dependence on soil water content (or soil water potential) of the processes involved in nutrient mineralisation and uptake.

Key questions:

1. Does the relationship between soil water content and the rate of mineralisation differ from that between soil water content and plant nutrient uptake?

2. Does the time lag between rewetting the soil and the onset of significant mineralisation differ from the delay in initiating plant nutrient uptake?

H - The process of mineralisation continues at water contents lower than those needed to sustain plant growth.

H- Microbial mineralisation of nutrients responds more rapidly to rewetting of the soil than plant growth does.

The consequence of either of the above hypotheses is a synchrony between nutrient availability and nutrient uptake, leading to nutrient flushes at the beginning of wet periods and the possibility of nutrient losses.

H - Mineralisation is stimulated by alternate wetting and drying of the soil, relative to a soil continuously wet for an equivalent period.

Example Experiments:

The first question and hypothesis can be tested in the field or in the laboratory by manipulating the water content of soil samples undergoing mineralisation incubations. The dependence of uptake on water content could be determined using plants grown in pots of different water content, and applying growth analysis techniques, or could be inferred from the dependence of plant physiological processes (such as transpiration rate) on plant water potential. The second question could be addressed by incubating rewetted soil for increasing periods, and extrapolating the mineralisation rates back to find the time lageeffect. The time lag for uptake could be determined with tracer experiments, or by inference from another easily-measured physiological indicator. The third hypothesis could be tested with a field or laboratory experiment measuring the mineralisation rates following different combinations of amount and frequency of applied water.

SOIL FAUNA

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

Soil fauna are important as regulators in decomposition, nutrient cycling, soil organic matter formation and soil structure. The soil fauna can be classified into ecological groups, based on their feeding habits and habitats, that help to understand their role in nutrient regulation and SOM formation. **Epigeic** animals live and feed in either layer; **endogeic** animals live in the soil and **anecic** animals eat surface litter but live in galleries or nests in the soil. The proportion of these groups of soil animals varies with vegetation types, climate, and land-use practices.

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. In addition, applied research should emerge from the understanding of the function and dynamics of soil fauna. Such applied research could involve manipulations (e.g., introduction) of soil fauna to biologically deficient systems in order to re-establish the importance of biological processes in maintaining soil fertility and structure.

The specific objectives of the Soil Fauna Principle can then be stated:

0-9 To quantify the effect of soil fauna in the formation and maintenance of soil structure.

0-10 To quantify the effect of soil fauna in the regulation of decomposition.

0-11 To develop techniques for managing soil fauna to improve soil fertility.

The following examples and hypotheses illustrate the nature of the basic and applied research relevant to the role of soil fauna in soil fertility.

Soil macroinvertebrates (primarily endogeics) through their activities and ingestion of soil organic matter within the soil profile, postively influence soil physical characteristics such as porosity and microaggregation.

H - High densities of soil macroinvertebrates facilitate the formation stable microaggregate structure in the soil.

Another example relates to the anecic group and its influence on the decomposition and incorporation of surface litter and subsequent nutrient availability. Detritivores take leaf litter from the surface and drag it into the soil or into their nests, thus incorporating in the soil a high quality material which will be more rapidly mineralised. The activities of different groups of fauna (e.g., earthworms as compared to fungus growing termites) are different in terms of the consequence of such litter foraging and will possibly differ in their relative importance in influencing nutrient availability.

H - Detritivores affect the incorporation of above-ground litter to the soil and increase the availability of nutrients to plants.

As the ecologies of certain groups of soil animals are understood and groups are identified that play a major role in influencing nutrient availability and soil structure more applied research objectives can be addressed. Soil fauna communities are specifically adopted to types of land use. Any rapid change in land use will result in dramatic changes of the soil faunal community and consequently of its role in soil processes. Therefore, recolonisation by adapted soil fauna, or introduction of exotic species, will help the system to sustain and/or restore its fertility, through improvement of soil structure and nutrients dynamics.

H - Land management determines the potential recolonisation of soil by an adapted community of soil fauna.

INTEGRATION PRINCIPLE

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 final principle serves to integrate the other four principles and to stress the TSBF approach to the study of soil fertility. It is hard, in fact, to isolate the processes or effects that pertain to one of the principles from those of the others. Laboratory studies that control for all but one variable help in understanding specifics about processes. Eventually however, that process must be studied in a natural context that includes multiple interactions among variables and processes. These interactions will vary according to climate, vegetation, and land-use. This approach is reflected in one of the overall objectives of TSBF:

0-12 To develop an integrated approach to the maintenance of soil fertility.

Several hypotheses demonstrate various interactions of the principles.

This hypothesis relates to both the SOIL FAUNA and SOIL WATER principles:

H - Surface mulching positively influences the structure and hydrological characteristics of the soil via the soil fauna.

Two hypotheses show how the SYNCHRONY and SOM principles are interrelated:

H - Below-ground inputs (roots) provide a more readily available source of nutients than an equivalent amount of above-ground organic inputs.

H - Below-ground inputs contribute more to SOM formation than above-ground inputs.

A further example shows how the SYNCHRONY principle can affect soil faunal activities which in turn affect soil water characteristics:

H - Surface mulching positively influences the structure and hydrological properties of the soil via the activities of soil fauna.

The final overall objective of TSBF reflects the original approach of TSBF to learn about soil biological processes in natural systems and to observe how these processes change when natural systems are converted to other uses and to use this information for designing more efficient management of land.

0-13 To identify processes that optimise the availability of nutrients in natural systems by comparing them with derived systems.

Comparisons between natural and derived systems, whether they are annual or permanent agriculture, forestry or pastures, will be made at the Programme Centres by taking the extensive list of measurements listed in Table 2.

4. Site characterisation

4.1. Table 1 - Measurements for TSBF Network Sites

I. Site Description

Present and past land use, topography and position on slope, fire and herbivory records.

II. Site Variable Measurement

Variable	Comment	*Freq.	Units
Climate			
Mean Monthly Precipitation			mm
Mean Montly Maximum Temp.			°C
Soils 0 - 0.20m	Record depth if soil < 1.5m		m
USDA Soil Taxonomy, family level (and profile description)			
pH	1:2.5 water		
Organic Carbon	Any complete oxidation, or Walkley-Black; state which		%
Total N P	H_2SO_4/H_2O_2/Se digestion		mg/kg
Exchangeable (Al + H)	N KCl if pH < 6.0		me/100g
Exchangeable K Ca Mg	N NH_4OAc pH 7.0		me/100g
ECEC	By summation		me/100g
Extractable P	Bicarbonate pH 8.5		mg/kg
Organic P	Difference on ignition		mg/kg
Mechanical Analysis	Hydrometer: sand silt clay (hand texture at least)		%
Bulk Density	Any appropriate method		g/cm^3

Vegetation

1. Woody plants by dominant species

Density

Mean DBH (for plantations) or			m
Basal Area (for natural vegetation)			m^2/ha
2. Herbaceous Plants/Crops			
Biomass	By harvesting towards max. and min. biomass (state date)	P/T	t/ha
Species Contribution to Biomass (for mulit-species communities)	Dry-weight-rank or harvest		%
3. Root Mass	10 0.05m diameter cores to 0.3m	P/T	kg/ha
Soil Fauna			
Density	By termites, earthworms and other functional groups		No/m^2
Biomass	10 (3) 0.25 x 0.25 x 0.30m samples		g/m^2
Organic Matter Inputs			
Mass	All inputs combined		kg/ha
Quality Characterisation	On all major organic inputs		
Lignin	Acid detergent fibre	WA	%
Total N	H_2SO_4/Se digestion	WA	%
Decomposition			
Lollipop stick standards	t_{50}		WA
days			

Notes:

- Figures in parentheses ( ) represent minimum number of samples where practical constraints limit experimental protocol.
- * Frequency of measurement
- WA When applicable. Sampling frequency for decomposition studies may vary according to mass loss rates of different reso types but should be at a minimum of 5 samples (i.e., t_0 and t_{1-4}) before 50% mass loss
- P/T At Peaks and Troughs of variable value; record date.

4.2. Table 2 Measurements for TSBF Programme Centres

I. Site Description

Present and past land use, topography and position on slope, fire and herbivory records.

II. Site Variable Measurement

Variable	Comment	*Freq.	Units
Climate			
Mean Monthly Precipitation			mm
Mean Montly Maximum Temp.			°C
Soils 0 - 0.20m	Record depth if soil < 1.5m		m
USDA Soil Taxonomy, family level (and profile description)			
pH	1:2.5 water		
Organic Carbon	Any complete oxidation, or Walkley-Black; state which		%
Total N P	H_2SO_4/H_2O_2/Se digestion		mg/kg
Exchangeable (Al + H)	N KCl if pH < 6.0		me/100g
Exchangeable K Ca Mg	N NH_4OAc pH 7.0		me/100g
ECEC	By summation		me/100g
Extractable P	Bicarbonate pH 8.5		mg/kg
Organic P	Difference on ignition		mg/kg
Micronutrients	If suspected to be limiting or toxic		mg/kg
Potential N Mineralisation	Laboratory at +- field capacity and *in situ* determinations**		mg/g//d
Microbial Biomass	Chloroform fumigation		mg/g

Light Fraction	Floatation		mg/g
Mechanical Analysis	Hydrometer: sand silt clay		%
Field Capacity	Gravimetric		%
Bulk Density	Any appropriate method		g/cm^3
Vegetation			
1. Woody plants by dominant species			
Density			No/ha
Mean DBH (for plantations) or			m
Basal Area (for natural vegetation)			m^2/ha
2. Herbaceous Plants/Crops			
Biomass	By harvesting towards max. and min. biomass (state date)	P/T	t/ha
Species Contribution to Biomass (for mulit-species communities)	Dry-weight-rank or harvest		%
3. Root Mass	10 0.05m diameter cores to 0.3m	P/T	kg/ha
Soil Fauna			
Density	By termites, earthworms and other functional groups		No/m^2
Biomass	10 (3) 0.25 x 0.25 x 0.30m samples		g/m^2
Organic Matter Inputs			
Litter from woody plants	20 (10) litter traps 0.50m x 0.50m collected two-weekly	WA	kg/ha
Herbaceous Standing Crop	20 (10) 0.50m x 0.50m quadrats harvested	P/T	kg/ha
	10 0.50m diameter cores to 0.30m	P/T	kg/ha
Quality Characterisation	On all major organic inputs		
Lignin	Acid detergent fibre	WA	%
Total N	H_2SO_4/Se digestion	WA	%
Polyphenolics	Follin-Denis on leaves	WA	%
Herbivory	If applicable to system		
Date/Type		WA	
Stockling Level		WA	kg/ha
Fire	If applicable to system		
Date		WA	
Completeness			%
Intensity			kJ/M/S
Decomposition			
Lollipop stick standards	t_{50}		WAdays
Tree Leaf Litter	Standard litter bags t_{50}	WA	days
Herbaceous Litter	Standard litter bags t_{50}	WA	days
Litter Standing Crop	20 (10) 0.50m x 0.50m quadrats	P/T	t/ha
Socio-Economics	Rapid Rural Assessment		

Notes:

- Figures in parentheses ( ) represent minimum number of samples where practical constraints limit experimental protocol.
- * Frequency of measurement
- ** *in situ* determinations may be impractical due to field constraints.
- WA When applicable. Sampling frequency for decomposition studies may vary according to mass loss rates of different resource types but should be at a minimum of 5 samples (i.e., t_0 and t_{1-4}) before 50% mass loss.
- P/T At Peaks and Troughs of variable value; record date.

DOMINANT SPECIES is a species contributing at least 10% to the total biomass. Minor species can be lumped together.
MAJOR INPUT is an input contributing at least 10% to the total inputs.

5. Socio-economic Research Components in Tropical Soil Biology and Fertility Studies

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5.1. Introduction

The TSBF objectives of determining "management options for improving soil fertility through biological processes" and providing "a means for the maintenance and improvement of soil fertility by influencing these processes through management practices" (*TSBF 1986*:1) inevitably link the programme with applied scholarship in the social sciences (particularly those involved in agricultural economics and extension) than to the biological sciences, and one with which biological scientists have tended to be uncomfortable. This notwithstanding, the organisers of TSBF have accepted the importance of the linkage and, backed by a well-argued rationale by Emilio Moran for the relationship between socio-economic and biological components in the programme, have incorporated a socio-economic component (SOCEC) in the research design, which includes *inter alia* the conduct of a socio-economic survey through the use of a structured questionnaire instrument (*TSBF 1986*:13-16; *TSBF 1987*:9-11, A1-A13).

With such a programme in place after the TSBF III Workshop in 1986, it was a reasonable expectation that two years later at TSBF IV one would be presented with examples of experimentation in integrated biological science/social science research for modification, refinement or elaboration. In the event, little progress appears to have been made on this front; evidently only a couple of the ten in-place programmes have incorporated the SOCEC component in their work to date, and only 2-4 have experimental plots located on farmer-operated sites. Comments from the floor at TSBF IV reveal:

a) a concern in some quarters about the perceived shift in the notional scientists/extension worker/farmer model of knowledge flow implicit in earlier formulations to the direct scientist/farmer linkage incorporated in Moran's approach;
b) a scepticism about the ability of the scientists involved to say anything of direct and immediate value to farmers;
c) a frustration over the extent of inputs required to conduct the socio-economic survey; and
d) reservations about the reliability, validity, and utility of the questionnaire instrument proposed.

The working group assigned to consider these matters reported back to the plenary reaffirming the importance of locating the research programme in the context of relevant land use practices and the value of multi-disciplinary approaches in this regard. It recommended a flexible approach depending on the specifics of each of the component research programme, suggesting that alternatives to rigid survey and structured interview techniques might be more appropriate, mentioning Farming Systems Research (FSR) and Rapid Rural Appraisal (RRA) as possible approaches.

All this constitutes the healthy re-appraisal to be expected of a dynamic programme of international research exploring uncharted waters of multi-disciplinary collaboration, and the working party's recommendations convey a lot of good sense. At the same time, the flexibility advocated may have the effect of marginalising the SOCEC component, or indeed excising it completely from the agendae of specific research programmes. Furthermore, there may some naivety concerning the inputs required by some of the alternatives suggested, leading to a parallel frustration on the part of those attempting to implement them. Either of these results would be unfortunate and severely emasculate the impact of the TSBF programme. SOCEC should be kept firmly on the TSBF agenda, viably orchestrated to fit the various constraints that it faces. With this in mind, I wish to review the rationale for SOCEC within TSBF, discussing options which may be available with some commentary on their implementation.

5.2. The Rationale for SOCEC

The rationale for SOCEC has already been provided in the TSBF documents and elaborated in Moran's article, cited above. What follows is a condensed re-statement of this rationale, structured to facilitate the discussion of possible programme outlines.

Contextual Relevance
This argument refers to the need to ensure that the biological processes examined by TSBF correspond to a relevant range of on-the-ground soil management conditions important to national agricultural production

systems. The "conditions" involved correspond roughly to the items listed in Table 3 of the TSBF Report under the heading "environmental constraints".

To a degree this is not an argument for the inclusion of SOCEC *per se*; the broad categories of contextual relevance can in most cases be derived from available documentation, as the detail in Table 3 indicates. But to the extent that these broad categories mask micro-environmental variations which determine specific management regimes the SOCEC component is relevant here, particularly if it is initiated simultaneously with, or in advance of, research on biological processes, as Moran suggests.

Applied Relevance

This argument suggests the importance of a SOCEC component to ensure that TSBF research results have an applied relevance in terms of yielding implications for management regimes which are viable in the context of the socio-economic constraints which prevail for specific target populations. Recognition of the importance of this context is found in the TSBF documents and is explicit in Table 3 of the TSBF Report under the columns headed "socio-economic constraints" and "target populations". Here the case for a SOCEC component is particularly strong, since these socio-economic factors cannot be properly identified, let alone analysed, without considerable investigation. While the typology provided in Table 3 is a useful starting point, it should be recognised that farmers and management units within given ecologically-defined units are rarely homogeneous. In other words, the categories appearing under the column "target population" in Table 3 suffer from conflation. In terms of TSBF's applied objective of providing viable management options some disaggregation is necessary, and at this level of specification it is hard to see how this can be done without considerable investigation of socio-economic variables. Such investigations need *inter alia* to carefully specify the relevant management units in respect to specific resources. In most of the "communal" contexts which the Programme covers the basic management unit for arable land is likely to the household, but this itself needs to be carefully examined since there may be intra-household and gender differentiations which are relevant for management issues. These communal contexts are also likely to exhibit different structures for the management of "common property" resources such as woodland and grazing and these also require careful examination. As it stands the TSBF programme is weak in its recognition of these matters, which have a vital relevance to the issue of viability.

The incorporation of indigenous technical knowledge

The recruitment of indigenous technical knowledge (ITK) into a programme of research such as TSBF has clear advantages, and its potential is acknowledged in the programme documents and Moran's article. I have however, the sense that this potential is still underestimated by some of the participants, who see it as little more than a limited local taxonomy coupled to a routine replication of traditional management techniques. ITK systems do, of course, usually contain local taxonomies, the qualities of which depend on specific socio-cultural histories and conditions. Some communities are "resource-poor" in this dimension; others "resource-rich". Among those which are rich in this resouce, cultures can be found which exhibit, for example, an ethnobotanical knowledge far more detailed than that of the professional scientists which have worked with them. (cf. Conklin, 1957; Heinz & Maguire, nd.; Richards, 1975) To ignore the taxonomic potential of ITK in these circumstances would be both wasteful and myopic.

ITK is however, usually much more than simply a useful local taxonomic source. The taxonomies involved are usually unconstrained by the disciplinary sub-specialisms of science and arise from an environmental holism which relates botanical, soil and meteorological data in an empirical understanding of localised ecosystems of great value to a programme such as TSBF. Furthermore, the insights of ITK possess one great methodological advantage over short-term scientific programmes of research, evolving as they have over long time-frames incorporating cyclical climatological variations or uni-directional environmental change. At TSBF IV in Harare, the importance of these variations and change was raised in the context of a number of discussions, coupled with complaints about the adequacy of the data and techniques available to analyse them. ITK provides one possible source of information relevant to this problem, as some current studies have shown (e.g., Scoones & Cousins, 1988).

In a valuable article on this topic, Howes summarises the points made above in stating that "indigenous observers possess assets in the form of empirical knowledge of the individual elements in their ecosystems, of the relations through which these elements are conjoined, and of the way in which these relations change through short and more extensive periods of time" (1975:13). There are, of course, limitations to ITK which often falls short in causal explanation, but given its potential to produce a large stock of empirical, localised knowledge to exclude it from the TSBF investigations would be to ignore an important resource. The value of this resource can also offset the costs of incorporating a SOCEC component in TSBF. As Chambers comments, it can be "highly cost-effective for investigations by organised science to be based on or linked with local classifiations and local knowledge. The neglect of ITK is, in these terms, a straight-forward form of inefficiency".

Localised Capacity - Building in Applied Science

A fourth argument for the inclusion of a SOCEC component which relates TSBF research directly to local initiatives in knowledge-generation and effective resource management arises from the fundamental issues of the development role of professional science in the contexts where TSBF is operating. In recent development thinking the dominant paradigm on this issue has shifted from one which sees professional science as offering development solutions to target populations which are exogenously derived to one which calls for science to impart development capacities for solutions which are locally generated. This stance emphasises the importance of the indigenisation of the processes of knowledge generation, communication and incorporation, the fundamental insight being the development imperatives require a degree of dispersed autonomy and localised participation in the process involved. The objective is not to displace the role of professional science but rather to open up a role for rural peoples in setting the research agenda and participating its execution, producing results which are responsive to what they want, need and can effectively manage.

This shift in perspective is implicit in current approaches mentioned at TSBF IV in Harare: Farming Systems Research, the Farmer-First-and-Last model of Chambers and Participatory Action Research strategies sponsored by UNRISD and others. The debates on this perspective are diffuse and complex and may to the conventionally trained biological scientist seem to be an irrelevant and inconvenient intrusion into what should properly be a much more tightly constructed agenda of scientific research. They are, however, of central importance for rural development, and any programme such as TSBF purporting to have a direct and applied relevance in this field should be familiar with the issues raised. The matter also has a direct relevance to the question of whether TSBF researchers should in their work relate directly to farmers or indirectly through extention agents or agencies. My strong personal view is that whenever possible, researchers working in TSBF should seek direct links with the local populations who are the intended beneficiaries of their work. TSBF offers excellent opportunities to incorporate farmers, who are natural investigative allies of the scientist, as co-researchers in the project. Such a tight linkage also accelerates "feed-back" in the experimental process and reduces the possibility that extension workers, who in spite of their title are often poor communicators, will distort research results.

5.3. SOCEC Options Within TSBF

My restatement of the rationale for SOCEC hopefully reinforces the resolve to retain this component within TSBF. At the same time this retention must be consistent, as stated in the Introduction, with the various constraints that component research programmes may be facing. This section reviews the various options which are available, presented in order of increasing SOCEC inputs that are required.

5.3.1. Experimental Investigation of Nutrient Cycling Processes Under Controlled Conditions

This first option involves a focus on the analysis of biological processes using the design protocols developed (MINEX), presumable largely at laboratory or research station sites, but not excluding the possibility of field operations at farmer-operated sites. The comparative dimension of the programme's objective of "a broad comparative study of natural and managed ecosystems" is supplied by the replication of a relevant range of conditions at the laboratory or field station. What the relevant range of conditions constitutes is in this option determined by available documentation on "environmental constraints" along the lines indicated in Table 3 or TSBF III. While no formal SOCEC activity is required for this, some informal socio-economic investigation may be necessary to determine micro-environmental variations which determine specific management regimes, as discussed in paragraph 2.1.

This option does not fundamental violence to general TSBF programme objectives and may well be the only viable option for constituent research programmes without the time, resources or inclination for a formal SOCEC component. The approach may at least minimally meet the requirement of contextual relevance. At the same time it should be recognised that it is unlikely to effectively address the issue of applied relevance for the reasons stated in paragraph 2.2. above, nor does it tap the resources of ITK.

Because this option is unlikely to adequately deal with issues of applied relevance, and managerial viability research programmes which take this approach should **ensure that findings and their implicit or explicit prescriptions include sub-optimal options.**
This exhortation is made for two reasons. Firstly, to broaden the applicability of findings arising from this

approach to a range of management regimes the socio-economic determinants of which have not been fully investigated. Secondly, to guard against the possibility that recommendations arising out of research conducted in "ideal" laboratory or field station conditions might become hegemonic, exclusive prescriptions which unintentionally, in resultant programmes and policies, reduce management options. Recent development history is replete with instances where, for example, the propagation of high-yield hybrids developed under laboratory conditions has effectively eliminated the cultivation of evolved indigenous varieties more effectively adapted to micro-environmental niches not considered in the research programme. TSBF should ensure that this experience is not replicated in its activities.

5.3.2. The Informal Approach to SOCEC

This option is a viable alternative for TSBF constituent programmes willing and able to conduct these programmes at farmer-operated sites and to be involved in informal and loosely structured investigations of socio-economic factors, but without the resources to involve social scientists in the research programme. Basically this is what Edmundo Barrios has done in his Orinoco floodplain study. A discrete, farmer-operated field has been chosen, the site representing a management system with internal heterogeneity. The researcher has proceeded on the assumption that what farmers do and why they do it is important and has the insight that there may be socio-economic as well as ecological constraints on high-input solutions to production objectives. This socio-economic contextualisation allows the researcher to design his research in terms of specific management requirements, draw on farmer knowledge in the analysis and formulate results in terms of viable options. The approach therefore addresses the issues of contextual and applied relevance and opens the research to inputs of ITK. No claims are made to having conducted a formal SOCEC exercise producing detailed quantitative socio-economic data, claims which are likely in any case to be spurious unless the exercise is conducted by trained personnel with considerable time at their disposal. This does not obviate the validity of findings since they are properly so qualified, and this option is in my view an appropriate one for TSBF component programmes without social science resources at their disposal.

5.3.3. Rapid Rural Assessment (RRA)

This option was proposed by the Working Group on SOCEC and Extension of TSBF IV in Harare as a possible approach, motivated at least in part by the frustration expressed by participants at plenary sessions over the time and effort required to implement the formal socio-economic survey adopted at an earlier stage. Rapid Rural Assessment (RRA) does provide a useful approach for the SOCEC component, but it should not be regarded as a quick, cheap, pre-packaged social science programme which can easily be implemented by biological scientists for TSBF purposes. RRA has rather cynically been described in some circles as a "quick and dirty" method of social investigation. It is quick, comparatively speaking, and if done properly, should not be dirty. But it is not easy, and unlikely to be cheap, although it may well be cost-effective.

The term RRA covers a number of relatively rapid techniques for the investigation of household and community socio-political factors and deals not only with project appraisal or evaluation but also the assessment of rural living conditions and social organisation. Its basic objective is to produce relatively rapid research results, short-circuiting the long time-frames usually required for socio-economic investigation. A basic rationale is that a rapid assessment of purposely selected case studies, with their acknowledged limitations, often is more desirable than either casual empiricism or the delayed results of a larger and more conventional study.

Specific RRA techniques vary, and TSBF participants interested in this option could, for an orienting example, refer to Hildebrand's description of the Sondeo approach (1981:423-432). The basic components in RRA include:

a) the selection of a limited number of research contexts (communities, households, etc.) for focused case studies, based on "best available" information or "common sense". This implies, of course, a notional sampling frame.
b) collaborative social science/natural science team research carried out intensively and over a short duration.
c) a compressed series of dialectic sequences juxtaposing data gathering and analysis.
d) a focus on the production of general profiles of socio-economic characteristics rather than the production of quantified, bench-mark data. Questionnaire instruments are rarely incorporated, since it is the assumption that the quantifiable information required for more detailed analysis will be provided by farm records in subsequent, longitudinal field trials and extended socio-economic research.

An RRA approach could provide a very useful dimension to the SOCEC component in TSBF. It produces rapid results, addresses the issues of contextual and applied relevance and by its nature places emphasis on ITK inputs. But it does demand multidisciplinary team effort and requires considerable administrative orchestration.

Furthermore, it is conceptualised as the initial phase in some longer, longitudinal field trial or research programme. Its utility as a "once-off" exercise standing on its own is limited and for TSBF purposes my view is that it should be considered as a possible component in a SOCEC programme rather than as a substitute for it. Indeed if properly conducted, an RRA exercise would require this.

5.3.4. The Structured Socio-Economic Survey

This is the option adopted at TSBF III and incorporated in the *TSBF Handbook of Methods*, involving "gathering information by means of a survey before, or at the start of, the Level I research phase" (1987:2). A draft survey questionnaire, the "Minimum Socio-Economic Survey" is provided in Appendix A of the *Handbook*. In my view this survey instrument is a good one, if adjusted to local conditions as recommended by Moran. If used, I would suggest that more detail on labour inputs (for composting, manuring, fertilising, pest control, etc.) be evoked.

This having been said, it was clear at TSBF IV in Harare that only a few of the constituent programmes had attempted to use this approach. The major implementational drawback to this option lies in its requirement of a major social science input to the exercise. As with RRA this constitutes no easy, pre-programmed social science package which natural scientists can conveniently implement. The local adaptations necessary, the detailed orchestration of data collection and compilation, and the careful quantitative and qualitative analysis implied require time and skills which are likely to be in short supply among natural scientists, suggesting that collaboration with social scientists is highly desirable if not necessary.

More substantively, it should be recognised that the Structured Socio-Economic Survey, like RRA, can only be properly considered as the first phase in an investigation of the socio-economic components relevant to TSBF. Socio-economic studies of this nature require examination over time, in the nature of a longitudinal or at least diachronic research design.

A structured socio-economic survey can yield descriptive, base-line statistics; it is unlikely to yield much regarding cause-and-effect relationships. Since the TSBF research programme is directed at producing an analysis analysing such relationships to limit the SOCEC component to a once-off survey exercise would be to unequally conjoin the natural and social science inputs, confining the SOCEC contribution to a deficient methodology.

5.3.5. Long-term Collaborative Biological Science/Social Science Research

This, the final option suggested here, calls for the greatest deployment of research resources and commitment to the administration and academic orchestration required. It is also the soundest strategy, and if properly implemented, has the greatest potential for realising all the objectives in the rationale for SOCEC. It also provides the best locus for the incorporation of the Farming Systems approach and the technology transfer objectives which are part of the TSBF agenda.

This option requires a commitment to sustained long-term participation by collaborating social scientists, which may be difficult to obtain. However, there are sound reasons why social scientists should be interested in such collaboration. The methodological arguments for longitudinal SOCEC activities, from the TSBF perspective, have already been stated. There are equally strong arguments for social scientists to take advantage of the TSBF programme in terms of the interests of their own disciplines. The social sciences, by nature of their subject, tend to suffer from a lack of data sets which allow casual inference, thus analyses tend to inferential and predictive models weak. Social science needs experimental designs which proceed from sound base-line data, adequately isolate significant variables and analyse their differential impact under comparative experimental conditions. TSBF offers the research context for such a design. Much of this paper has been devoted to a rationale of what social science can contribute to TSBF; social scientists should grasp that TSBF can equally contribute to the interests of their own disciplines.

In such an option the collaborative cadre of social scientists need not be large, and the long-term sustained participation of one or two social scientists will be more valuable than the intermittent contributions of a larger but less committed group. What is required from both the natural and social scientists involved is an appreciation of the advantages of multi-disciplinarity for their own disciplines, a willingness and capacity to learn from other disciplines and a comimmitment to invest the time and effort required for productive collaborative scholarship. If effectively implemented, such scholarship may produce the added benefit of moving from multi-disciplinarity to inter-disciplinarity to the degree that the different paradigms and methodologies involved coalesce.

5.4. Implementing SOCECC: Some Con luding Remarks

The options outlined in this paper have been delineated in a manner indicating both their strengths and possible disadvantages, and with the objective of providing a basis for the implementation of a SOCEC component in each of the constituent TSBF research programmes consistent with the various constraints and in-place realities which now exist. It should be clear that the options described are not mutually exclusive alternatives, and what follows are remarks based on a limited knowledge of the detailed phasing and progress of specific participating research units in TSBF.

Clearly, the optimal approach to achieve the SOCEC objectives of TSBF is that described under 5.3.5., an approach which could include aspects of the options discussed in 5.3.3. and 5.3.4. This option does require, however, access to significant social science inputs and could only be carried out where there are the resources and commitment necessary. From my limited perspective it would seem that some programmes may be in a position to pursue this option (Zimbabwe, Peru, Venezuela?) and if this is the case this possibility should be actively pursued.

It also seems clear that other programmes will not be in a position to follow this optimal approach, but will wish to incorporate some form of SOCEC activity in their agenda. For such programmes I think the best basic strategy is that described in 5.3.2., that of informal investigation of relevant socio-economic factors conducted in conjunction with biological science research at farmer-operated sites and continued over the duration of the research period. RRA (5.3.3.) or structured survey techniques (5.3.4.) could be included in this approach, but as already indicated, I think that these are more viable when done as part of option 5.3.5. Finally, I think that it must be accepted that some of the constituent programmes, for various reasons, will run their course without any active socio-economic component. This approach is unlikely to directly address many of the central issues in the rationale for SOCEC cut can indirectly yield results of applied relevance, particularly if the prescriptions implied in research findings include sub-optimal options (5.3.1.).

In conclusion, these remarks imply that there are in practical terms three options now available to TSBF, one which effectively excludes a SOCEC component but which maintains an awareness of this omission in its research findings, one which informally incorporates a socio-economic dimension in the research and one which includes a sustained SOCEC activity in research design and implementation. Even at this stage in the life of TSBF, the third option should be considered in spite of possible phasing problems. Ideally, of course, SOCEC activities should start simultaneously, if not prior to, research by the biological sciences. However, ideal conditions in multi-disciplinary research are rarely encountered and I see no fundamental problems in imitating a SOCEC component at the stage most of the TSBF research centres have currently reached.

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6. Agroforestry and the TSBF Programme

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How relevant are the objectives and concepts of the Tropical Soil Biology and Fertility Programme (TSBF) to the design and development of agroforestry systems? What does agroforestry have to offer, in terms of practical management options, towards fulfillment of the aims of the TSBF?

These are the questions addressed in this paper and we shall anticipate the conclusion, that the answers to both are strongly positive. This leads to a third question: how best can the research programme of TSBF be integrated with agroforestry research, and specifically, with that of ICRAF?

6.1. The Nature and Scope of Agroforestry

Agroforestry is a collective term for land use systems in which woody perennials (trees, shrubs, etc.) are grown in association with herbaceous plants (agricultural crops or pastures) or animals, in a spatial arrangement or a temporal sequence, and in which there are both ecological and economic interactions between the tree and non-tree components.

An essential feature of this definition is the existence of ecological interactions. These take place through micro-climate, soil and fauna, both above and below the ground surface; examples are shading, mutual effects on soil moisture, plant nutrient recycling or competition, and suppression of pests. The effects can be of the tree upon the crop (or animal) or crop upon the tree, and can be positive (beneficial) or negative (adverse). For example, the presence of trees may increase soil moisture availability to crops through reduction in evapo-transpiration, or reduce it through root competition.

It is this feature of agroforestry that distinguishes it from soil forestry, albeit that there is a large overlap. A village or farm woodlot can be good soil forestry and sound land use planning, but if it is managed only with the aim of maximising wood production it is not agroforestry. But if there are other management objectives which interact with the farming systems, such as forest grazing or cutting of foliage for compost, then it is also agroforestry.

There are many thousands of agroforestry systems, traditional and modern, but these can be grouped into about 20 practices, where an agroforestry practice is defined as a distinctive arrangement of trees and non-tree components in time and space. In the classification in Table 3, rotational practices are those in which interactions between the tree and crop components take place dominantly over time, spatial practices those in which the interaction is mainly in space. In spatial mixed practices, the trees are found over more or less the whole of the land use system; in spatial zoned practices they are planted in particular patterns, such as rows, belts or blocks, or occupy one element of the system, such as boundaries or soil conservation structures.

This range of practices, and the design options within each, offer a wide range of opportunities for integration with considerations of soil biology.

Table 3 - Agroforestry Practices

Mainly Agrosylvicultural (trees with crops)

Rotational:
Shifting cultivation
Improved tree fallow
Taungya

Spatial mixed:
Trees on cropland
Plantation combinations
Multistory tree gardens

Spatial zoned:
Hedgerow intercropping (alley cropping, barrier hedges, also agrosylvopastoral)
Boundary planting
Trees on erosion control structures

Windbreaks and shelterbelts (also sylvopastoral)
Biomass transfer

Mainly or Partly Sylvopastoral (Trees with pastures and livestock)

Spatial mixed:
Trees on rangeland or pastures
Plantation crops with pastures

Spatial zoned:
Live fences
Fodder banks

Multi-purpose Forestry (cf., also taungya)

Woodlots with multi-purpose management
Reclamation forestry leading to multiple use

Other Components Present

Apiculture with forestry
Aquaforestry (trees with fisheries)

6.2. Agroforestry, Soil Conservation and Sustainability

Agroforestry is carried out for a range of purposes, productive and service. Productive functions of the tree component include provision of fuelwood, fodder and fruit, in some cases without loss of crop production. Among the service functions, the most important is certainly that of maintenance of soil fertility. This, in turn, makes a major contribution to sustainability, defined as land use in which production is combined with conservation, thereby permitting that production to be sustained.

The potential of agroforestry for soil conservation has been the subject of a recent ICRAF review, completed in draft form and shortly to be revised and consolidated (Young, 1986a, 1987, in press a and b; Young *et al*, 1987). This rejects the older view, in which conservation was equated with control of soil erosion. It takes as a basis, the concept that soil conservation means essentially maintenance of soil fertility - for which erosion control is one necessary, but by no means sufficient, condition. Equally important to conservation are maintenance of physical, chemical and biological conditions conducive to plant growth.

The rationale for supposing that agroforestry can assist in maintaining soil fertility lies in the generally beneficial effects of trees on soils, known from the inherent fertility of forest soils and the recuperative capacity of forest fallows. This is the theme of another research programme, that of the Commonwealth Science Council of amelioration of soils by trees (Prinsley & Swift, 1986). Trees improve soils by augmenting inputs (e.g., photosynthesis and litter decay, nitrogen fixation), reducing losses (erosion protection, nutrient recycling) improving soil physical properties, and modifying the nature and timing of plant residue additions to the soil (Young, 1986b, 1987 p. 31).

The existence of high soil fertility under tree canopies than in adjacent open land has been shown in tree-soil transects (e.g., Kellman, 1980; Bernhard-Reversat, 1982), whilst the apparent capacity of agroforestry systems to sustain soil organic matter levels has been demonstrated by computer modelling (Young *et al*, 1987, Cheatle *et al*, in press).

The basic soil-agroforestry hypothesis can be stated as:
Appropriate agroforestry systems have the potential to control erosion, maintain soil organic matter and physical properties, and promote efficient nutrient cycling.

To what extent, and under which environmental conditions, this is true is a matter for research; readers may form their own opinions from recent reviews (Sanchez, 1987; Young, 1987).

Options in Agroforestry Design and Management

Agroforestry itself, and its different practices, offers a range of management options to farmers: in one way or another, they can integrate trees and shrubs with crops or pastures. Moreover, many of these options are demonstrable practical, for they are to be found in the wide range of indigenous agroforestry systems (Nair, 1984-88), as well as in some current successful development projects.

But even within a single agroforestry practice, say hedgerow intercropping, there is a wide choice in design and management. Some of these options are shown in Table 2. Their relevance to TSBF principles is apparent. For example, the nature and amoung of plant residue additions to soil organic matter can be influenced by choice of tree species, and whether herbaceous and/or woody residues are returned. The clearest instance concerns the TSBF principle of synchrony: in agroforestry systems, the timing of release of nutrients from tree litter can be influenced by choic of tree species (fast or slow litter decay), timing of pruning, and manner of litter addition (surface, buried or composted).

Agroforestry systems can therefore be designed purposefully, to maximise positive tree-crop interactions and minimise negative ones. Among the aims will be that of maintaining soil fertility, to a large extent by biological means.

Hence, efficient agroforestry design is dependent on having a basic knowledge of soil biological processes. Conversely, agroforestry offers management choices, by means of which, results from research into soil biological processes can be translated into sustainable land use practices.

Table 4. Some Design and Management Options in Agroforestry

Choose tree
- products
- biomass production
- N fixation
- rate of litter decay
- rooting pattern

Manage tree
- form (prune, etc.)
- shade
- timing of litter addition

Vary tree/crop
- rotational or spatial interaction
- number or density of trees
- arrangement of trees

Manage plant
- herbaceous and woody residues
- surface or buried
- direct or via livestock

plus agricultural management options.

6.3. Diagnosis and Design: the Need for Basic Knowledge

The set of procedures normally used to plan agroforestry, diagnosis and design, is sometimes misunderstood, being thought to consist of "sociologists directing questionnaires at farmers". This is far from being the case: the greater part of it consists of scientists putting their heads together, and drawing upon a wide range of scientific information.

The initial stage, that of diagnosis of problems, does indeed consist of talking to farmers, although if possible with an agriculturist or forester in the team. But this forms only a small part of the total system specifications, selection and short-listing of interventions, functional specifications for components, assessment of likely performance, and other steps. These design procedures are carried out primarily by a team of scientists, who would be helpless unless they could draw upon an established body of scientific knowledge (Young, 1986c; Raintree, 1987).

6.4. Agroforestry Research

At present, there is an explosion of activity in agroforestry research, the result of the rapid growth in awareness of its potential. Because of the urgency of the problems and addressed, brought about fundamentally by population growth and pressure upon natural resources, it is trying to achieve much in a shorter time. This calls for the structured planning of research.

Agroforestry research can be thought of as falling into three levels: what, why and how (Figure 3).

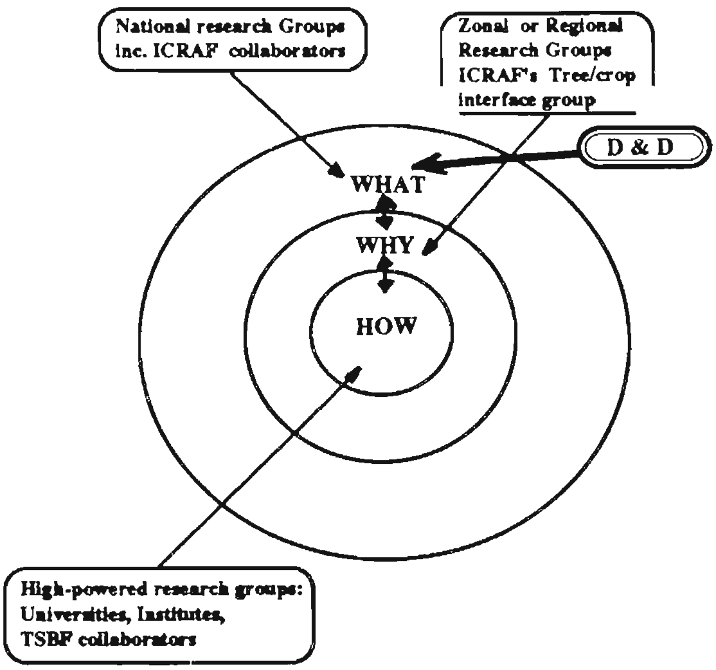

Figure 3- Levels of research in agroforestry.

"What" research is intended to answer the immediate needs of farmers and other land users. Rural extension agents and farmers need advice on what tree species are appropriate to plant, in what number and arrangement, and with what management practices. Locally-conducted trials of prototype systems, on-farm as well as on-station, are the level of research which directly precedes such advice.

"Why" research seeks answers to questions of why the components of agroforestry systems perform in a certain way. Why does the crop on the upper side of a contour-planted hedge grow better than that on the lower side? Why is one tree species more competitive with an adjacent maize crop than another? This level of work is trying to determine cause-and-effect relationships operating on a specific site (soil, slope) and under each year's weather conditions. "Why" research is needed in order to design the prototype tested in "what" research.

"How" research is concerned with the fundamental processes operating within systems. How are mineralisation rates affected by moisture? How does assimilate pass between roots of trees and crops? At this level we are looking at specific processes and effects, which operate as associations of effects in "why" research.

Research at the "what' level is being undertaken extensively within ICRAF's collaborative networks, including the Agroforestry Research Network to Africa (AFRENA) and the All-India Coordinated Agroforestry Research Programme. At least 150 management trials are currently in progress at the 31 participating centres of the Indian programme. In Africa, the network is organised into four climatic zones: subhumid unimodal climates of Southern Africa (the "miombo" zone), subhumid bimodal climates of East and Central Africa, the humid lowlands of West Africa, and the semi-arid zone or Sahel. The specifications for management systems to be tested are determined by the diagnosis and design procedure (Raintree, 1987). Country-based trials, focused on selected problem regions, are currently being planned and started.

6.5 Research at the "Why" Level

It is intended that there will also be some research at the "why" level in AFRENA, through zonal research centres, but at present this is undertaken by ICRAF at its field station at Machakos, Kenya. A starting point in planning was to simplify the huge array of components and situations into five experimental situations (Huxley, 1986a, 1986b):

1. Multipurpose tree species selection and evaluation, fundamental to all types of agroforestry systems;
2. Studies of rotantional agroforestry systems;
3. Studies of spatial mixed agroforestry systems, in which interactions between tree and crop are more or less ubiquitous;
4. Studies of spatial zoned systems, in which interactions take place along a specific zone, the tree/crop interface;
5. Special studies (e.g., nitrogen-cycling, apiculture).

Two examples of "why" level research may be cited, to illustrate the complexities involved: tree/crop interface studies and the ecological approach to on-farm research.

Studies of the tree/crop interface (TCI) are investigations of the complex set of interactions that take place along the zone where the tree (tree, shrub or hedge) meets the crop (agricultural crop or pasture). This depends in turn on the strategies of the component plants. The first step in creating a controlled experimental situation is to isolate well-defined interfaces; the second is to exercise control over some variables (e.g., by root separation) thereby isolating the effects of others. Two experimental designs are being tested at the Machakos site: a "Y" design-- three arms of trees with surrounding crops; and a disaggregated star design-- individual crop-hedgerow-crop units at all 45° orientations in a randomised arrangement. An inert hedge, i.e., a non-living fence, is being used to isolate micro-climate from soil and root interactions.

High seasonal variations in rainfall occur at the site, causing large differences in crop yields. There is often a strong interaction between seasonal and treatment effects. Much of the analysis has been primarily descriptive, seeking clues to the dominant effects amid the complex array of interactions. This should lead to more focused hypotheses for subsequent investigation.

Such is the complexity of the situation that at present there are two *Cassia siamea*/castor bean "Y" designs on the station exhibiting opposite effects at the TCI. One castor crop shows a strongly positive effect, increasing in height and yield towards the interface, whereas at the other the effect is negative. At *Cassia*/maize interfaces, the biomass and yield profiles across the maize show much variation with aspect and from season to season.

A contrasting technique is that of the ecological approach to on-farm experimentation (Huxley & Meade, 1988). This is an attempt to find ways to capture information concerning tree/crop interactions in existing situations on farms and landscapes. The simplest situation is that of a single tree. Measurements made on replicates of such a unit may lead to an understanding (albeit at the level of measurement envisaged) of the strategies of the tree, surrounding crops and their interactions.

A higher level of complexity is to make observations upon a farm where perennials are planted. Initially, ecological quadrats could be used to answer "what" questions, what is happening. The crux of such a technique is to select quadrats which are the same (for replication) and those which are different.

These ecological situations or treatments could be very valid in a highly heterogeneous environment such as a farmer's field. Imposing such quadrats for both observation and treaments would cause minimal disruption to the traditional land use system, therefore allowing observations on the farmer's strategies for exploiting environmental heterogeneity.

6.6. Agroforestry Research, ICRAF and TSBF

The current experience of agroforestry research has come at a time when there is also a focus on "useful" research, directed at meeting the practical needs of farmers. As a result, current agroforestry research is heavily concentrated on trials of potential systems ("what"-level research), at the expense of studies of basic processes. The statement, "Research should be directed towards the practical needs of farmers" is true; but the reasoning, "Therefore it should consist of field trials of practical management systems" is false.
The drawback with "try-it-and-see" research can be seen from an example. Consider a single practice, that of hedgerow intercropping. On a given site it would certainly be possible to test four hedge species, three within-row plant spacing, four between-row spacings and three pruning heights; with three replicates this would give 432 plots - without considering alternative agricultural crops! Some saving is possible through partial replication and confounding, or the use of systematic designs, but the research effort needed remains considerable. The having found the optimum combination, all you know is that it works on that soil, and in the weather conditions for the years of the trial.

By analogy, take a product desired by users, namely a bri‹ ge. It is essential that this should function correctly, in this case, carry loads over a river. If you visit a bridge-building research station, do you therefore see hundreds of bridges, of metal and wood, thick and thin, suspended and cantilevered, with worried-looking men driving lorries full of stones across them to see if they break? Of course not! The research is into the strength of materials, conducted in laboratories using sophisticated instruments. From the knowledge so acquired, the bridge is designed by calculation. Sydney Harbour bridge had to work the first time!

It would be far-fetched to suppose that our knowledge of environmental interactions in agroforestry will ever reach the point when a precisely functioning system can be designed in this way, but the principle is applicable. If we understand how trees and crops share, and compete for, climatic and soil resources, we should be able to design agroforestry prototypes, systems that are likely to operate satisfactorily in a given set of conditions. Trials ("what" research) can then be conducted over small margins of variation.

Thus in order to design practical systems for farmers, agroforestry needs to be able to draw on the body of scientific knowledge. It presently makes use of results from many disciplines, both fundamental, such as microclimatology and soil science, and applied, including agriculture, horticulture and forestry.

It is in this respect that opportunity exists for a major contribution from TSBF. Knowledge of the formation, functioning and decay of soil organic matter, and of the supply, releae and cycling of plant nutrients, are essential to agroforestry design, as are interactions with soil water and fauna.

The basis for collaboration with agroforestry research lies in the two fundamental objectives of TSBF: to devise management options for improving tropical soil fertility through biological means, and to gain the understanding of soil biological processes necessary to achieve this. If research under TSBF can supply the basic knowledge, then agroforestry most certainly offers means of applying it to practical situations.

Figure 4 represents the relation that is conceived between the TSBF programme and agroforestry research.

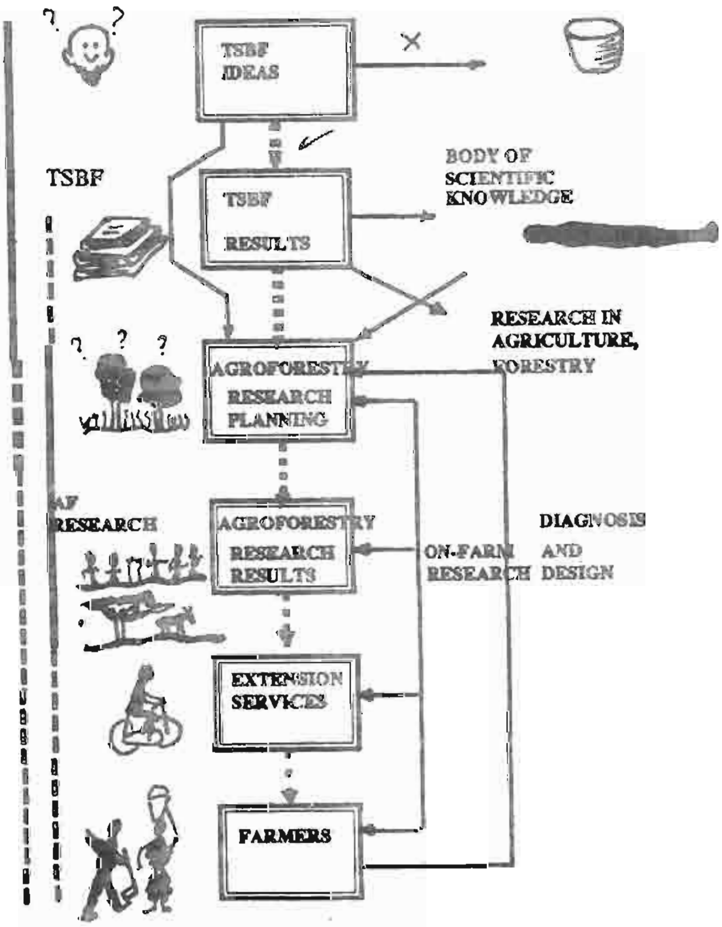

Figure 4- The relation between TSBF and agroforestry research

The starting point is TSBF ideas, the principles and hypotheses formulted and refined at successive meetings. These are leading, as the interim reports presented at this meeting show, towards TSBF research results. A few hypotheses may be found wrong, and are cast into the waste paper basket, whilst those that are proven enter the body of scientific knowledge.

These results will be drawn upon for applied research in agriculture, forestry and agroforestry. In agroforestry research planning, we have not waited for the results, but made use of the more promising hypotheses in the design of technologies. As an example, the decompotition and nitrogen release curves of leaves of *Gliricidia sepium, Flemingia congesta* and *Cassia siamea* were compared with nitrogen uptake by maise, a direct application of the TSBF Synchrony principle (Yamoa *et al*, 1986).

Applied agroforestry research leads to usable results, which can be passed to extension services for transfer to farmers. Current practice is to enrich this one-way sequence by the inclusion of on-farm research. The follow-up stages of diagnosis and design provide a further element of feedback.

There is an opportunity for a two-way exchange, not only of information but of active research. On the one hand, it is to be hoped that some TSBF centres will include agroforestry treatments in testing of hypotheses. Particular interest attaches to the manipulation of the woody and herbaceous residues produced by trees, and their distinctive root patterns.

On the other hand, it would be valuable to include the testing of some of the TSBF hypotheses within ICRAF's research activities. It would fall outside its mandate to conduct Level I studies of natural ecosystems, but selective testing at Level II could form a valuable component of its research programme. Further testing would be possible within its collaborative research networks. A three-way link with soil management research through IBSRAM's networks is a further possibility. Since the inception of TSBF, ICRAF has maintained close contacts in terms of exchange of information. It is to be hoped that means can now be found to extend this into field experimental collaboration.

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7. Programme Centre Description Tables

<u>LOCATION</u>	**Yurimaguas** **Peru**	**Mapire** **Venezuela**	**Ticoporo** **Venezuela**
Altitude	184m	56m	185m
Longitude	76°5'W	64°46'W	70°56'W
Latitude	5°45'S	7°42'N	8°12'N
VEGETATION			
Natural	Tropical moist Forest	Savanna/Tropical moist forest (Seasonally flooded)	Montane cloud forest
Experimental	Crops, Pastures a)Low input cropping b)High input cropping c)Alley cropping d)Mixed grass and legume pastures	Crops comparison of inundated forest and derived arable cropping system-cotton crop monoculture and corn and bean systems without fertilizer and pesticide input.	a)Natrual forest selectively logged planted with native *Cordia apurensis* in 1976. b)15 yr old teak (*Tectonia grandis*) plantation, planted in 1973. Natural forest clear felled and used afterwards for cattle grazing. c)16 yr old pine plantation (16 ha) mainly *Pinus Caribbaea* and *P. oocarpa* originally a provenance study area previously forested, clear felled and later used for cattle grazing.
CLIMATE			
Rainfall	2200 mm	1486mm	2154mm
Mean annual temperature (range)	25,9°C (25-27)	27.9°C (27,5-28.1)	25.8°C (25.3-27.5)
SOILS			
Taxonomy	Ultisol	Entisol	Inceptisol
Texture	Sandy loam	Clay loam	Silt loam
% OC	0.75		2.6
SOIL FAUNA			
<u>Biomass (g fw/m^2)</u>			
Earthworms	22.1		
Termites	9.8		
Myriapoda	7.4		
Arachnida	3.9		
Coleoptera	3.7		
Ants	2.0		
<u>Density (no/m^2)</u>			
Termites	2787		
Ants	688		Total 951
Earthworms	168		
Coleoptera	78		
Myriapoda			
Isopoda			

Programme Centre Description Tables (Continued)

LOCATION	Luquillo Puerto Rico	Rubber Res. Inst. Sri Lanka	LAM/BOR/FER/BOU Côte d'Ivoire [1]
Altitude	500m	a)470m b)30m	a)100m b) 455m cd)320m
Longitude	65°52'W	a)80°26'E b)80°03'E	a)5°02'W b)7°33'W c)5°14'W d)3°00'W
Latitude	18°18'W	a) 6°23'N b) 6°30' N	a)6°13'N b)8°28'N c)9°35'N d)9°16'N
8°12'N			
VEGETATION			
Natural	Tropical montane Forest	Tropical rain forest	Savanna
Experimental	12 yr old pine plantation a)Low input cropping b)High input cropping c)Alley cropping d)Mixed grass and legume pastures	a) Aseasonal lowland tropical rain forest b) 5 yr old *Hevea* rubber plantation with *Puraria phaseoloides* ground cover	a)Guinean savanna b)Sub-sudanian c)Sudanian savanna d)Sudanian savanna <u>NOTE</u> LAM= Station d'Ecologie de Lamto (a) BOR= Station de Booro Borotou (b) FER= Station de Ferkes Sedougou (c) BOU=Station de Bouna (d)
CLIMATE			
Rainfall	3807 mm	2000mm	1212mm
Mean annual temperature (range)	22.8°C (21.15-24.4)	24.7°C (21.0-28.2)	27.34°C (25.8-28.9)
SOILS			
Taxonomy	Ultisol	Ultisol	Alfisol
Texture	Silty clay loam	Sandy loam/Sdy Clay Loam	Silt loam
% OC	1.9		2.6
SOIL FAUNA			
<u>Biomass (g fw/m^2)</u>			
Earthworms	4.7	5.5	48.0
Termites		4.6	3.4
Myriapoda		1.3	3.0
Arachnida			
Coleoptera		1.2	
Ants			
<u>Density (no/m^2)</u>			
Termites		1230	1007
Ants		738	302
Earthworms	186	49	251
Coleoptera			250
Myriapoda			
Isopoda			

Programme Centre Description Tables (Continued)

LOCATION	Marondera Zimbabwe	Nylsvley South Africa	Brigalow Village (a) Narayen (b) Australia
Altitude	1640m	1100m	a) 300 m
Longitude	31'36E	28°42'E	a) 150°40'E b) 150°52'E
Latitude	18°12'S	24°39'S	a) 26°45' S b) 25°41'S
VEGETATION			
Natural	Semi-arid savanna	Semi-arid dystrophic savanna	Dry deciduous forest Brigalow (*Acacia harpophylla*)
Experimental	Crops Low imput corn	Comparisons of a) dystrophic savanna b) eutrophic savanna c) crop-corn	1)*Panicum maximum* grassland consisting of areas invaded by Rhodes grass (*Chloris guyana*) and broad leaved winter weeds.
CLIMATE			
Rainfall	931 mm	620 mm	675 mm
Mean annual temperature	17.2°C	18.9°C	20.0°C
(range)	(12.6-19.7)	(12.5-22.9)	(13.0-26.7)
SOILS			
Taxonomy	Alfisol	Entisol	Vertisol
Texture	Sandy loam/Sdy clay loam	Loamy sand	Clay loam
% OC	0.75	0.2	
SOIL FAUNA			
Biomass ($g\ fw/m^2$)			
Earthworms	0.89	0.0	
Termites	1.33	7.7	
Myriapoda	8.33	1.0	
Arachnida		1.3	
Coleoptera	4.2	7.2	
Ants			
Density (no/m^2)			
Termites	90	1859	
Ants		697	
Earthworms		0	
Coleoptera		348	
Myriapoda		0	
Isopoda	106	162	

8. Soil Organic Matter Decay Experiment (KILLSOM)

R.J. Scholes
in consultation with C. Palm, W.J. Parton, E. Elliott & P.A. Sanchez

8.1. Objectives

1. To measure the size of the slow SOM pool in different soils.
2. To determine the rate of turnover of SOM in various soils under different climates and how this rate is altered by soil tillage.
3. To establish a decomposition constant for intersite comparisons, based on the *in situ decay* rate of SOM.

8.2. Rationale

The conceptual scheme of SOM dynamics which has been adopted by the TSBF programme is the "functional model" (Parton *et al*, 1987). For the theoretical and experimental bases of this approach, consult Jenkinson and Rayner (1977) and van Veen and Paul (1981). The model considers the SOM to comprise three fractions with increasing mean residence times: the Active pool (MRT 1-2 years); the Slow pool (MRT 20-50 years) and the Passive pool (MRT 800-100 years). It is not possible to evaluate the magnitude of these pools by analysing the SOM within a single sample using current techniques, although it has been suggested (Sollins *et al*, 1984) that the pools are correlated with more traditional SOM fractions such as light and heavy fractions, with microbial biomass or the clay-associated SOM. Elliott (1986) suggests that the Fast and Slow pool are associated with the location of the SOM within or between soil aggregates.

This experiment aims to estimate the SOM pools by the repeated measurement, over a period of years, of the decline in organic carbon in small plots from which all organic inputs have been excluded. It is predicted that the decline will stabilise after a time at a level corresponding to the Slow plus Passive SOM pool. The active pool is suggested to be equivalent to the microbial biomass. The rate of the decline relative to a control plot under natural vegetation will provide a SOM turnover index for that particular soil-climate-vegetation combination. The experiment is to be replicated at TSBF programme participating centres all over the tropical regions of the world, providing a standardised database for the comparison of SOM dynamics under different conditions. The data will provide a rigorous test of the CENTURY model of SOM dynamics, which is based in the three-pool hypothesis (Parton *et al*, 1987).

An elaboration of the experiment is to include a treatment in which the isolated soil is disturbed on a regular basis by manual hoeing. This will provide an estimate of the degree to which SOM declines can be accelerated by agricultural practices, as well as providing a test of the Elliott hypothesis regarding the protection of SOM fractions in soil aggregates. Since the fate of nitrogen and phosphous in soils is intimately linked with that of carbon, their dynamics are expected to show a similar pattern.

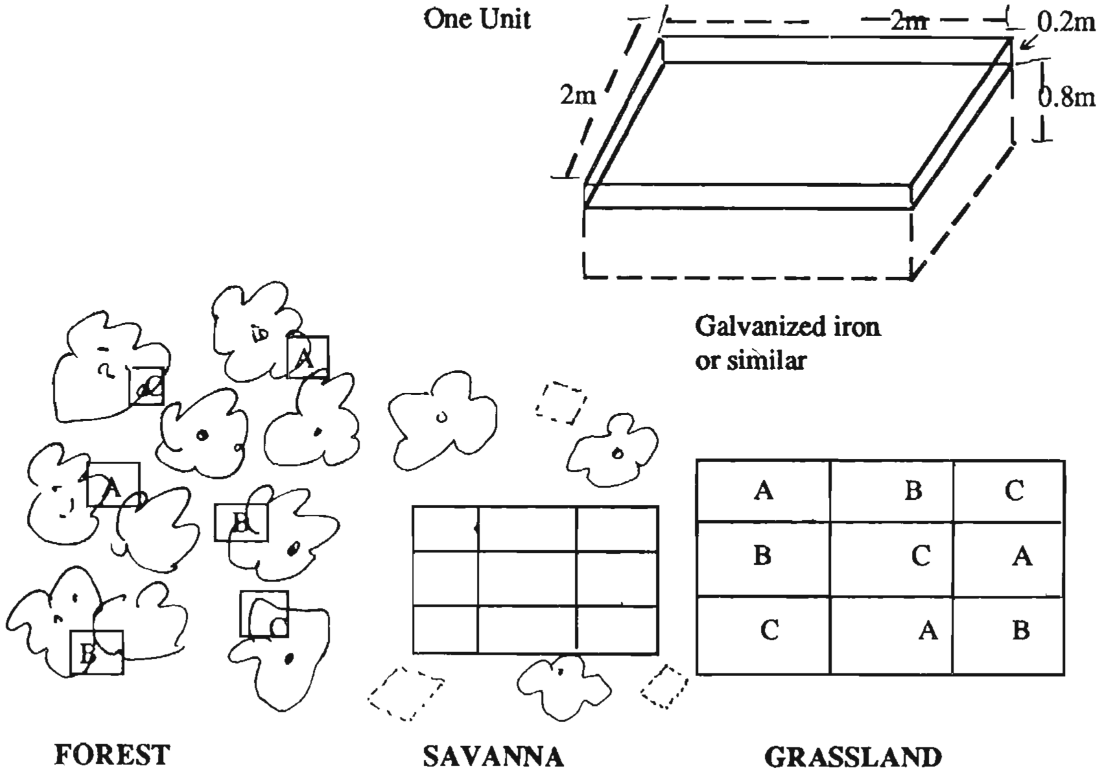
8.3. Experimental Design

The recommended size of the plots is 2x2m and the number of replicates should be three or more. There are three treatments:

A no organic inputs;
B no organic inputs = soil disturbance;
C control (long-term natural vegetation).

Therefore a minimum area of 36m2 is needed for the experiment. It is important that it be homogeneous with respect to soil (especially texture), past organic inputs and microclimate. All the replicates need not be in one contiguous block in order to satisfy these conditions. In treatments A and B the exclusion of above-ground organic inputs is achieved by keeping the plots free of vegetation by regular weeding (taking care not to disturb the soil in treatment A) and by removing fallen litter. The frequency with which the weeding and cleaning will have to be performed will depend on the time of year and the nature of the vegetation, but on an average should not need to be more ferquently than once a month. The below-ground inputs are permanently excluded by root barriers extending from above the soil surface down to 0.8m (or the lithic contact, in shallow soils). These barriers can be made of galvanised iron or any other durable material (such as concrete or glass-fibre reinforced plastic) which is impenetrable to roots. The barriers are inserted into narrow trenches, which are then back-filled, endeavouring to keep soil disturbance to a minimum. Where the natural vegetation includes trees, the control plots cannot be surrounded by treatment plots with root barriers, therefore disallowing strictly randomised block designs. A variety of example designs in different vegetation types are given in Figure 5.

Figure 5. Possible Experimental Designs in Different Vegetation Types for the KILLSOM Experiment



8.4. Sampling Procedure

The experiment should commence at the beginning of the rainy season and samples should be taken at 0, 2, 4, 8, 16, 26 and 52 time units from the start. In wet, warm climates such as tropical lowland forests, the suggested time unit is one week, thus completing the experiment in one year. In drier or cooler climates, such as the moist savannas or the montane forests a time unit of 2 weeks would be appropriate, and in the dry savannas 3 weeks is suggested. Some flexibility in timing samples to match growth seasons is acceptable.

Samples should be taken with a small-diameter (40mm or less) corer or auger at four random locations within each plot and combined for analysis. Excess sample should be returned to the holes. In treatments A and C a strict record of sampling position should be kept (for instance by placing a marker at each location) to prevent resampling an old hole.
The cores should be separated into 0-5, 5-10, 10-20, 20-40 and 40-80 cm depth segments and the following analyses performed (*TSBF Handbook of Methods*).

Depth (cm)	Sample time 0	2	4	8	16	25	52
0-5	Mic N LF Tot	Mic N	Mic N	Mic N LF Tot	Mic N	Mic N	Mic N LF Tot
5-10	Mic N LF Tot	Mic N	Mic N	Mic N LF Tot	Mic N	Mic N	Mic N LF Tot
10-20	Mic N LF Tot	Mic N	Mic N	Mic N LF Tot	Mic N	Mic N	Mic N LF Tot
20-40	LF Tot			LF Tot			LF Tot
40-80	LF Tot			LF Tot			LF Tot

Mic N - Microbial Nitrogen (microbial carbon and phosphorus are optional)

LF - Light Fraction

Tot - Total organic carbon, total nitrogen and organic and inorganic phosphorus

The dry mass of soil taken for each depth interval at each sample time must be recorded, along with the dimensions of the sample hole, to allow the bulk density of the soil to be calculated.

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