ISSN 1516-781X
June, 2002

Brazilian Agricultural Research Corporation
National Soybean Research Center
Ministry of Agriculture, Livestock and Food Supply

Documentos 182

International Technical Workshop on Biological Management of Soil Ecosystems for Sustainable Agriculture

Program, Abstracts and Related Documents

24 - 27 June, 2002

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Londrina, PR
2002

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1st Edition
1st Printing 06/2002: 300 copies

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Bibliographical standardization
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International Technical Workshop on Biological Management of Soil Ecosystems for Sustainable Agriculture (*2002 : Londrina, PR*)
Program, abstracts and related documents of the International Technical Workshop on Biological Management of Soil Ecosystems for Sustainable Agriculture. / — Londrina: Embrapa Soybean: FAO, 2002.
256p. - - (Documentos / Embrapa Soja, ISSN 1516-781X; n.182)

Organized by George G. Brown, Mariangela Hungria da Cunha, Lenita Jacob Oliveira, Sally Bunning, Adriana Montañez.

1.Agriculture-Production. 2.Sustainability. 3.Biodiversity. 4.Soil mannagement. I.Title. II.Serie.

CDD 338.16

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Foreword

Given escalating population growth, land degradation and increasing demands for food, achieving sustainable agriculture is critical to food security and poverty alleviation. Soil health and soil quality are fundamental to the sustained productivity and viability of agricultural systems worldwide.

Sustainable agriculture involves the successful management of agricultural resources to satisfy human needs while maintaining or enhancing environmental quality and conserving natural resources for future generations. Improvement in agricultural sustainability requires, alongside effective water and crop management, the optimal use and management of soil fertility and soil physical properties which rely on soil biological processes and soil biodiversity.

The promotion of soil biological management requires efforts to bring together indigenous knowledge/innovation and conventional science through participatory research methods and ecosystem approaches to soil management that help farmers understand soil-plant-water-pest-livestock interactions.

The soil is a very complex and multi-faceted environment. This complexity has prompted the evolution and adaptation of a highly diverse biotic community, which uses the soil as its permanent or temporary habitat or refuge. Many thousand species of animals and microorganisms can be found in soils, ranging in size from the almost invisible microbiota (e.g., bacteria, actinomycetes and fungi) to the more conspicuous macro and megafauna (e.g., earthworms, termites, millipedes, moles and rats).

Several processes crucial to the function and stability of natural and agricultural ecosystems are mediated or influenced by soil organisms. Organic matter decomposition and nutrient cycling, carbon sequestration and conversely greenhouse gas emissions, water infiltration and runoff and moisture retention (through effects on soil structure), plant production, suppression or induction of plant diseases and pests, detoxification and restoration of soil physical, chemical and biological properties are examples of such processes.

Soil organisms have also been used extensively for agro-industrial purposes such as food and medicine production as well as for genetic engineering purposes. It has been estimated that the value of the industrial and ecosystem services provided gratuitously each year by the soil biota (or soil-derived organisms) may exceed several hundred billion US dollars.

Human activities in using and managing the land for agricultural and forestry purposes have multiple direct and indirect impacts on soil organisms, soil properties and processes. It is increasingly recognized that the sustainability of agricultural systems depends on the optimal use of the available natural resources, including the important soil biotic community. Thus, a proper understanding of the influence of agricultural practices on the soil communities and their functions and, in turn, of the effects of the diverse organisms on agricultural productivity must be acquired. In this way the negative impacts on soil organisms and biodiversity can be minimized and their positive effects on agricultural productivity maximized for the benefit of humankind.

Today’s knowledge in this area is, however, fragmented and remains largely in the research domain, which limits its practical application by farmers. Various reasons include difficulty of observation and limited local understanding of below ground interactions and processes, specialised research focus and lack of holistic or integrated solutions for specific farming systems, and lack of, or inadequate institutional capacity or support services that allow a concerted resource management approach.

With increasing pressure on land resources, most countries worldwide are facing problems of soil erosion and degradation, biodiversity loss, low or diminishing soil fertility and unsustainable agriculture. Integrated soil management practices that build on a biological, physical and chemical knowledge-base and take into account the socio-economic context of the various land users, are essential to adequately address such problems. The strategies of each country to deal with these issues vary tremendously and some programmes or actions have been more successful than others.

In this context, there is a need to promote a concerted effort to understand the complexity of soil ecosystems, the soil-water-plant interactions and the role and importance of biological soil processes and management. Moreover, there is a need for achieving worldwide recognition of the need to protect soil and its functioning as the basis for human life on this planet. In this light, Embrapa (Brazil) and the Food and Agriculture Organization of the United Nations (FAO) joined forces to organise the “International Technical Workshop on Biological Management of Soil Ecosystems for Sustainable Agriculture,” hosted by the

Embrapa Soybean Research Centre in Londrina, Paraná from 24 to 27 June, 2002, with funds from the Netherlands Partnership Programme/FAO.

Over 45 participants from 20 countries, representing a range of scientists and practitioners with different backgrounds gathered to discuss the concepts and practices of integrated soil management, share successful experiences of soil biological management, and identify priorities to be implemented. The outcome is expected to guide the development of the International Initiative for the Conservation and Sustainable Use of Soil Biodiversity that was adopted by the 6th session of Conference of the Parties (The Hague, April 2002) of the Convention on Biological Diversity (COP/CBD), under its recent decision on agricultural biodiversity (decision VI/5).

Embrapa Soybean is honoured to have been chosen to host this event, and urges that the results of the workshop be promoted by multiple stakeholders to improve the land management practices of rural and urban communities, to enhance their livelihoods and achieve a truly sustainable agriculture that is both environmental sound and economically viable.

Dr. Caio Vidor
Director
Embrapa Soybean

Dr. Parvis Koohafkan
Chief
Land and Plant Nutrition
Management Service, FAO

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Introduction

The **"International Initiative for the Conservation and Sustainable Use of Soil Biodiversity"**

The Conference of the Parties to the Convention on Biological Diversity (CBD) (decisions III/11, IV/6 and V/5) identified soil biodiversity as an area requiring particular attention in regard to agricultural biodiversity.

It further decided, at its 6th meeting in April 2002, (VI/5) to establish an **International Initiative for the Conservation and Sustainable Use of Soil Biodiversity** as a cross-cutting initiative within the programme of work on agricultural biodiversity, taking into account case studies which may cover the full range of ecosystem services provided by soil biodiversity and associated socio-economic factors and, inviting FAO, and other relevant organizations, to facilitate and co-ordinate this initiative.

Given escalating population growth, land degradation and increasing demands for food, achieving sustainable agriculture and viable agricultural systems is critical to the issue of food security and poverty alleviation in most, if not all, developing countries.

Sustainable agriculture (including forestry) involves the successful management of agricultural resources to satisfy human needs while maintaining or enhancing environmental quality and conserving natural resources for future generations.

Improvement in agricultural sustainability requires, alongside effective water and crop management, the optimal use and management of soil fertility and soil physical properties. Both rely on soil biological processes and soil biodiversity. This calls for the widespread adoption of management practices that enhance soil biological activity and thereby build up long-term soil productivity and health.

This workshop is the first step by FAO to consider the issue of Soil Biodiversity and Sustainable Agriculture at a technical level and with a view to its subsequent consideration by FAO Governing Bodies, in regard to its role and cooperation in response to the proposed CBD Initiative and in accordance with FAOs mandate and programme of work and budget.

General Objectives

- **Share knowledge and increase awareness on the importance of soil biological management:** To raise attention in agricultural research, development, extension and education to soil biological activity and the importance and value of soil biodiversity in maintaining key soil functions - issues which have been seriously neglected compared to work on soil nutrient management, soil and water conservation and tillage.
- **Promote principles and practices for integrated management of land resources:** To support land users for the adoption of a holistic land management approach, which enhances agro-ecosystem health and soil quality by promoting biotic and abiotic synergies in the system, with a view to ensuring the sustainable use of agricultural systems and their biodiversity.
- **Provide technical guidance to realise the benefits of integrated soil biological management:** To develop strategies, approaches and technologies on integrated soil biological management to enhance the productivity and sustainability of the range of land use systems. These should build on available knowledge, safe technologies and experiences of farmers and researchers through the application of the ecosystem approach and multi-disciplinary and multi-stakeholder participation.

Specific Objectives

- **Promoting technical assessments:** to advise farmers, policy makers and planners on indicators and methods for assessment and monitoring of soil health and functions, notably, to improve knowledge on a) the roles and importance of diverse soil organisms in providing key goods and services and b) on the positive and negative impacts of existing and new agricultural technologies and management practices. This should further the development of appropriate guidance for field practitioners and technicians and for national and international priority setting and policies. It should lead to a set of practical and rapid assessment indicators and methods for use on farm to determine the effects of agricultural practices and intensification on key soil biota/ biological communities and their biological activity and functions, with particular attention to soil fertility, agro-ecosystem resilience and sustainable production capacity.
- **Strengthening capacities and partnerships** among farmers/land resource users, researchers and development programmes: a) for the monitoring and assessment of different farming systems, technologies and management practices in regard to their effects on soil biodiversity and its functions; b) for integrating soil biodiversity issues into agricultural and land management training materials and relevant programmes and policies (guidelines, compendia of “best practices”, etc.); and, c) for facilitating participatory research and technology development on soil biodiversity/biological management, with a view to promoting sustainable and productive agriculture and improved land management. There is a need to evaluate relevant on-farm skills for and educational and professional training needs for the adaptation and development of improved soil biological management for different farming systems and farmers at various socio-economic levels.
- **Sharing of knowledge, information and awareness raising** on the outcome of the above monitoring, assessment and adaptive

management activities in specific agro-ecosystems and farming systems. Further contributions are to be encouraged in response to the COP's call for case studies illustrating experiences in the conservation and sustainable use of soil biodiversity, from all concerned actors in the agriculture and environment sectors. This is intended to facilitate the review and prioritisation process for further work. In particular, efforts are needed to determine the economic importance of soil biota/biological activity through invitation and support of countries to review and assess the direct and indirect values of soil biodiversity and its functions.

- **Mainstreaming** soil biodiversity/biological management into agricultural and land management and rehabilitation programmes **and strengthening collaboration** among relevant programmes, networks, research institutes and national and international bodies on integrated soil biological management. This could include *inter alia,* mainstreaming the results of the above items, for example: a) the application of soil bio-indicators and field methodologies for monitoring and assessing soil biodiversity and its functions; b) promoting best soil biological management/land use practices for maintaining soil quality and health under different agro-ecological and socio-economic conditions. There is also a need to harmonise and strengthen national policy and planning mechanisms through integrating soil biology management in land-use planning, agricultural production, environmental impact assessment, soil fertility, soil and water conservation practices and rehabilitation and reforestation programs among others.

Expected results

1. Agree on the strategy and modalities (what, who, where and how) to develop the International Initiative for the Conservation and Sustainable Use of Soil Biodiversity, with a focus on concrete actions for the management and restoration of a healthy and well functioning soil through farmer driven and multi-sectoral approaches.
2. On the basis of existing know-how and experiences, determine priorities and key elements for action in the agricultural sector, as part of an eventual strategy for implementing the International Initiative for the Conservation and Sustainable Use of Soil Biodiversity including:
   a) identification of opportunities for capacity building (farmer, institutional and policy level) for the participatory adaptation and use of improved soil biological management;
   b) Identification of opportunities for collaboration and networking with the aim of raising awareness and knowledge and exchanging information and practical experience;
   c) Identification of constraints (social, technical and economic) and opportunities and required modalities for promoting improved management of soil ecosystems, applying the ecosystem approach;
   d) Identification of needs for further research/clarification to overcome gaps in knowledge or other limitations (social, economic, political, etc.) to biodiversity conservation and improved management of soil ecosystems;
   e) Development of practical guidelines adapted to different farming systems for promoting the sustainable use of soil biodiversity and enhancing its functions, including recommendations for their application and further development;
   f) Formulation of specific recommendations concerning the further development of the International Initiative on Soil Biodiversity through a multi-stakeholder and multi-partner process.

3. Coordination with: a) other programmes of work (dry and sub-humid lands; forest biodiversity) and cross-cutting issues (indigenous knowledge, benefit sharing, etc.) and national Biodiversity strategies and action plans under the CBD: and b) with other international and national action plans and processes (UNCCD, UNFCCC, NEAPs, GSPC, agriculture strategies, etc.)

   The proposals should be pragmatic and realistic and to the extent possible time-bound.

   The recommendations and actions will be shared with other stakeholders and submitted to SBSTTA-8 for consideration together with any suggestions of FAO Governing Bodies.

Official Program

Arrive Sunday 23 June Evening reception (18:30 - 22:30)

Day 1 - Monday 24

8:30 - 9:00	Bus leaves from hotel to Embrapa Soybean
9:00 - 9:30	Registration and orientation
9:30 - 9:45	Opening session and General Welcome from Brazilian host (Embrapa Soybean Director, Caio Vidor)
	Introductory presentation by FAO and CBD representatives
9:45 - 10:05	Context and scope of the workshop, FAO role and International Initiative on Soil Biodiversity, need for integrated approaches and expected results, including questions from the floor (Sally Bunning, FAO)
10:05 - 10:25	The experience and process for an International Initiative: building on the Pollinators experience (Braulio Dias, Brazilian Ministry of the Environment)
10:25 - 10:45	Coffee break
10:45 - 11:00	Overview of workshop process and sessions (Adriana Montanez, FAO)
	Presentation of experiences on Biological Management of Soil Ecosystems
	1. Assessment and Monitoring
11:00 - 11:20	Bioindicators of soil health: assessment and monitoring for sustainable agriculture (Clive Pankhurst, CSIRO)
	2. Adaptive management
11:20 - 11:40	Adaptive management of soil ecosystems and soil biodiversity: an overview and examples (Lijbert Brussaard, Wageningen Agricultural University)
	3. The role of innovative technologies

11:40 - 12:00	Organic farming management with biological agriculture in drylands (Klaus Merckens, Egyptian Biodynamic Association)
12:00 - 12:20	Research amd innovation in biological management of soil ecosystems (Paul Cannon, CABI)
12:20 - 13:45	Lunch at Embrapa
13:45 - 14:30	Plenary Discussion: Presentation of scope and aims of Working Group Session 1
14:30 - 16:30	**Working Groups (session 1)**
15:40 - 16:00	Coffee Break
	Wider implications of soil biological management
16:30 - 17:00	Soil C sequestration for sustaining agricultural production and improving the environment (Rattan Lal, Ohio State University)
17:00	Back to hotel Dinner on your own

Day 2 - Tuesday 25

8:30 - 9:30	Plenary Discussion: Report back from working groups.
	Presentation of case studies
	1. Assessment and Monitoring
9:30 - 9:50	Practical tools to measure soil health and their use by farmers (Martin Wood, University of Reading)
	2. Adaptive management
9.50 - 10:10	The role of ecosystem engineers in soil rehabilitation process (Abdoulaye Mando, INERA).
10:10 - 10:30	Transition from traditional to monocropping and more recently to weed-free mixed cropping and no tillage systems (Richard Fowler, ACT)
10:30 - 10:50	Coffee break
	3. The role of innovative technologies
10:50 - 11:10	Plant flavonoids and cluster roots as modifiers of soil biodiversity (Felix Dakora, University of Cape Town)

11:10 - 12:30	**Working groups (Session 2)**
12:30 - 13:45	Lunch at Embrapa
13:45 - 14:45	**Working groups session 2 (cont)**
14:45 - 15:40	Plenary Discussion: Report back from working groups
15:40 - 16:00	Coffee Break
16:00 - 17:30	**Presentation of several Case Studies** Insect-pests in a biologically managed soil and crop - the experience at ICRISAT (Om Rupela, ICRISAT) Management of macrofauna in traditional and conventional agroforestry systems from India with special reference to termite and earthworms (Bikram Senapati, Sambalpur University) Mycorrhizae in Cuban agricultural systems (Eolia Treto, INCA) Adaptive management for redeveloping traditional agroecosystems (P.S. Ramakrishnan, Nehru University)
17:30	Back to hotel
19:30 - 22:00	**Workshop Dinner** (Churrascaria Galpão Nelore)

Day 3 - Wednesday 26

	Capacity building and mainstreaming in assessment, management and research
8:30 - 8:40	Introduction of theme on capacity building and manistreaming (George Brown)
8:40 - 9:00	Strategies to facilitate development and adoption of integrated resource management for sustainable production and productivity improvement (Fidelis Kahiura, Tanzania Agricultural Research and Development Institute)
9:00 - 10:00	**Round table discussion** Opportunities and constraints for South-South cooperation: technology development, training, etc

10:00 - 10:20	Coffee break
10:20 - 12:00	**Working groups (Session 3)**
12:00 - 18:00	Packed Lunch and Field trip: Humanitas Project, São Jerônimo (100 Km)
19:30	Arrive back to hotel
	Dinner on your own

Day 4 - Thursday 27

8:30 - 10:00	Plenary Discussion: Report back from working groups 1. Monitoring and Assessment 2. Adaptive management 3. Information management, exchange and networking 4. Public education and awareness raising 5. Research and technology, gaps and opportunities 6. Policy issues 7. Define responsibilities 8. Financial resources
10:00 - 10:20	Coffee Break
10:20 - 12:15	Steering committee pulls together results with reporter and chairman of each group
10:20 - 12:15	Tour of Embrapa Station (labs, greenhouses, field projects) for other participants
12:15 - 14:00	Lunch at Strassberg (German restaurant near Embrapa)
14:00 - 16:00	Final Plenary session. Workshop Conclusions
16:00 - 16:30	Coffee Break
16:30 - 17:30	Workshop Evaluation. Reports, commitments for follow-up activities, deadlines for activities
17:30	Back to Hotel

Friday - Sunday: Post workshop tour to COAMO and Iguaçu

Abstracts

Theme 1: Monitoring and Assessment

BIOINDICATORS OF SOIL HEALTH: ASSESSMENT AND MONITORING FOR SUSTAINABLE AGRICULTURE

Clive Pankhurst

CSIRO Land and Water, Davies Laboratory, PMB P.O., Aitkenvale, Townsville, Queensland 4814, Australia. Clive.Pankhurst@csiro.au

The soil is a dynamic, living resource that is vital not only to the production of food and fibre, but also for the maintenance of global balance and ecosystem function. Soil health has been defined as "the continued capacity of the soil to function as a vital living system, within ecosystem and land-use boundaries, to sustain biological productivity, promote the quality of air and water environments, and maintain plant, animal, and human health". The critical component of this definition is the importance it places on the continued capacity of the soil to function over time. We are all familiar with what these soil functions are – the capacity to decompose organic matter and recycle nutrients essential for plant growth; to provide a medium for plant growth (dependent on the maintenance of good soil structure); to maintain gaseous balance in the environment through the carbon cycle and to maintain environmental quality through the degradation of toxic chemicals and hazardous wastes. The continued capacity of the soil to provide these functions is critical to the maintenance of life as we know it.

Traditional agricultural practices (including monoculture plant production, mechanical cultivation and harvesting, excessive and indiscriminate use of chemical fertilizers and pesticides) used to maintain and increase crop and fibre production in many parts of the world, are placing pressure on the soil's capacity to maintain its function. This has resulted in the need to develop (1) a capacity whereby we are able to assess both the

degree of functional degradation of the soil and the rate at which it is occurring, and (2) a holistic ‘biological systems management’ approach to agricultural production which is focussed on maintaining soil health through improved management of the soils biological functions.

The concept of soil health indicators, whether they be measures of soil physical, chemical or biological properties, has evolved over the last twenty years or so. There have been several drivers behind this, none more so than producers, researchers and conservationists asking the question ‘What measurements should I make or what can I observe that will help me evaluate the effects of management on soil function now and in the future?’ Considerable research effort has gone into evaluating measurement of different soil properties for their indicator potential, resulting in several different approaches to how such indicators might be used and for what purpose. Whilst there is still no universally accepted list (or minimum data set) of what soil attributes could or should be measured in a given situation, the research has highlighted many practical considerations that need to be taken into account. These include standardisation of sampling and measurement methodology, standardisation of interpretation including definition of minimum threshold values for particular indicators, the frequency with which measurements should be made, and above all how to engage land-users into the process of using soil health indicators.

Whilst some proposed lists of soil health indicators do not include direct measures of soil biological attributes (ie. bioindicators) it has long been recognised that soil organisms and soil biological processes often are rapid and sensitive indicators of effects of changes in soil management. Changes in soil organism populations or biological processes (eg. microbial biomass, soil enzyme activity) in many instances may precede changes in soil chemical or physical properties. Since soil organisms are intimately involved in soil functioning, they also provide an integrated measure of soil health, an aspect that cannot be obtained with chemical / physical measures alone. Some problems with bioindicators include the fact that the measurements are often more costly and difficult to perform, they are more prone to spatial and temporal variation and it may be more difficult to convince land-users of their value and significance.

The importance of maintaining soil biodiversity as a pre-requisite of the soils 'continued capacity to function' has been the subject of many debates in recent years. Whilst there appears to be general agreement that diversity confers stability / resilience, the potential value of biodiversity measurements as indicators of soil health requires more research. Little is known of the biodiversity of most functional groups of soil organisms and one may legitimately ask would the capacity to assess this diversity be of practical value as a bioindicator of soil health. On the other hand, recent approaches based on measurements of functional diversity (eg. DNA technology to detect and quantify the activity of functional genes) in the soil may provide more insight into the linkages between soil biodiversity and the soils continued capacity to function.

Of immediate concern is how to engage land-users into the practical use of soil health indicators and into adopting a more holistic biological systems management approach to food and fibre production. Most land-users are driven by economics with a mind-set that increasing production is the only way to be profitable. Most are aware of the importance of replacing nutrients taken from the land in produce (eg. through the addition of fertilizers) and most are aware of disease problems and how they may be controlled (eg. with pesticides). The drivers for change are generally market-driven (eg. commodity prices), declining productivity or instances where off-site impacts (eg. nitrate leaching to groundwater, eutrophication of rivers) can be linked to agricultural management practices. A good example of this is the Australian sugar industry where cane yields have been declining for many years despite the development of new cane varieties and pesticide controls for known pests (eg. the cane grub). However, the reason for the declining yields can be associated with poor soil health resulting chiefly from the growth of cane as a monoculture and excessive tillage at planting required to remove soil compaction caused by heavy harvesting machinery. Using soil health indicators, the extent to which the soils had become physically, chemically and biologically degraded could be demonstrated to cane-growers. They were also advised that the only way to reverse this is was by changing the way they manage their soils. There were no ‘silver bullet or magic quick-fix solutions’. An essential component of this process has been for researchers to work in close collaboration with groups of canegrowers to develop a new systems approach based around the incorporation of green manure rotation breaks (to improve the biological health of the soil), and reduced tillage (to keep areas trafficked away from growing plants) into the farming system. Demonstration trials together with an economic analysis of the new system compared with the old were also important tools to facilitate this process. The approach was also based around providing the cane-growers with information concerning the health of their soils and the principles and benefits of maintaining good soil health. It was not based around providing them with recipes because what might work successfully in one region may not in another.

PRACTICAL TOOLS TO MEASURE SOIL HEALTH AND THEIR USE BY FARMERS

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We have tested a simple method for use by farmers and growers to assess the overall biological activity in soil. This method, based on soil respiration, provides information on soil health which can be used as the basis for management decisions, and can also be used as an educational tool for raising awareness of farmers about the living nature of soils. We consider this to be a necessary first stage in soil biodiversity/ soil biological management. This presentation will demonstrate the approach and will draw on experience of soil biological management with farmers in Bhutan and Kenya.

BIOLOGICAL SOIL QUALITY FROM BIOMASS TO BIODIVERSITY - IMPORTANCE AND RESILIENCE TO MANAGEMENT STRESS AND DISTURBANCE

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I think of the soil as a living system, where many, if not most, physical and chemical properties and processes are mediated by the soil biota, affecting plant productivity. Various aspects of the soil biota react sensitively to changes in the environment, including agricultural management. I will evaluate the usefulness of various biological parameters as indicators of soil quality, their ease of assessment, and their susceptibility to change due to disturbances or management. I conclude that certain measures of microbial biomass and activity, earthworm biomass, and community structure of microbes, nematodes, enchytraeids and earthworms give early warnings of long-term changes in organic matter, nutrient status and soil structure, which cannot be easily observed directly. These parameters are easy to measure and they are responsive to agricultural management.

In addition, I conclude that diversity confers stability/resilience on the ecosystem if (management) stress and disturbance reduce the number of species. However, the relationships between various diversity parameters at the level of the entire (soil) community on the one hand and community and ecosystem functioning and stability on the other are not straightforward, i.e. a causal relationship between soil biodiversity and ecosystem functioning and stability does not seem to exist, and the existing knowledge at this level is not yet sufficiently complete and quantitative to be of practical value for management.

Finally, I conclude that scientific knowledge that can contribute to the process of establishment of reference values of indicators of soil quality is often available, but the assessment of threshold values for management is something to be subjectively agreed upon in practical situations, rather than objectively assessed.

INTEGRATED MANAGEMENT OF PLANT-PARASITIC NEMATODES IN MAIZE-BEAN CROPPING SYSTEMS[*]

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A field study to determine the distribution and population densities of plant parasitic nematodes associated with beans was undertaken in Kakamega, Kiambu, Machakos and Siaya districts of Kenya. *Meloidogyne* spp. and *Pratylenchus* spp. were the most predominant endoparasites, occurring in 86 and 61% of the root samples, respectively. Ectoparasitic nematodes in the genera *Scutellonema* and *Helicotylenchus* were recovered in 86 and 59% of the soil samples, respectively. Field experiments were conducted to determine the efficacy of organic amendments (chicken manure, compost, neem leaves, baobab remains and farm yard manure) in the control of root-knot nematodes. The amendments showed varying levels of nematode suppression with chicken manure being rated as the most effective with galling index of 2.4 while sisal wastes were least effective with galling index of 5.1. Another study was undertaken to determine the reaction of 35 bean genotypes to *Meloidogyne* incognita. Ten genotypes were rated as susceptible while 3 and 22 genotypes were rated as resistant and moderately resistant, respectively. The potential of different *Bacillus* isolates to suppress galling by root knot nematodes in beans was investigated using sterile sand in Leonard jars under greenhouse conditions. The isolates had varying effect with the majority (93%) of the isolates causing a reduction in root galling when compared to the control (water). Twelve percent of the isolates were more effective than carbofuran (nematicide). In another greenhouse experiment investigating the interaction between *Bacillus* spp. and *Rhizobium* strain inoculations using N-free sterile sand, 4 out of the 20 *Bacillus* isolates significantly promoted nodulation in bean plants.

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[*] *See complete case study on page 155*

MICROBIAL QUANTITATIVE AND QUALITATIVE CHANGES IN SOILS UNDER DIFFERENT CROPS AND TILLAGE MANAGEMENT SYSTEMS IN BRAZIL

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Several quantitative and qualitative evaluations of soil microorganisms have been made in Brazilian soils with three to 20 years under different combinations of legumes and non-legumes, in rotation or intercropping, as well as under different tillage systems. Under no-tillage, C and N in the microbial biomass were significantly increased (up to 50%), while CO_2 evolution decreased in relation to conventional tillage practices. The metabolic coefficient of soils under no-tillage was also lower, therefore contributing to the accumulation of C in those soils. Furthermore, substantial differences were verified in soils under different crop management, and were related mainly to rotation with legumes. Thus, these microbiological parameters proved to be good indicators of soil quality. Symbiotic nitrogen fixation with legumes such as soybean (*Glycine max*) and common bean (*Phaseolus vulgaris*), plays a critical role in Brazilian agriculture, therefore the rhizobial community was used as a model to evaluate microbial biodiversity. No-tillage systems and crop rotations including legumes resulted in higher rhizobial population and genetic diversity, evaluated by the DNA analyses with specific or arbitrary primers and/or restriction enzymes. Physiological differences related to C and N metabolism, tolerance to high temperature and salinity were observed among rhizobial isolates from soil under different management systems. Symbiotic properties also varied among isolates, resulting in higher nodulation, N_2-fixation rates and yield in sustainable systems. However, even in areas under proper soil management after some years of cropping several rhizobia species were undetectable.

DIVERSITY IN THE RHIZOBIA ASSOCIATED WITH *PHASEOLUS VULGARIS* L. IN ECUADOR AND COMPARISONS WITH MEXICAN BEAN RHIZOBIA

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Common beans (*Phaseolus vulgaris* L.) have centers of origin in both Mesoamerica and Andean South America, and have been domesticated in each region for more than 5000 years. A third major gene pool may exist in Ecuador and Northern Peru. The diversity of the rhizobia associated with beans has also been studied, but to date with an emphasis on the Mesoamerican center of origin. In this study we compared bean rhizobia from Mexico and Andean South America using both phenotypic and phylogenetic approaches. When differences between the rhizobia of these two regions were shown, we then examined the influence of bean cultivar on the most-probable number count and biodiversity of rhizobia recovered from different soils.

Three clusters of bean rhizobia were distinguished using phenotypic analysis and principal-component analysis of Box A1R-PCR banding patterns. They corresponded principally to isolates from Mexico, and the northern and southern Andean regions, with isolates from Southern Ecuador exhibiting significant genetic diversity. Rhizobia from *Dalea spp*, which are infective and effective on beans, may have contributed to the apparent diversity of rhizobia recovered from the Mesoamerican region, while rhizobia from wild *P. aborigineus* showed only limited similarity to the other bean rhizobia tested. Use of *P. vulgaris* cultivars from the Mesoamerican and Andean *Phaseolus* gene pools as trap hosts did not significantly affect MPN counts of bean rhizobia from the soils of each region, but did affect the diversity of the rhizobia recovered. Such differences in compatibility of host and *Rhizobium* could be a factor in the poor reputation for nodulation and N_2 fixation in this crop.

SISTEMAS INTEGRADOS GANADERÍA-AGRICULTURA EN CUBA*

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En 1994 se gestó en el Instituto de Investigaciones de Pastos y Forrajes de Cuba, un proyecto para el estudio, promoción, divulgación y puesta en práctica de sistemas integrados ganadería – agricultura a pequeña y mediana escala. Este proyecto cubrió las principales regiones ganaderas del país y su trabajo abarcó no solo fincas experimentales, sino que se realizó un fuerte movimiento de promotores en diferentes provincias que iniciaron un proceso de extensión participativa y trabajo práctico para la introducción de los conceptos de la integración.

Los indicadores seleccionados fueron aplicados a diferentes fincas de 1 a 20 hectáreas bajo diferentes condiciones de suelo y clima y su evaluación refleja como en todas las fincas integrales estudiadas se incrementó la biodiversidad durante tres años de establecimiento partiendo de áreas de ganadería con una biodiversidad reducida. El número de árboles por hectárea se incrementó a un ritmo de 26-50% anual y el promedio de productos alimenticios fue de 14, 17 y 20 para los tres primeros años. La biodiversidad total de plantas y animales varió entre 46 y 78 especies por hectárea. Además de los incrementos en la biota edáfica y fitófagos estudiados en algunas fincas.

Se ha comprobado además que es posible producir abono orgánico de buena calidad (pH 6.8, MO 42.6%, N 1.8%, P 0.7%, K 1.3 ppm, Ca 2.1 ppm; promedio de 17 composts estáticos) y de forma manual, a partir de los subproductos disponibles dentro de las fincas. Esto permitió fertilizar el área agrícola de los diferentes diseños ganadería- agricultura a razón de 2-6 t/ha de abono orgánico. Además, se produjo humus de lombriz en menores cantidades y se aplicó en mayor medida abonos verdes enterrados en el suelo.

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[*] *Presented by Eolia Treto Hernández.*

En lo relacionado con el reciclaje de nutrientes se puede observar como a través de la utilización de los abonos orgánicos, y fundamentalmente el compost, se pueden lograr altas tasas de reciclaje y regeneración A través de la fabricación de compost se logró devolver al suelo del área agrícola, donde se realizan las mayores extracciones, en forma de elementos fertilizantes hasta 120 kg./ha de N, 40 kg./ha de P, 90 kg./ ha de K y 140 kg./ha de Ca, además de los niveles de materia orgánica aportados que son de alrededor de 1.7-2.9 t/ha. Estos datos muestran en qué medida es posible la reincorporación de nutrientes por esta vía en beneficio de las condiciones fisico-químicas del suelo y como es posible sostener producciones altas prescindiendo de la incorporación de insumos externos.

La transformación de pastizales en áreas de cultivo con técnicas de agricultura orgánica produjo variaciones en la densidad y composición de la meso y macrofauna del suelo (especialmente de lombrices de tierra) produciéndose los valores más altos de densidad en el área de Forraje.

El comportamiento de las áreas fue diferente en la relación C mineralizado / aporte de C en la hojarasca, presentando el área de forraje un mayor aporte de hojarasca y cobertura al suelo lo cual ejerce un papel amortiguador de las variaciones bruscas en la mineralización del C así como en la biota del suelo en el periodo de seca.

El cambio a áreas de cultivos (C) produjo mejoras en sus propiedades físico-químicas al presentar mayor contenido de MO y menor densidad aparente, pero no en las condiciones necesarias para el establecimiento de la macro y meso fauna.

La abundancia y distribución de la fauna edáfica en las capas superficiales, el número de turrículos (deyecciones de las lombrices), el balance entrada/mineralización de carbono, la descomposición in situ de la hojarasca, la densidad aparente y el contenido de MO, pueden ser indicadores para evaluar la eficiencia en la aplicación de técnicas agroecológicas.

SOIL MACROFAUNA AS BIOINDICATOR OF SOIL QUALITY

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Soil macrofauna comprises a large number of taxa that exhibit highly diverse responses to soil condition and disturbances. They are relatively easy to collect, as they are seen by un-aided eyes, and can be identified at the family level with reasonably limited training. The objective of our work was to build a set of indices of soil quality that could be measured for any location using quantitative assessments of their communities performed with a standard methodology. A case study in France is presented as an example. Indicators of organic matter status were sought-for in cropped systems submitted to four organic treatments with or without mineral N applications, controls with no organic input and a forest.

The standard TSBF method was used for collection in the field. Collected invertebrates were separated into 42 taxonomic units (mainly at the family level) found to be relevant in previous studies and counted per sampling units. Data treatment allowed the identification of indicator taxa for different situations. Along the first axis of a correspondence analysis, sites were ranked (37,4% of variance explained) depending on the type of organic treatment as follows: control without organic input (C), biowaste (BW), farmyard manure (FYM), green waste composted with sewage sludge (GWS), municipal solid waste compost (MSW) and a forest (F). Isopoda, Myriapoda, snails, Pseudoscorpionida and Opilionida characterised sites with a developed litter system (forest, MSW and GWS) whereas Diptera larvae, Carabid beetles and anecic and endogeic earthworms characterised sites with no organic input.

The second axis opposed sites with-N to sites without-N application. Earthworms were found in treatments with no mineral N input whereas Diplopoda Polydesmidae and Diptera larvae characterized treatments with mineral N application. In this case, coordinates of sites along the first two axes may be considered as indices of (1) presence of a litter system and quality of organic inputs (axis 1) and (2) inputs of mineral N fertilisation.

A coinertia analysis between a set of 26 variables describing physical and chemical soil conditions and macrofauna showed a good match between the two sets of data ($p = 0.036$). In a second step, the application of the bioindicator index IndVal (Dufrêne and Legendre, 1996) will allow identification of groups that are specific indicators of a given type of system. Further calibration and validation of indices is needed and will be realized at different scales in order to consider the application limits and the standardization possibilities of such indices.

BIOLOGICAL FUNCTIONING OF CERRADO SOILS

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Soil microbial biomass, microbial respiration, and the activities of soil enzymes (acid phosphatase, β-glucosidase and arilsulfatase) have been evaluated at Embrapa Cerrados, since 1998. The objective of these studies is to determine the impact of different agricultural management systems (conventional tillage and no-tillage) on soil functioning and to evaluate the possibility of using these parameters as biological indicators of soil quality. These measurements were also conducted in different types of native vegetation (Campo Sujo, Cerrado Ralo, Cerrado Sentido Restrito, Cerradão and Mata de Galeria), with the purpose of gaining more insight about the biological functioning of undisturbed Cerrado soils. Soil samples were collected at the 0 to 5cm and 5 to 20cm depths, during the dry (August) and the rainy (January) seasons. In relation to a native Cerrado, located near the experiments, significant reductions in microbial biomass and phosphatase activity were observed in the agricultural areas. At the 0 to 5 cm depth, the no-tillage (NT) system presented higher levels of phosphatase, arilsulfatase and β-glucosidase activities as compared to the conventional tillage (CT). These effects were related to the lack of tillage, fertilizers' placement, and to the accumulation of crop residues at the soil surface.

HYDROLYSIS OF FLUORESCEIN DIACETATE AS A SOIL QUALITY INDICATOR IN DIFFERENT PASTURE SYSTEMS

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Microbiological measurements have the potential to be soil quality indicators. Thus, the effects of the environmental conditions and soil management practices on soil microbial activity were determined by the hydrolysis of fluorescein diacetate, during four seasons of the year, in five different ecosystems: native forest vegetation and four degraded pastures recovered by different techniques, including the use of an industrial effluent waste. The results indicate that microbial activity in native forest soil was higher than all the other treatments and varied from 32,46 to 58,99 µg of hydrolyzed FDA min^{-1} g^{-1} soil. There was also a tremendous increase in the total microbiological activity, in all soil treatments during the summer, reaching up to 45,11 µg of hydrolyzed FDA min^{-1} g^{-1} soil. The results indicate that the type of soil management used to recover degraded pastures and the season of the year influence microbial activity.

SOIL MANAGEMENT AND SOIL MACROFAUNA COMMUNITIES AT EMBRAPA SOYBEAN, LONDRINA, BRAZIL

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The soil macrofauna, comprised of invertebrates >2mm, includes both beneficials and pests of agricultural crops (e.g., termites, ants, earthworms, beetle white-grubs, true-bugs, snails, millipedes, centipedes, spiders, crickets, larvae of insects and others). Their diversity tends to be low in highly-disturbed systems (especially with cultivation and pesticides), but can be increased with appropriate soil and ecosystem management, including organic matter addition, direct drilling (NT) and crop rotations. Their activity is important for soil physical, chemical and biological properties and processes and also for plant growth and ecosystem productivity. Studies on the soil macrofauna communities were undertaken in 2001, in several trials with different soil and crop management systems in a distrophic Red Latossol at Embrapa Soybean. Samples were taken in the summer crop (soybean) and after winter wheat harvest, in plots with 8, 13 and 20 years of conventional planting (CT: disk plow) and NT with (NT1) or without scarification (NT2), planted with continuous double crops (wheat/soyebean) or crop rotation (lupine/maize-oats/soybean-wheat/soybean). In NT a large number of earthworms and millipedes were found, while in CT more beetles and enchytraeids were observed. In CT termites, lepidoptera larvae, spiders and pseudoscorpions (predators) were rare or absent. The abundance of natural predators and saprophages tended to be larger in NT that in CT. The total group diversity of the soil macrofauna and its equitability (Nº taxonomic groups sample^{-1}) was also larger in NT (16-18 and 10-11 groups, respectively) that in CT (12-13 and 6-7 groups). Studying the community composition of the soil fauna is important for the holistic understanding of the soil and its function, since the equilibrium/

disequilibria processes of these communities can result in the explosion of pests, the loss of good soil physical structure, soil fertility and productive potential. So far, very few measurements of the soil fauna communities in agricultural systems have been performed in Brazil and, due to their importance for soil function, these organisms deserve more attention.

Financed by the CNPq.

SOIL MACROFAUNA IN A 24-YEAR OLD NO-TILLAGE SYSTEM IN PARANÁ, BRAZIL

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The soil macrofauna was studied in a 24-year old no-tillage (NT) system on the Rhenânia farm, N Paraná, Brazil, in July, 1996. This is the oldest continuously managed NT farm in Brazil. Four treatments were studied: no-tillage, rotation no-tillage/pasture, pasture and native vegetation mixed with *Eucalyptus sp*. Using a modified TSBF method, five monoliths of 20x20x20 cm were sampled each treatment, 5 m apart and divided in three layers: litter, 0-10 cm and 10-20 cm. The macrofauna was removed manually from the soil and conserved in alcohol 75%. Posteriorly, they were separated in taxa, counted and weighed (0.0001g). Most of the fauna were concentrated in the upper part of soil in 0-10 cm (61,5%). The major components of density were Hymenoptera (Formicidae), Coleoptera (Scarabaeidae), Oligochaeta, and other invertebrates. Population density was highest in native vegetation, followed by no-tillage/pasture, no-tillage and pasture. Taxa diversity was higher in no-tillage.

INVERTEBRATE MACROFAUNA OF SOILS IN PASTURES UNDER DIFFERENT FORMS OF MANAGEMENT IN THE CERRADO (BRAZIL)

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The soil macrofauna of the Cerrado region near Uberlândia-MG, Brazil, was assessed, on May, 1997 in four treatments on Oxisols (Latossols): 1) Native Cerrado, 2) traditional *Braquiaria decumbens* pasture (20 years), 3) recovered *B. decumbens* pasture (improved) and 4) *B. decumbens + Stylosantes guianesis* pasture. The soil macrofauna was examined based on the recommendations of the T.S.B.F. (Tropical Soil Biology and Fertility) handbook of methods. The macrofauna was separated manually; the population density and the biomass were determined in the laboratory. Higher populations densities were found in Cerrado and *B. decumbens* (improved) treatments. The major component of the density were termites (91,5%); ants (4%), beetles (1,2%); earthworms (0,5%), and other invertebrates (2,8%). The Cerrado, *B. decumbens* (improved), *B. decumbens + S. guianesis* had the highest biomass. Populations were concentrated in the upper part of the soil in the 0-10 cm layer (47%). The management practices used in the recovered *Braquiaria* as well as in the *Braquiaria* combined with leguminosae (*S. guianesis*) were satisfactory for the recovery of areas degraded by long-term *Braquiaria decumbens* pastures.

SOIL TILLAGE MODIFIES THE INVERTEBRATE SOIL MACROFAUNA COMMUNITY

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The soil invertebrate macrofauna community is composed of many different groups, including earthworms, insects, diplopods and chilopods, among others. These animals are involved in the physical, chemical and biological processes of the soil, modifying the soil structure, nutrient cycling and the decomposition of organic materials. The following experiment was conducted to determine the impact of soil tillage on macrofauna, when part of a 4-year old no-tillage plot was transformed into conventional tillage management. In both systems, no-tillage (NT) and conventional tillage (CT), six monoliths, 25 x 25 x 30cm, were collected at three dates (1, 2 and 3 months after tillage). The soil macrofauna were removed manually (following the TSBF methodology), separated into taxonomic groups, counted and weighed. The data were then submitted to principal components analysis (PCA). The group of predators, including arachnids and chilopods, diminished in CT, having a greater correlation with the NT system; conversely, the number of earthworms and diplopods, consumers of organic matter, increased and were more correlated with the new CT system.

SOIL MACROFAUNA IN VARIOUS TILLAGE AND LAND USE SYSTEMS ON AN OXISOL NEAR LONDRINA, PARANÁ, BRAZIL

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The effect of tillage systems on soil invertebrate macrofauna was studied by comparing various agricultural systems with a forest, all located on an Oxisol near Londrina-PR, sampled on two dates: December 1998 (wet season) and August 1999 (dry season). The different systems studied were: forest, conventional tillage (PC), no-tillage with scarifier (SDE) and no-tillage (SD). Five monoliths (25 x 25 x 30 cm) were removed in each area, following the TSBF methodology. Soil macrofauna were counted, separated in taxons and weighed. The treatments SD and SDE were little different in terms of the taxonomic groups and population parameters observed, however the PC was significantly different in terms of the abundance of oligochaetes (enchytraeids) and ants, which tended to be greater than in the other systems.

INTERFERENCE OF AGRICULTURAL SYSTEMS ON SOIL MACROFAUNA

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The soil invertebrate macrofauna have an important influence on soil function through the formation of aggregates and holes (aeration) in the soil and the transport and decomposition of organic matter. Thus, several representatives of the soil macrofauna are “ecosystem engineers.” Thus, to evaluate the importance of these fauna and the engineers in different soil ecosystems, the differences in the macrofauna communities among no-tillage and other agricultural systems was assessed by taking samplings in four areas: no-tillage, conventional tillage, pasture and forest. Samples were taken in April 2000, in two locations in the district of Bela Vista do Paraíso, N Paraná State, established on a Red Latossol (Oxisol). Five monoliths were collected in each area (according to the TSBF methodology), with dimensions 25x25x30 cm, each 10 m apart. The monoliths were divided in four layers: litter, 0-10 cm, 10-20 cm and 20-30 cm. The macrofauna were removed manually and placed in alcohol 75%. They were then separated into taxonomic groups, counted and weighed. Data were submitted to the method of analysis multivariate, Principal Components (PCA), and to an ANOVA and test Tukey. No-tillage, when compared to the conventional tillage and pasture, presented the largest number of large soil organisms in the superficial layers (litter and 0-10 cm), while deeper in the soil, densities were similar among the different land-use systems. Thus, of the various systems sampled, no-tillage showed the greatest benefit for the maintenance of a large and active soil macrofauna and engineer community.

SCARAB BEETLE-GRUB HOLES IN VARIOUS TILLAGE AND CROP MANAGEMENT SYSTEMS AT EMBRAPA SOYBEAN, LONDRINA, BRAZIL

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With the aim of studying the efect of scarab beetle larvae (white-grubs, or corós) on the properties of an Oxisol at the Embrapa Soybean Research Station, the number, diameter and depth of the beetle-grub holes opened at the soil surface were measured in a long-term tillage and cropping systems trial. The measurements were performed in 12-year old experimental plots submitted to conventional (CT), no (NT) tillage, or scarification (chisel-plow) every 3 yr. All plots were either in continuous double-cropping (wheat/soybean) or a rotation including lupine/maize-oats/soybean-wheat/soybean. The results revealed that the beetle grub holes were much more abundant in NT (8,8-9,6 m^{-2}) than in CT (0,7-1,3 m^{-2}) plots, where tillage destroys them. The largest and deepest holes were also found in NT (up to 33,5 mm diam. and 117 cm deep). Consequently the total volume of pores opened in NT was up to almost 10 times greater than in CT. However, the mean diameter and depth of the few holes found in CT tended to be greater than in NT, probably due to the looser soil, and/or the need to go beyond the plow layer. Beetle grubs are not only pests, but they can also have important beneficial effects on the soil by burying litter (anecic behavior), and creating vertical holes that act as preferential pathways for water infiltration in large storms. Their predominance in NT is important, and their potential beneficial effects on soil function in these systems deserves more attention.

Financed by CNPq and Embrapa Soja.

BIOLOGICAL MANAGEMENT OF AGROECOSYSTEMS

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Nitrogen and phosphorus remain the most limiting nutrients for crop growth in the majority of developed and poor countries. The contribution of the symbioses between rhizobia/legumes, *Frankia*/actinorrhizal plants and arbuscular mycorrhizal (AM) fungi in recycling nutrients to exploit in crop rotations is to supply these nutrients. The aims of this study were to evaluate the effects of soil and legume cover/rotation crops managements on microbial biomass, AM fungi and *Rhizobium* populations and to identify the plant responses to inoculation with beneficial microorganisms. We found that legume cover crops between rows of perennial plants such as coffee trees altered the microbial biomass (C and N) and abundance of rhizobial populations that were highest in the soil cultivated with *Leucaena leucocephala*. Based on morphological characters of spores it was observed that composition and fluctuation of AM fungi population are changeable as a function of soil/crop management. Inoculation of “Peroba rosa” (*Aspidosperma polyneuron*) with *Gigaspora margarita* and *Glomus clarum* had significantly increased seedling growth. Also, *L. diversifolia, Casuarina equisetifolia* and *C. cunninghamiana* responded to inoculation with AM fungi and rhizobia/*Frankia*, implying that inoculation of trees probably improves N and P in degraded soils.

Partially supported by the Consórcio Brasileiro de Pesquisa e Desenvolvimento do Café; BIRD/Paraná 12 meses.

SOIL BIOTA AND NUTRIENT DYNAMICS THROUGH LITTERFALL IN AGROFORESTRY SYSTEM IN RONDÔNIA, AMAZÔNIA, BRAZIL

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A simple formulation of agroforestry system (AFS) using only three plant species (*Theobroma grandiflorum*, *Bactris gasipaes* and *Bertholletia excelsa*) was generally adopted in 1989 by farmers belonging to RECA´s (Reflorestamento Econômico Consorciado e Adensado) Association, in Rondonia, as their land use management model. Recently, after a period of high productivity, the sustainability of the systems seems to be declining. In this study we tested the hypothesis that low plant diversity in the systems prevents litter production in adequate quantities and nutritional qualities to maintain an efficient turnover of nutrients promoted by soil biota activity. We have compared AFS and the surrounding natural forest regarding the following parameters: (i) the amount of carbon immobilized by soil microbial biomass; (ii) the soil and litter macro-fauna biomass and density; (iii) the stock of soil mineral nitrogen, relating their amounts with N input from litterfall; (iv) the litter-layer mass and its nutrients content; and, (v) the influence of soil type in the nutrient dynamics in both AFS and native forest. The study was conducted in three small farms in each of two secondary roads (Linha 5 and Pioneiro) each of them with a different soil type, Yellow Cambisol and Red Latosol, respectively, but very similar agroforestry systems adjacent to native primary forest, used as a control. In each plot (AFS or forest) three composite samples (made of five subsamples) of litter layer and surface soil (0-10 cm) were colected producing a total of 36 samples (3 farms x 2 locations x 2 land use types x 3 replicates). For macrofauna, in each plot three monoliths (25 cm x 25 cm x 30 cm) were sampled. Microbial biomass was estimated according to Vance *et al*. (1987) and nutrients in litter-layer and macro-fauna analysed following Anderson & Ingram (1993).

Cambisols are poorer in nutrients than Latosols but Cambisols were generally higher in soil moisture, essential for soil biota activity. For both sampling, in wet and transitional season periods, total litter mass accumulation was similar on both Cambisol and Latosol, regardless of the land use type (Table 1). However, on Latosol and only for the leaf litter, the fastest decomposing fraction, differences between land use type were evident with AFS accumulating higher proportions of leaf litter than the forest (Table 1). In the litter layer, nitrogen and calcium were the nutrients with higher stocks independently of both soil and land use types (Table 2). In the wet season sampling, soil microbial biomass was significantly higher in the forest than in the AFS and particularly in the Cambisol, higher in soil moisture, than in the Latosol (Table 3).

There were no significant differences in the total density and in the number of taxonomic groups of macro-fauna between AFS and forest in both soil types (Table 4). The most abundant groups were Isoptera, Hymenoptera and Oligochaeta. In general, the AFS showed highest total macro-fauna biomass than the adjacent forest. In the Latosol,

TABLE 1. Fine litter-layer mass (total and parts) (g m^2) in agroforestry systems (AFS) and forest, on two soil types, in the wet and in the transitional periods. Values are the means of three plots of each treatment (n = 3).

	Cambisol (Linha 5)				Latosol (Pioneiro)			
	Wet season		Wet-dry transition		Wet season		Wet-dry transition	
	AFS	Forest	AFS	Forest	AFS	Forest	AFS	Forest
Leaves	289	226	425	419	545	226	415	290
Wood material	58.7	112	130	136	62.9	154	120	124
Reproductive parts	5.9	9.3	17.6	8.0	21.7	12.9	8.9	4.9
Total	353	347	572	563	430	394	544	419

TABLE 2. Macro-nutrient stocks in the litter layer (g m^{-2}) in agroforestry systems (AFS) and forest, in two soil types, in the wet season. Values are the means of three plots in each treatament (n = 3).

	Cambisol (Linha 5)		Latosol (Pioneiro)	
	AFS	**Forest**	**AFS**	**Forest**
N	41.7	34.3	40.2	35.8
P	1.5	0.9	1.7	1.1
K	2.8	2.5	2.7	1.9
Ca	8.1	3.3	8.3	5.8
Mg	3.0	1.8	2.8	1.3

TABLE 3. Soil microbial biomass (µg C g^{-1}) and soil mineral N (µg N g^{-1}) in agroforestry systems (AFS) and forest, in two soil types, in the wet season. Values are the means of three plots in each treatament (n = 3).

	Cambisol (Linha 5)		Latosol (Pioneiro)	
	AFS	**Forest**	**AFS**	**Forest**
Microbial biomass	258	471	156	237
Ammonium	7.3	4.6	10.0	6.8
Nitrate	17.5	24.6	6.9	25.9
Ammonium + nitrate	24.8	29.2	16.9	32.8

among the most abundant groups, Oligochaeta density was significantly higher in AFS than in forest soils opposed to Hymenoptera density, which was significantly lower in AFS than in forest soils. In the Cambisol, Isoptera was among the most abundant taxonomic groups, with higher density in the forest than in the AFS soils, while Oligochaeta density, including the introduced species, was lower in the forest than in the AFS soils. Nitrate was the dominant form of soil mineral nitrogen in both soil types and systems (Table 3). Nitrate concentrations were similar in forest soils of both Cambisol and Latosol but different in AFS

TABLE 4. Soil macro-fauna density (ind m^{-2}) in agroforestry systems (AFS) and forest, in two soil types, in the weet season. Values are means with standards error in parenthesis (n = 3).

	Latosol (Linha 5)		Cambisol (Pioneiro)	
Order	AFS	Forest	AFS	Forest
Gastropoda	4(4)	0	0	0
Oligochaeta	128(20)	43(17)	197(84)	21(11)
Isopoda	12(8)	9(9)	21(6)	7(5)
Aracnida	9(5)	11(3)	25(5)	30(4)
Diplopoda	2(2)	4(4)	0	4(4)
Chilopoda	30(15)	18(4)	11(5)	32(24)
Orthoptera	2(2)	4(2)	5(3)	2(2)
Heteroptra	2(2)	2(2)	4(4)	4(2)
Homoptera	2(2)	2(2)	0	0
Coleoptera	18(10)	14(8)	11(6)	20(2)
Hymenoptera	596(167)	192(90)	363(152)	427(137)
Isoptera	267(14)	299(57)	784	1349
Others	172(42)	68(49)	96(17)	160(32)
Total	1243	663	1516	2055

soils, where concentrations were significantly higher in Cambisol than on Latosol.

Thus, despite its lower fertility, the Cambisol, with a better soil physical structure, showed higher microbial and fauna biomasses, especially for important macro-fauna decomposers, such as Oligochaeta, Isopoda and Isoptera. That, in turn, caused a more efficient turnover of the litter and of the organic-N mineralization in the form of nitrate. As for the Latosol, a system management including a fast-growing forage legume may be recommended to improve soil structure and functioning.

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SOIL-C STOCKS AND EARTHWORM DIVERSITY OF NATIVE AND INTRODUCED PASTURES IN VERACRUZ, MEXICO

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The State of Veracruz is the second most important in Mexico regarding beef cattle and milk production. More than 60% of the state is in grasslands, dominated (70%) by native pastures which may be important sources of above and below-ground biodiversity as well as sinks for CO_2. However, these pastures are rapidly being converted to introduced (mono-specific) grass pastures. Little is known of the consequences of this conversion to the soil ecosystem. An IFS- & ICI-sponsored project studied the productivity and edaphic and biological properties and processes under native and introduced pastures during 2 years (in wet and dry seasons), at 5 sites in a N-S transect in the state of Veracruz. At all sites, native pastures were at least >10 up to >100 yrs old. Introduced pastures were >8 up to 36 yrs old. Soils ranged from clayey to sandy-loams and the C stocks from 42 up to 168 T ha^{-1} (0-80cm). C stocks were higher in native than introduced pastures on 4 sample dates and in introduced than native pastures on 3 occasions. These results differ from those obtained in Colombia (Fisher *et al*., 1994), where C stock of native pastures was always lower than in introduced pastures. Other recent results (da Silva *et al.*, 2000) show the important role of management practices in C storage-capacity of introduced pastures. Soil texture effects on C stocks are also important; soils with higher clay content presented much higher C storage-capacity than soils with more sand and less clay. The main differences between stocks at each site were observed at depths <40cm (AB horizon), and not deep in the soil profile, highlighting potential problems if these soils are converted to arable agroecosystems. Finally, seasonal variation in the

C stocks was also observed in several sites, revealing another often-disregarded factor in soil C-stock calculations.

Earthworm density at the sites ranged from 8-440 and 68-698 ind. m^{-2} in the dry and wet seasons, respectively, and biomass from 0.3-27.7 (dry season) and 7-97.5 (wet season) g m^{-2}, respectively. At some sites, biomass values exceeded those of the grazing livestock. Few significant differences were observed in the biomass and abundance values between native and introduced pastures. On the other hand, the conversion of native to introduced pastures tended to have negative effects on the number of earthworm species; twice as many species on average were found in native (4 sp.) than introduced (2 sp.) pastures (diff. sign. at $p < 0.07$). The earthworm fauna found at each site was also different: species and families (Megascolecidae) typical of N America were found in the sites N of the transverse neovolcanic axis, while those typical of S America (Glossoscolecidae) were found in the southern sites. A total of fourteen species, 10 native and 4 exotic were found, indicating slow exotic species invasion rates or little replacement of natives by exotics. At Martinez de la Torre (on the axis), only exotics (*P. corethrurus* and *O. occidentalis*) were found, while at Tuxpan only natives were observed. Highest species diversity was observed at Paso del Toro (7 sp.) and Isla (6 sp.), S of the Transverse Neovolcanic axis, and lowest was seen at Martínez de la Torre (2 sp.) on the axis, although further sampling efforts may reveal more species at these sites.

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Theme 2: Adaptive management

SOME THOUGHTS ON THE EFFECTS AND IMPLICATIONS OF THE TRANSITION FROM WEEDY MULTI-CROP TO WEED-FREE MONO-CROP SYSTEMS IN AFRICA

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Traditional crop production in Africa evolved as grain-centred, shifting-cultivation, multi-crop systems. With the advent of European technology, the mouldboard plough and population pressures, emphasis shifted from the planting, in association with self-seeding vegetables, of teff, millet and sorghum, to pure stands of wheat and maize; from minimum tillage to clean cultivation; and from shifting cultivation to continuous cropping. Mono-cropping and the elimination of all non-crop species have depleted soil nutrient resources in crop rooting zones; reduced the feed-sources available to soil macro- and micro-organisms; and restricted the range of foods and consequently nutrients available for animal and human nutrition. Repeated inversion of soils and the absence of rest periods have further reduced soil organism populations, in turn resulting in reduced pores, increased runoff and desertification. Yield potentials and hectarage continue to shrink, and human populations are becoming more susceptible to disease, famine and conflict. The promotion and adoption of minimum tillage and multi-cropping is essential if these trends are to be reversed or reduced. Such initiatives will require policy shifts at the highest levels; the re-orientation and training of government agencies and agents; the empowering of farmers; and the encouragement of especially multi-nationals to ensure profits are not attained at the expense of people or the environment, present or future.

TOWARDS SUSTAINABLE AGRICULTURE WITH NO-TILLAGE AND CROP ROTATION SYSTEMS IN SOUTH BRAZIL

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The use of cover crops and crop rotation not only protects the soil surface by water and wind erosion but also contributes with nutrients recycling and/or nitrogen fixing (mainly legumes) which favor the following crops. The understanding of how crop residues influence soil chemical, biological and physical properties, combined with the integration of residue management strategies into different cropping systems is a key to good soil fertility management. The no-tillage system associated with cover crops minimizes soil degradation processes, diminishes pests, diseases and weed populations, promoting changes in soil properties and also reducing the chemical external inputs needed, simultaneously enhancing crops yields over the long term. Crop residues provide a source of nutrients and inputs to soil organic matter and play an important role in maintaining soil productivity. The great challenge is to attain favorable mulch effects, and the equilibrium between organic input application and the synchrony of nutrient release with plant growth demands. Crop residue management that follows this purpose should be stimulated. In tropical conditions, improved residue management and reduced tillage practices should be encouraged because this will certainly promote soil and water conservation and consequently maintenance and/or increase in soil fertility and productivity, which will contribute to sustainable production.

EFFECT OF TERMITES ON CRUSTED SOIL REHABILITATION IN THE SAHEL[*]

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Land degradation is a major agricultural problem in the Sahel. During the recent decades the Sahelian soils have gone through serious and various form of degradation, the most spectacular one being the extension of completely bare and crusted-soils. The use of various mulch types and termite activity to rehabilitate crusted soil were tested, showing that, when mulch is placed on a crusted and bare soil, within a relatively short time it may be attacked by termites. Termite activity results in the change of crusted-soil's structure. Many voids are open through the surface seal and a loose layer is created on top of the soil due to termite sheeting. Throughout the soil profile, chambers and channels with irregular shapes are created. The aggregation of the soil by termites is also another form of crusted-soil structure modification. The change in soil structure improves soil physical properties like soil resistance to cone penetration, which can be reduced from critical level for vegetation growth to a level suitable for vegetation development. Bulk density is decreased and soil hydraulic conductivity greatly increased. Water infiltration and drainage are greatly improved. The combination of the increase in infiltration and the voids results in an increase of soil water storage in the soil profile. The change in soil characteristics due to termite activity is enough to create conditions necessary for natural vegetation development and crop production.

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[*] *See complete case study on page 191*

MANAGEMENT OF MACROFAUNA IN TRADITIONAL AND CONVENTIONAL AGROFORESTRY SYSTEMS FROM INDIA WITH SPECIAL REFERENCE TO TERMITES AND EARTHWORMS*

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The importance of beneficial soil organisms is generally well recognized by farmers and by traditional ecological knowledge, but conventional agrotechnologies mostly eliminate them. Low-energy feedbacks that operate through ecosystem engineers like earthworms and termites have high-energy effects for ecosystem stability. It is in this context earthworms and termites have been used as bio-monitoring agents in two agroforestry systems: 1) a traditional shifting cultivation system of the Bhuyan tribe of Orissa on the one extreme; and 2) a conventional tea plantation in Tamil Nadu on the other end. In shifting cultivation, the environment after the slash and burn is more conducive to termites than earthworms, and vice versa during the regenerative phases. In the conventional system, soil degradation is closely associated with high termite/earthworm biomass ratio which is reversed when preventive measures are undertaken for soil restoration. This experience shows that termite/earthworm relationships could be used as a synthetic index to indicate the status of land use patterns and soil health. Conventional practices need critical re-evaluation for the loss of sustainability and symbiosis from traditional practices, to optimize different ecosystem services for economical assurance and ecological insurance.

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* *See complete case study on page 172*

ADAPTIVE MANAGEMENT FOR REDEVELOPING TRADITIONAL AGROECOSYSTEMS

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Traditional societies (humans living close to Nature and natural resources) living in the forested tropics perceive themselves as an integral component of the ecosystem and landscape. They depend upon forests for sustaining a variety of multi-species complex agroecosystems, ranging from shifting agricultural systems to a whole range of traditional agroforestry/sedentary systems. These land use systems are dependent upon biodiversity, both natural and human-managed, for their traditional management. Traditional Ecological Knowledge (TEK) linked to biodiversity has always played a key role in balancing productivity on the one hand, with relative stability and resilience of these agroecosystems, and coping with uncertainties in the environment. However, these systems have undergone a whole variety of distortions, arising out of extensive exploitation of natural resources due to external pressures on natural resources. But, developmental efforts so far has largely been based upon text-book based knowledge of land use development, being completely divorced from the socio-ecological context in which these societies operate; this has often been rejected by these societies. Added on to these complex issues, these societies are also increasingly threatened by rapid ‘global change’ in an ecological sense and increasing ‘globalization’ in an economic sense. The challenge before the scientific community, therefore, lies in combining TEK with ‘formal knowledge’, and designing technologies that could form the basis for a redeveloped agroecosystem, based on community participation in the developmental process.

Validating TEK, which is a key issue, demands intense participatory research with local communities. This in turn implies linking natural with social sciences, and working at the inter-phase between ecological and social processes. Starting in the early 1970s, with an interdisciplinary research initiative on shifting agriculture in north-east Indian hill regions, I have been involved in looking into agroecosystem redevelopmental issues, in the Himalayan and the Western Ghat region in India. From these research efforts, I have come to the conclusion that the mix between TEK and ‘formal knowledge‘ would largely depend upon the varied stages at which the society finds itself today, in their socio-ecological perceptions and the way that they relate to nature and natural resources.

Reaching out to policy planners in the area of land use development/ management with community participation, is a complicated exercise; the first step in the direction is to build a strong socio-ecological basis. This demands new approaches based on an ecological paradigm that is different than that to which we are accustomed. This is discussed in the context of many experiences. This paper discusses adaptive management experiences in the area of: (a) shifting agriculture in the north-eastern Indian State of Nagaland, and, (b) a variety of other traditional agroforestry systems that were already breaking down due to land degradation in the Central Himalayan and the Western Ghat mountain areas of India. On a wider scale, I believe these experiences have relevance to traditional agroecosystem redevelopment in the tropical region, at large.

CONSERVATION AND SUSTAINABLE USE OF SOIL BIODIVERSITY: LEARNING WITH MASTER NATURE!

Odo Primavesi

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While working on environmental education, the main principles of Nature are to change and develop a primary natural rocky and practically inert environment to a climax natural environment were observed, in a multidisciplinary and global approach. This climax environment has a great biomass productivity and biodiversity of flora and fauna, in macro and microscale, with a very high photosynthetic efficiency per surface unit.

Considering the availability of sufficient energy, the key to the success for environmental restoration rests on the increase of available resident water in soil and the atmosphere, obtained by diversified vegetation, partially deep rooted perennial plants, its shade, its root activity and the energetic litter for the soil biota. Thus, any attempt to improve soil biodiversity for a sustainable agriculture needs to consider all technologies that improve resident water through diversified plant management on a soil protected by litter and a rooting network. Legume trees, inoculated with *Bradyrhizobium* and Mycorrhizae are very important tools. They are the same technologies suggested for clean water and soil conservation, for carbon sequestration, to reverse degraded landscapes, to stabilize microclimatic parameters and others. The main causes are the same. The remedies generally also.

CONVERGENCE OF SCIENCES: INCLUSIVE TECHNOLOGY INNOVATION PROCESSES FOR BETTER INTEGRATED CROP/ VEGETATION, SOIL AND BIODIVERSITY MANAGEMENT

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The approach to setting a scientific research agenda is to first carry out "technographic studies", i.e. an analysis of the institutional and policy environment in which soil and biodiversity problems, as perceived by farmers (from smallholder farms to plantations and from subsistence to market) and other stakeholders, become apparent. These are then followed by "diagnostic" studies to define concrete research projects. This approach should guarantee that social, cultural and natural science aspects are covered in a way which is conducive to adoption of any technology developed. In some of the projects biological management of soil is central. Although there are no results yet, I will explain this approach in broad lines, giving examples from The Philippines, Benin and Ghana.

POTENTIAL FOR INCREASING SOIL BIODIVERSITY IN AGROECOSYSTEMS

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Biological N_2 fixation and mycorrhizal fungi have been studied in farming systems as a contribution to nutrient transfer in the plant-soil system. Although most agricultural land-uses affect various beneficial microorganisms that play important roles in nutrient (such as N and P) cycling, some practices seem to be less harmful than others. The amount, activity and diversity of soil microbial communities seem to be related to organic C and N maintenance. Even though we still know little about the best management practices for soil quality or healthy soils, the available results seem to show that fewer cultivations are generally beneficial to the microbial community, including rhizobial and mychorrizal fungi. Although low pH does not seem to exclude *Phaseolus*-rhizobia from common bean cultivated soils, acidity combined with low P may limit rhizobia survival, diversity, and persistence, reducing legume nodulation. Long-term effects of liming, pig sludge application and legume crop rotations on microbial communities under no-tillage systems have been observed, such as: increases in microbial biomass, rhizobia/bradyrhizobia populations and mycorrhizal fungi colonization. Many of the benefits resulting from no-tillage, rotation with legumes and green manures appear to arise from changes in the soil organism (microbial and fauna) community and activity, which help improve the possibility of attaining a truly sustainable agriculture.

Partially supported by the World Bank - Paraná.

BIOLOGICAL NITROGEN FIXATION AND SUSTAINABILITY IN THE TROPICS

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The contribution of biological N_2-fixation (BNF) to the soybean crop in Brazil is the best example of economic return from investments in agricultural science and technology. However its benefit has been restricted mostly to soybean and to the large industrial farming operations. Removing limiting factors to productivity and developing, within the farmers, management practices that includes BNF are urgently needed. Nodulated and mycorrhizal legume species, together with addition of rock phosphate have been used successfully to colonise exposed subsoil and substrates derived from mining operations devoid of organic matter and does have a great potential to enhance productivity in a land management system involving perennials. Legume grain crops for family farming, agroforestry, pasture arborization, live fences, live poles, shifting cultivation, green manure, cover crops and organic farming are some areas of study that may be used to increase the benefit of BNF on soil sustainability and crop production in the tropics. Organic farming in Brazil today comprises around 200,000 ha of cropping area. On a world wide basis it is projected to expand from 10 to 20 % of all agricultural products. Research on BNF may also use this opportunity to work within the farm to enhance its insertion in soil management.

Theme 3. Research and innovation

PLANT FLAVONOIDS AND CLUSTER ROOTS AS MODIFIERS OF SOIL BIODIVERSITY

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Meeting the nutrient demands of plants for cell growth and biomass accumulation is a major challenge confronting most species growing in nutrient-stressed environments. Under conditions of nutrient limitation, symbiotic legumes optimize their nutrient acquisition by forming root nodules, fixing atmospheric N_2, and enhancing the uptake of other macro- and micro-nutrients. Germinating legume seeds and seedlings release flavonoids, betaines, and aldonic acids that serve as signals to root nodule bacteria and promote microbial growth and nodule formation. Additionally, some of these flavonoid molecules also function as defense compounds against soil-borne pathogens, or as weedicides against other plant competitors sharing the same ecological niche. In acidic and low nutrient soils such as those of the Cedarberg mounatins in South Africa, some plant species, such as the legume *Aspalathus linearis*, form cluster roots that promote nutrient mobilization through the exudation of organic acid anions. In this legume, cluster roots are probably a major source of nutrients for nodule formation and function. This is because our results show that nodules in closer proximity to cluster roots of *A. linearis* generally have higher concentrations of N, P and other nutrients compared to non-cluster root nodules. This presentation will explore some of the novel ways by which symbiotic legumes mobilize and/or acquire nutrients in low-nutrient environments.

THE SIGNIFICANCE OF BIOLOGICAL DIVERSITY IN AGRICULTURAL SOIL FOR DISEASE SUPPRESSIVENESS AND NUTRIENT RETENTION

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In terrestrial ecosystems diversity of vegetation and soil biota might affect the occurrence of plant diseases and the loss of nutrients. Reduction of pesticide use and mitigation of nitrogen and other nutrient losses from soil are important policy objectives. It is hypothesized that the coupling of activities between the plant and the decomposer subsystem is a key feature in terrestrial ecosystem functioning.

LINKING ABOVE- AND BELOWGROUND BIODIVERSITY: A COMPARISON OF AGRICULTURAL SYSTEMS

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Nutrient retention and disease suppressiveness are two important management objectives in agriculture. Since soil organisms play a key role in nutrient cycling and can reduce disease incidence, managing agricultural systems to increase soil biodiversity seems a promising new approach. Here we address the question whether below-ground biodiversity can be affected by increasing the above-ground biodiversity.

INSECT-PESTS IN BIOLOGICALLY MANAGED SOIL AND CROPS: THE EXPERIENCE AT ICRISAT

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The soil processes of decomposition and nutrient mineralisation are vital to eco-system functioning and crop production. It has been increasingly recognized that soil-fauna have a significant role in soil processes, affecting the quantity, composition and activity of soil microflora (Couteaux and Bottner, 1994; pages 159-172 in *Beyond the Biomass*, John Wiley, Chichester). Large quantities of crop residues are burnt in at least four Asian countries. Instead of burning, biomass can be used as energy source for microflora and fauna and contribute to soil nutrients. In an ongoing field experiment, on a Vertisol, initiated in 1999, we have four treatments in large plots. Two of the four treatments (RM - rice-straw mulch and FM - farm-waste mulch) received large quantity of biomass (10 t ha^{-1}) as surface mulch (no tillage), about 2 t ha^{-1} compost, and microorganism as soil inoculants and as plant protectants (all isolated from natural sources). Of the other two, one was a control - receiving normal tillage and all inputs as recommended for a given crop in the area, including chemical fertilizers and chemical pesticides. This treatment is considered as mainstream agriculture (MA). The fourth treatment (MA + biomass) is the same as MA but also received biomass at same level as in the first two treatments (RM and FM). The experiment is rainfed (normal rainfall around 730 mm). A different cropping system was followed in each of the three years; Pigeonpea followed by Chickpea in year 1, Sorghum/Pigeonpea intercrop in year 2 and Cowpea/Cotton intercrop in year 3. One of the focuses was to assess level of control of *Helicoverpa armigera*, a major insect-pest of several crops, with the biological management of soil and crops.

Three years were completed in April 2002. *Helicoverpa* was managed well in the RM and FM treatments in all the three years. Higher population of natural enemies of insect-pests such as *Coccinelids* and Spiders was noticed in the RM and FM treatments than in the control treatment. It was very apparent in year 3 and data was collected four times during the year. This indicates that the microbial pesticides used in the experiment did not adversely affect population of natural enemies of insect-pests. Except in year 1, the overall productivity per annum was highest in RM and FM than in the other two treatments. In the year 1, although the damage by *Helicoverpa* was low in RM and FM, the damage by pod sucking bugs such as *Nezara viridula* was high in pigeonpea and it reduced its yield. The high yield of RM and FM was largely due to less damage by insect-pests. The total dry matter yield, particularly of cereals, was generally higher in the MA and MA + biomass than in the RM and FM. Although we did not add any chemical fertilizers in RM and FM, the total N, total P total K and OC% in the soil after year 2 was similar or marginally higher in RM and FM, than in the other two treatments.

SISTEMAS AGRÍCOLAS MICORRIZADOS EM CUBA*

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El Instituto Nacional de Ciencias Agrícolas(INCA) ha impulsado, en los últimos años, en Cuba y otros países de América Latina el manejo efectivo de la simbiosis micorrízica a través de la investigación y el diseño de productos que permiten su aplicación exitosa en los cultivos de siembra directa (granos, cereales y otros) mediante el recubrimiento de las semillas. Esta técnica amplia extraordinariamente el espectro de acción práctica de la simbiosis. En este trabajo se resumen los principales resultados obtenidos con la inoculación, sobre diferentes modelos de producción agrícola como: obtención de posturas de cafeto en 6 tipos de suelos, desde Acrisoles hasta Cambisoles así como la producción en Cuba, Colombia y Bolivia de cultivos de alta importancia para la agricultura latinoamericana como son: el maíz, los frijoles, la soya, el arroz, la yuca y otros, tanto en condiciones de altos insumos como de una agricultura familiar. Se encontraron efectos siempre positivos de la inoculación micorrízica sobre el crecimiento y rendimiento en todos los cultivos. Se diseñó un manejo eficiente de la simbiosis a partir: 1) De la selección e inoculación de cepas eficientes basado en la baja especificidad cepa - cultivo; para un mismo tipo de suelo una o más cepas fueron efectivas para los diferentes cultivos. 2) Del tipo de suelo y su fertilidad asociada, lo que determinó el comportamiento de las cepas eficientes; la amplitud de este rango dependió de la cepa en particular. 3) De la necesidad de garantizar un suministro óptimo de

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* *Presented by Eolia Treto Hernández.*

nutrientes a las plantas micorrizadas para la obtención de altos rendimientos; este resultó inferior al de los sistemas intensivos no micorrizados. 4) De la efectividad de la micorrización, que no queda circunscrita a condiciones de suelo o sustratos de baja fertilidad.

Los resultados demuestran la importancia de introducir el enfoque de planta micorrizada eficientemente como elemento fundamental en los sistemas de producción agrícola.

THE EFFECT OF VELVETBEAN (*MUCUNA PRURIENS*) ON THE TROPICAL EARTHWORM *BALANTEODRILUS PEARSEI*: A MANAGEMENT OPTION FOR MAIZE CROPS IN THE MEXICAN HUMID TROPICS

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The beneficial effects of green manures on soil fertility and tropical annual crops are widely known. Velvetbean (*Mucuna pruriens*) is a tropical annual legume that is been intensively used in Central America as a green manure, mainly because it fixes nitrogen, decomposes very fast and has positive effects on the growth of annual crops (e.g. maize). In southern Mexico this legume has been in use for the last 30 years; a practice that has reduced and replaced the use of chemical fertilizers.

The objectives of this study were: i) to evaluate earthworm populations in maize crops that have been cultured during several years with *M. pruriens* (during the post-crop phase), ii) to test the impact of this legume in a selected earthworm species and iii) to clarify the effect of earthworms + Mucuna on growth and grain production of maize.

The field study was carried out in the southern Mexican state of Tabasco, where earthworm populations were surveyed in three different land use systems: maize, maize + Mucuna and pastures (three replicates for each system). The community was dominated by the native *Balanteodrilus pearsei*, a common species of S Mexico. Values of both abundance and biomass of this species were significantly lower in the maize culture than in maize + Mucuna and pastures; in terms of biomass, however, the highest values were found in the maize + Mucuna system (38.3 g m^{-2}). In laboratory experiments, growth and reproduction of *B. pearsei* were significantly higher in treatments improved with Mucuna. Finally preliminary results indicated that height and number of leaves of maize plants were higher in treatments of *M. pruriens* + *B. pearsei*. We conclude that the use of this tropical legume in annual crops should be encouraged as it improves earthworm populations, soil fertility and maize growth in a synergistic manner.

THE POTENTIAL OF EARTHWORMS AND ORGANIC MATTER QUALITY IN THE REHABILITATION OF TROPICAL SOILS

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Degraded soils are characterized by hostile conditions of low organic matter content, soil compaction and variable pH that often limit soil organisms and plant establishment. It has been suggested that earthworm inoculation and organic matter addition could improve the fertility of these soils, by enhancing processes such soil organic matter mixing, nutrient cycling and nutrient supply. Soil rehabilitation practices have included mainly anecic earthworms (given their active role in the subsoil bioturbation process) with very few studies addresing the role of other ecological categories. Another key factor in rehabilitation practices is the addition of different kinds of organic matter and its impact on earthworms.

In this study we investigated: a) the role of four tropical earthworm species, two endogeic and two epigeic, on organic matter burial, b) the effect of different mixtures of organic matter and soil on endogeic and epi-endogeic earthworms and c) the effect of species interactions (endogeic and epi-endogeic) on organic matter burial (the multi-species strategy for soil rehabilitation).

The results showed that i) endogeic *P. corethrurus* have a greater effect in the burial of organic matter than epi-endogeics *Amynthas corticis* and *A. gracilis*; ii) mixtures of soil with organic matter of different quality are necessary for supporting both endogeic and epi-endogeic species; iii) there was not a synergistic effect of species interaction on organic matter burial; iv) growth and reproduction in single-species treatments were higher than in multi-species treatments.

We conclude that multi-species strategies should be encouraged, since synergistic effects of multi-species treatments are expected to occurr in other variables that are currently under study (such as decomposition and nutrient cycling).

RESEARCH AND INNOVATION IN BIOLOGICAL MANAGEMENT OF SOIL ECOSYSTEMS

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Biodiversity is the key to sustainable soil ecosystems. 40% of the world’s agricultural land is now degraded to the extent that the soil is essentially inert, making it all but useless for farming. Land currently devoted to natural ecosystems is being used unsustainably at an every-increasing rate through “wreck-and run” agriculture policies, in both the North and the South. Below-ground systems are increasingly being recognized as crucial to healthy agriculture and forestry, yet research on biotic ecosystem components lags way behind above-ground studies.

Soil biotic activity occurs in many forms. One of the most critical is nutrient cycling, with C and N mineralization following degradation of (mostly) plant materials. The primary decomposers are fungi and bacteria, sometimes in synergy with other soil organisms such as earthworms. Also crucially important are symbiotic relationships between microorganisms and plant roots, especially fungal mycorrhizas promoting nutrient and water exchange, and nitrogen-fixing rhizobia. A wide range of soil organisms including bacteria, fungi, nematodes and soil-dwelling insects are antagonistic to plant growth, causing root and systemic diseases and infestations. Other organisms are beneficial to plant growth through competition with or direct parasitism/predation of the antagonist organisms, including fungicolous fungi and predatory nematodes.

The challenges involved in measurement and manipulation of soil biodiversity are considerable, but measurement is essential to manage manipulations. The number of species involved, especially of microorganisms, is often very large. Many species are poorly defined or completely unknown, and are difficult to quantify. Similar stories can be told for soil mesofauna, algae, protozoa and other major organism groups. Especially in tropical countries, identification manuals are scarce to non-existent. Despite these shortcomings in knowledge, there are ways of estimating soil biodiversity which do not require extensive and time-consuming high-level taxonomic investigations.

For some organism groups, functional characterization such as determination of trophic groups of nematodes provides good basic information on their diversity without identification of individual specimens. For microbial taxa, modern molecular tools show considerable promise in measurement and characterization of soil biodiversity. Techniques such as DGGE (differential gradient gel electrophoresis) of DNA profiles extracted from soil are well established for bacteria, are starting to be used for fungi and have the potential for diversity measurement in other important organism groups. Identifications cannot be obtained directly using these methods, but the gel profiles are a good indication of the diversity of organisms present. Molecular methods can also be used to detect particular species such as pathogens, and are potentially much more reliable than traditional baiting or isolation techniques. Modern and traditional tools can be combined to give a more complete picture of soil biodiversity.

These techniques give us the tools to measure differences in soil biodiversity following perturbations or changes in management practice, and to understand the relationship between pest/pathogen levels and saprobic competitors. There is some evidence that cultural practices which promote saprobic fungal diversity and biomass also lead to reductions in pest and pathogen problems, especially in the seedling establishment stages. There is great potential for the addition of biotic supplements to sown seed to aid establishment, and to use fungal antagonists such as *Trichoderma* species to protect vulnerable plants. Little research has been done on bioremediation of soils for tropical agriculture, but there are indications that such innovations could aid establishment in marginal areas, with the potential to restart the nutrient cycling process. Many of the techniques needed need only very basic equipment, and could be adapted with ease to small-scale farmer-based industries.

APPLICATION OF BIODYNAMIC METHODS IN THE EGYPTIAN COTTON SECTOR

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Introduction

Cotton is known worldwide as one of the most pesticide intensive crops. 18 percent of the chemical plant protection active ingredients are used worldwide in cotton fields, which represent only 0.8 percent of the cultivated areas in the whole world.

Due to the positive experience the SEKEM initiative has made in the biodynamic cultivation of herbs, cereals and vegetables, the Egyptian Government asked SEKEM in 1990 to develop a biodynamic cultivation method for cotton, as cotton is an important cash crop in Egypt. During the following years the SEKEM initiative developed a holistic biodynamic concept for organic cotton cultivation in close co-operation with scientists, farmers, consultants and consumers. This concept introduced for the first time in Egypt the use of pheromones to control cotton insects. Trained and experienced advisors support the farmers during the whole cultivation process. The cultivated varieties are two extra long stable and long season types. At the moment (1999) there are in Egypt 162 biodynamic farms, certified according to international standards (EU Reg. 2092/91 and Int. DEMETER Standards) with a total area of 5145 acres and 65 farms grow biodynamic cotton on an area of 815 acres.

In special processing steps, developed with Egyptian experts, the biodynamic cotton is spun, knitted or woven, dyed and finished without any synthetic chemical additives by mechanical and thermic measures. From the ready-made material the SEKEM textile factory produces high-quality children’s and baby wear. The distribution is based on two different ways. Firstly the export through the partner companies, who mainly supply important wholesalers in the United States, Germany, Switzerland and Austria. Secondly since 1995 through intensive local marketing and distribution. The nine SEKEM Shops in Cairo and a retailer chain with 10 boutiques in Cairo and Alexandria are selling the organic textiles successfully. The project is financing itself through the profits it gains out of the activities mentioned and will be continued.

Sustainable development issues addressed

The EBDA and SEKEM biodynamic cotton cultivation approach marks an important progress in the extension of land resource management in general and especially in sustainable agriculture, as cotton is one of Egypt’s main cash crops.

Results achieved

After the Aswan high dam stopped the fertile Nile mud flooding, Egyptian farmers started to use agrochemicals in agriculture. In only 20 years the total amount of pesticides in cotton cultivation raised up to 1.800 tons for 980.000 acres. The average yield of raw cotton remained stable at 900 kg per acre.

After applying the biodynamic methods to control the insects, which are nowadays promoted by the Egyptian authorities, the total intake of pesticides in Egyptian cotton areas could be reduced to less than 10% of the previous amount on nearly the same cultivation area. Today they are applied on nearly 80 percent of the whole Egyptian cotton cultivation areas. The average yield of raw cotton increased nearly 30 percent to 1.220 kg per acre. Furthermore biodynamic cotton is to a lesser extent contaminated with leaf fragments, has a better fibre elasticity as well as a few other fibre quality parameters, which are in general better than those of cotton from conventional origins.

This world-wide recognised success led the SEKEM initiative to organise the first international IFOAM conference of organic cotton cultivation in Cairo.

Lessons learned

EBDA and SEKEM have developed an exemplary solution for biodynamic cotton, which covers the whole chain from cultivation to processing, including the marketing up to the customer. This enabled them to build up a comprehensive understanding of the market and its constraints and improved the communication between all parts involved, in order to create products according to the customer's demands. In addition to that, they gained experience on how big the impact of biodynamic cultivation methods can be if applied to major cash crops, as the conventional methods used are to a big part responsible for land degradation in the most fertile areas of the country.

A successful cooperation from Producer to consumer - a case study

Organic cotton cultivation in Egypt is based on an intensive cooperation between farmers, scientists and manufactures. The final product design and of course the customers in Europe as here in Egypt are also involved.

The farms where cotton is cultivated organically are located in Fayoum, Kaliubea (southern delta area) and in Abou Matameer in the north. The cultivated varieties are two extra long stable and long season types. As previous crops preferably clover is cultivated and/or early onions as additional crop. The onions have high potential to protect the plants and stimulate the mycorrhiza, stimulating the young cotton plants during the first weeks.

The fertilization in biodynamic cotton cultivation is based on 45 - 60 m^3 / ha composted manure. If not already added to the compost, 500 kg/ha wooden ash and/or 600 kg/ha of Rock-phosphate are applied. Sowing starts at the end of February until the beginning of March.

After some years of field research and continuous improvement, a system for insect control was developed based only on natural substances and pheromone control. The design and location of the Pheromone traps as the application of Pheromone are essential for success in plant protection against the mayor pests the Leaf worm, the Pink bollworm and the Spiny bollworm. Therefore the Egyptian biodynamic farmers are working together with experts from the research centres.

The complete cultivation processes is done with the help of trained and experienced advisors. In the small scale farm structure of the rural areas, they help the farmers observing the development of harmful insects. A team of experts is on farm visits each week in a different region, to answer questions and solve urgent problems.

Picking the cotton by hand is the normal way in Egypt. The biodynamic fields like the conventional cotton is harvested in 2-3 picking rounds. 30-40 days before harvesting the last irrigation is done. Due to this measure the cotton plants ripen evenly. An application of the biodynamic Quartz preparation supports the ripening of the last capsules.

Unlike conventional plants the biodynamic cotton remain green up to the harvest. This reduces the faulting of the cotton fibres by brown leaf fragments and thus increases the quality.

Biodynamic cotton shows better fibre elasticity. Also other fibre quality parameters are generally better than those of cotton from conventional origins.

In special processing steps, developed with Egyptian experts, the biodynamic cotton is spun, knitted or woven, dyed and finished without chemical-synthetic additives by mechanical and thermic measures.

From the ready-made material the SEKEM textile factory produces high-quality children’s and Babies Wear. Textiles produced out of biodynamically grown cotton are offered under the name “CoTToN PEOPLE organic”.

The product range contains standard articles like pijamas, baby bodies and underwear. Twice a year a collection for children and teens are designed in cooperation with the sales partner in Germany and produced by SEKEM.

The distribution is made in two different ways. First the export through the German partner AlnaturA who mainly supplies important wholesalers in Germany, Switzerland and Austria. And second since 1995 also intensive local marketing and distribution were started. The three SEKEM Shops in Cairo and a retailer chain with 10 shops in Cairo and Alexandria is selling CoTTon PEOPLE organic Textiles successfully.

We think that we have developed an exemplary solution for biodynamic cotton cultivation, processing and marketing. Based on the chain from the cultivation up to the ready product and the customer in Egypt. In cotton cultivating countries it may be necessary to consider specific needs and situations however our experience may be helpful. We are looking forward to an open and lively exchange of different information.

Theme 4. Capacity building and mainstreaming

SOIL ECOLOGY AND BIODIVERSITY: A QUICK SCAN OF ITS IMPORTANCE FOR GOVERNMENT POLICY IN THE NETHERLANDS

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The quick scan ‘Soil ecology and biodiversity’ was commissioned by the Netherlands Ministry for Housing, Spatial Planning and the Environment to a group of scientists. The objective was to advise the government on how the ecological functioning of the soil can be described and used in promoting a more sustainable soil use in the Dutch policies on spatial and environmental planning. The focus had to be on soil ecological boundary conditions for certain types of land use and on insight into the indicators to be measured so as to evaluate the need and effectiveness of human interventions.

The group concluded that biological soil quality is to be protected because of its importance in terrestrial ecosystem functioning; the sustainable use of soil resources; the prevention of losses of greenhouse gases; the filtering and degradation of toxic compounds; and the enhancement of biological regulation of soil structure, plant nutrition and control of pests and diseases in agriculture. *A priori* assessment of effects of changes of land use for soil quality and resulting limitations to the desired use of the soil is needed, as well as a national monitoring programme of soil quality.

AGROTECHNOLOGICAL TRANSFER OF LEGUME INOCULANTS IN EASTERN AND SOUTHERN AFRICA[*]

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Legumes are an important component of smallholder farming systems in Eastern and Southern Africa and efforts are underway to improve legume yields and symbiotic biological nitrogen fixation (BNF) for replenishment of N depleted soils. Seed inoculation with rhizobia is recommended and solid formulations are produced in Kenya, Uganda, South Africa, Zambia and Zimbabwe where 40-50 tonnes of the solid carrier based rhizobia are produced annually. Although efforts to popularize this technology are in full gear, distribution and acceptance is still low.

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[*] *See complete case study on page 167*

AGRICULTURA URBANA EN CUBA[*]

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Un alto grado de sostenibilidad se ha logrado en la agricultura urbana, esta se base en varios principios básicos: distribución uniforme por todo el país con correspondencia entre la producción planificada y la población de cada territorio. Interrelación cultivo-animal procurando el reciclaje de todos los desechos. Uso intensivo de la materia orgánica. Manejo agroecológicos de suelos, sustratos, cultivos y plagas, con técnica de rotaciones, asociaciones, intercalamiento y controles biológicos. Utilización de cada metro cuadrado disponible durante todo el año. Integración interdisciplinaria e interinstitucional para dirigir la producción. Entre los impactos mas importantes, estan el incremento de la biodiversidad con mas de 10 especies por unidad, el autoabastecimiento territorial de semillas en 176 fincas municipales, la capacitación a productores con métodos participativos, la creación de 324,000 nuevos puestos de trabajo y 80,000 en perspectiva inmediata. La creación de un movimiento nacional de materia orgánica que trabaja para acopiar, procesar y aplicar 3 millones de toneladas de abonos orgánicos y un millón de toneladas de humus de lombriz. Se presentan los resultados del uso de varios sustratos con varios tipos de abonos orgánicos en hortalizas y la relación entre el contenido de materia orgánica y los rendimientos anuales.

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[*] *Presented by Eolia Treto Hernández.*

SOIL CARBON SEQUESTRATION FOR SUSTAINING AGRICULTURAL PRODUCTION AND IMPROVING THE ENVIRONMENT

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Agricultural ecosystems generally contain less soil organic carbon (SOC) pool than their potential capacity because of the low return and high rate of mineralization of bio solids, and severe losses due to accelerated erosion and leaching. Conversion of natural to agricultural ecosystems usually causes depletion of 50 to 75 percent of the antecedent SOC pool, thereby creating a potential sink capacity of 35 to 40 Mg C/ha. The depletion of SOC pool leads to decline in soil quality and resilience with attendant reduction in biomass productivity, decreased capacity to degrade and filter pollutants and increase in emission of greenhouse gases (GHGs). The depletion of SOC pool is more from soils of the tropics than temperate regions, and resource-based and low-input than science-based with judicious input of farm chemicals.

The SOC sequestration, increasing SOC pool through conversion to an appropriate land use and adoption of recommended management practices (RMPs), can reverse soil degradation trends, improve soil quality and resilience, increase biomass production and decrease the rate of enrichment of atmospheric concentration of GHGs. There exists a strong link between the labile fraction of SOC pool and soil biodiversity - the activity and species diversity of soil fauna (micro, meso and macro) and micro-organisms. Soil biodiversity is usually higher under pastures and planted fallow systems than under crops, and is likely to increase with adoption of conservation tillage and mulch farming, integrated nutrient management and manuring, and mixed farming systems. Similar to the impact on SOC pool, SOC sequestration can also be achieved by conversion from plow tillage to no till or conservation tillage, growing cover crops in the rotation cycle, achieving a positive nutrient balance through integrated nutrient management and precision farming, increasing use efficiency of fertilizers and pesticides, conserving soil and water and restoring degraded soils and ecosytems. Soil biodiversity is also achieved by replacement of toxic chemicals with benign ones, substitution of mixed crops and rotation for monoculture, and restoration of degraded soils and ecosystems.

The gross rates of SOC sequestration through adoption of RMPs range from 400 to 800 kg/ha/yr for cool and humid regions and 100 to 200 kg/ha/yr for dry and warm climates. The sustainability of a RMP, indicated by the non-negative trend in ratio of carbon output:input over a long-period of time, can be improved by enhancing the net rate of SOC sequestration through enhancing the use efficiency of input. The SOC sequestration is a win-win situation: it improves soil quality and resilience, achieves food security, improves water quality and mitigates the risks of accelerated greenhouse effect. Because adoption of RMPs may require land owners to change behavior from their business as usual plan, it is important to assess economic costs and benefits and identify policies that facilitate adoption of RMPs. Human dimensions research in political cultural and political ecology is needed to specifically address these issues.

CONSERVATION AND SUSTAINABLE MANAGEMENT OF BELOW-GROUND BIODIVERSITY: THE TSBF-BGBD NETWORK PROJECT

Michael J. Swift et al.

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The Global Envrionment Facility (GEF) has awarded $9 million to a consortium of seven countries (Brazil, Mexico, Cote d'Ivoire, Uganda, Kenya, India and Indonesia) for a project (of total cost with co-financing of $22 million) on the above topic. The project will be administered by the Tropical Soil Biology and Fertility Institute of CIAT (TSBF) located in Nairobi, Kenya, and will run for 5 years (2002-2007).

The project addresses the means by which below-ground biodiversity (BGBD) may be adequately managed and conserved in tropical agricultural landscapes. The processes of land conversion and agricultural intensification are a significant cause of biodiversity loss, including that of BGBD, with consequent negative effects both on the environment and the sustainability of agricultural production.

The objective of the project is 'to enhance awareness, knowledge and understanding of below-ground biological diversity important to sustainable agricultural production in tropical landscapes by the demonstration of methods for conservation and sustainable management'. The project has a particular focus on tropical forest margins and the complex community of organisms which regulates soil fertility, greenhouse gas emissions and soil carbon sequestration, and which is routinely ignored in biodiversity conservation and assessment projects. The project will explore the hypothesis that, 'by appropriate management of above- and below-ground biota, optimal conservation of biodiversity for national and global benefits can be achieved in mosaics of land-uses at differing intensities of management and furthermore result in simultaneous gains in sustainable agricultural production'.

In order to achieve this goal the project will produce five primary outcomes:

1. Internationally accepted standard methods for characterization and evaluation of BGBD, including a set of indicators for BGBD loss.
2. (a) Inventory and evaluation of BGBD in benchmark sites representing a range of globally significant ecosystems and land-uses. (b) A global information exchange network for BGBD.
3. Sustainable and replicable management practices for BGBD conservation identified and implemented in pilot demonstration sites in representative tropical forest landscapes in seven countries.
4. Recommendations of alternative land use practices, and an advisory support system, for policies that will enhance the conservation of BGBD.
5. Improved capacity of all relevant institutions and stakeholders to implement conservation and management of BGBD in a sustainable and efficient manner.

Background and Rationale:

The soil organism community, including bacteria, fungi, protozoa and invertebrate animals, is extremely diverse with, for example, over 1000 species of invertebrates identified in $1m^2$ of soil in temperate forest. The diversity of the microbial component may be even greater than that of the invertebrates yet is only just beginning to be realised by phylogenetic and ecological studies using molecular methods

Soil organisms contribute a wide range of essential services to the sustainable function of all ecosystems. They are the driving agents of nutrient cycling; they regulate the dynamics of soil carbon sequestration and greenhouse gas emission; they modify soil physical structure and water regimes; they enhance the amount and efficiency of nutrient acquisition by the vegetation through mycorrhiza and nitrogen fixing bacteria; and they influence plant health through the interaction of pathogens and pests with their natural predators and parasites. These services are not only essential to the functioning of natural ecosystems but constitute an important resource for the sustainable management of agricultural ecosystems.

Sustainable and profitable management of agricultural biodiversity, including BGBD, is dependent on information about the current status, the value perceived by the various sectors of society, and the factors which drive change in one direction or other. Despite its importance to ecosystem function the soil community has been almost totally ignored in considerations of biodiversity conservation and management even at the inventory level. This failure is partially attributable to the absence of agreement on standardised methods for the study of BGBD, and a lack of both knowledge and awareness of this key component of global biodiversity.

Amidst a policy and economic environment that often fails to acknowledge the importance of managing and conserving agrobiodiversity; farmers, rural communities, scientists, NGOs and the general public have become increasingly aware of the high environmental cost of many intensive high-input agricultural practices. Furthermore, it is now accepted that loss in biodiversity (including BGBD) is one of the major factors leading to degradation of ecosystem services and loss of ecosystem resilience. In many countries, however, conflicts have arisen between policies to support biodiversity conservation and ecosystem protection and those of agricultural development.

Documentation of BGBD, including the biological populations conserved and managed across the spectrum of agricultural intensification, is an essential component of the information required for assessment of environment-agriculture interactions, as is the evaluation of the impact of agricultural management on the resource base, particularly that of the soil. Development of appropriate policy requires, in particular, reconciling the needs for meeting food-sufficiency by high levels of agricultural productivity with those for conserving biodiversity and environmental protection. A major barrier here has been the lack of data on changes in diversity within agricultural landscapes and the assumption that there is necessarily a trade-off between biodiversity and agricultural productivity. There is now however growing evidence that farm landscapes can conserve significant levels of biodiversity.

Agricultural intensification can take a variety of paths. The conventional ‘green revolution’ path of arable cultivation (and its equivalents in livestock and vegetable production), utilizing high yielding varieties and supported by high levels of input is only one of a number of trajectories. Among the alternatives are those which deliberately retain higher levels of biodiversity. Examples include agroforestry systems, inter-cropping, rotational farming, green cover-cropping and integrated arable-livestock systems. All of these approaches are more or less closely derived from traditional practices of agriculture in the tropical regions. The values perceived in this dependence on diversity as opposed to the homogeneity of modernized agriculture are multiple and extend beyond the market value. They include, in addition to product profitability, the desire for multiple products, the spreading of risk, the social and cultural value of certain products and perceptions of resource conservation and enhanced pest control.

The total biological diversity of such intermediate systems can be very high. The deliberate maintenance of even a limited diversity of crops and other plants (particularly if trees are included), results in substantial multiplication of the associated diversity - for example of the above-ground insect population and of the below-ground invertebrates and micro-organisms. Landscapes which include such systems are more likely to conserve biodiversity in comparison with those restricted to high-input systems. There is evidence that mosaics of different systems, including those at different levels of intensification, maintain a higher diversity than monotypic landscapes of any kind including natural ecosystems on their own. A major issue to be examined in this project is that of whether there are additional benefits in integrating, as compared with segregating, different types of land-use

The current inability to evaluate and manage BGBD is also hampered by a lack of capacity and a shortage of expertise in many countries to perform this task. The wide spectrum of stakeholders affected includes the scientific community with respect to training in the taxonomy, ecology, economic valuation and management of agrobiodiversity (particularly BGBD); and members of both the agricultural and environmental sectors from practitioner to national decision-maker with respect to awareness and access to knowledge.

Seven countries with significant expertise in soil have joined together to participate in this project. This present capacity will be built upon, or provided when lacking by “South-South” exchanges and training.

THE TROPICAL SOIL BIOLOGY AND FERTILITY INSTITUTE OF CIAT (TSBF)

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The Tropical Soil Biology and Fertility Institute of CIAT (TSBF) was formed by an agreement between the TSBF Programme and CIAT (Centro Internacional de Agricultura Tropical) in December 2001. The Institute operates as an integral part of the CIAT research programme and is governed by CIAT rules and procedures although the Institute retains a certain degree of autonomy with respect to its research agenda and funding. Institute staff are employees on CIAT terms and conditions and the TSBF Director reports to the CIAT DG. The Institute is guided in terms of its research programme by a special advisory committee of the CIAT Board of Trustees, derived in part from the former Board of Management of the TSBF Programme. The Institute is housed on the ICRAF campus in Nairobi.

The TSBF Programme was launched with the mission ‘to contribute to human welfare and the conservation of environments in the tropics by developing improved practices for sustaining tropical soil fertility through the management of biological processes and organic resources in combination with judicious use of inorganic inputs’. The mission is implemented through activities directed towards four goals:

1. Improve understanding of the role of biological and organic resources in tropical soil fertility and their management by farmers to improve the sustainability of land-use systems.
2. Enhance the research and training capacity of national institutions in the tropics in the fields of soil biology and management of tropical ecosystems.

3. Provide land users in the tropics with methods for soil management which improve agricultural productivity but conserve the soil resource.
4. Increase the carbon storage equilibrium and maintain the biodiversity of tropical soils in the face of global change in land-use and climate.

The major mode of implementation of TSBF research is through collaboration with national scientists through networks. The African Network for Soil Biology and Fertility (AfNet) now has about 110 members from Universities and NARIs in about fifteen countries. The AfNet Coordinator is based at TSBF HQ in Nairobi and has a major responsibility to work with network members to raise funds for research and capacity building activities. There is also a small network in India (TSBF South Asian Regional Network, SARNet), coordinated from the Jawaharlal Nehru University in Delhi. Institute staff also participate in a number of System-Wide and Eco-Regional Programmes such as ASB, AHI and SWNM. The TSBF Director is responsible for the latter for which CIAT is the convening centre.

During 2002 the soils research of CIAT and TSBF will be integrated into a single programme which will be managed by the TSBF Director.

The Institute has four full-time professional and thirteen locally recruited staff (Finance and Administration, Secretarial and Technical) in Kenya as well as similar staff in the other locations. Following the merger the TSBF Director is also responsible for CIAT staff in soils research which include the SWNM Coordinator, a further two senior staff in Africa (based in Uganda and Ethiopia), one in Laos and four in Latin America. The Latin American research is managed by a Project Manager.

The agreement with CIAT establishes that the Institute will maintain a distinct programmatic identity within the CIAT donor relations strategy. In 2002 the expected budget will be about $2.5 million. Most of the funding is for restricted projects from around eleven donors. All of these grants are for research in partnership with national and/or international research partners.

The TSBF Programme was founded in 1984 under the patronage of two international initiatives: the ‘Man and the Biosphere’ (MAB) of UNESCO and the ‘Decade of the Tropics’ of the International Union of Biological Sciences (IUBS). The Programme was founded with the aim of promoting and developing capacity for soil biology as a research discipline in the tropical regions on the premise that the biological management of soil fertility is an essential component of sustainable agricultural development.

A Programme Office was established in 1987 at the University of Zimbabwe when a grant from the Natural Environment Research Council (NERC) of the UK enabled the employment of the first full-time Programme Coordinator. The Rockefeller Foundation became a major investor in 1988 and took over the funding of the Programme Office. In 1989 the Programme Office moved from Harare to Kenya where it was hosted by UNESCO at the United Nations Office in Nairobi (UNON). In the first ten years of its existence TSBF was an informal network of scientists from a range of tropical, European and North American Universities. From about 1992 additional staff were engaged to conduct strategic research and capacity building activities and links established with the CGIAR. There has been a full-time Director since 1993.

SOUTH-SOUTH INITIATIVE FOR TRAINING AND CAPACITY BUILDING FOR THE MANAGEMENT OF SOIL BIOLOGY/BIODIVERSITY

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It is recognised that there is limited capacity to undertake research in the area of soil biology in Africa. On the other hand some countries in Latin America (Brazil, Colombia, Argentina, Mexico and Venezuela) are already embracing new technologies for soil biological studies and are building research and teaching capacities. In addition the efforts started in Latin America are well grounded within the context of the major problems of agricultural production and sustainability of tropical countries. Many of these problems such as soil degradation, nutrient depletion, loss of soil organic matter are common to Africa and Latin America and also to S-E Asia. Thus there exists some advantages to develop South-South cooperation in the area of training and capacity building in soil biology rather than, but not exclusive to, South-North cooperation.

Examples of such South-South exchanges already exist - such as the EMBRAPA-Africa Agreement and the Brazilian Federal and State University/Africa Collaborative Training Scheme.

Examples of expertise and training capacity in Brazil include: soil microbiology mycorrhizas and rhizobia (Federal University of Lavras); nutrient cycling; soil fauna; tree legumes; organic farming; associative nitrogen-fixing organisms (Embrapa Agrobiologia, Rio de Janeiro); ectomycorrhizae and rhizobiology (Federal University of Vicosa, Minas Gerais), microbiology and genetics of beneficial soil organisms (Embrapa Soja), soil microbiology (Federal University of Rio Grande do Sul and State University of São Paulo - ESALQ).

The International Centre for Tropical Agriculture (CIAT) based in Cali, Colombia also has projects and training in soil biology in cooperation with developed countries (ORSTOM/University of Paris and Complutense Madrid, Spain). CIAT also proposes to facilitate the establishment of a “Virtual” School of Soil Biology (Escuela Latin Americana de Biologia de Suelos) which will organize training courses and short-term research projects with scientists and teachers from both developing and developed countries.

At the same time developments in Africa such as the work of the Tropical Soil Biology and Fertility Programme and others on the management of organic material in cropping systems, have relevance to agriculture in Latin America. Thus there are advantages of linking Africa and Latin America in a joint effort to improve knowledge via comparative research and to increase capacity for the management of soil biology.

The development of these capacities in research and training can form part of, or be linked to, the initiative on Integrated Biological Management of Soil facilitated by the TSBF Programme in Nairobi, Kenya.

TSBF held a workshop on Soil Biology during March 16-19, 1999, which brought together expertise from Africa and other regions to develop a proposal for research and capacity building in Africa. A similar meeting in Latin America is now taking place at Embrapa Soja and should facilitate South-South exchanges.

The advantages of furthering south-south collaboration can be summarized as:

- Familiarity with adapting new methodologies and technologies to tropical conditions
- Familiarity with agricultural problems of tropical countries
- Cadre of trained personnel from tropical countries
- Existing projects on agricultural problems of tropical countries. Some of these projects involve farmer-managed and researcher-managed studies and include efforts to document farmer knowledge and awareness of soil biology.

To move these ideas forward the following steps are proposed:

1. The establishment of the School for Soil Biology in Latin America and possibly one for Africa.
2. The development of training courses and other capacity building exercises between African and Latin American institutions (including formal degree training at M.Sc. and Ph.D levels).
3. Development of joint projects.

Some of the activities outlined above will form part of the CGIAR's systemwide initiative on Soil, Water and Nutrient Management. This program consists of four research consortia (2 in Africa, 1 in Latin America and 1 in S-E Asia). The Managing Acid Soils consortium (MAS) has already participated in a School of Soil Physics held in Latin America. The management of soil biology could form an across-consortia theme within the SWNM programme. However the programme would need to attract additional funding from other sources. A logical step would be to link the steps above with the initiative for Africa.

A concept note on the above suggestions will be formulated and circulated to likely donor agencies.

STRATEGIES TO FACILITATE DEVELOPMENT AND ADOPTION OF INTEGRATED RESOURCE MANAGEMENT FOR SUSTAINABLE PRODUCTION AND PRODUCTIVITY IMPROVEMENT

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Production constraints on small-holder farms in tropical environments, particularly in sub-saharan Africa, are those associated with low soil organic matter content, shallow surface soil depth, nutrient mining, acidity and erosion. Water stress is another factor that constrains production particularly in semi-arid environments.

Soil management for productivity improvement should therefore address the manipulation of nutrients and water reserves within the rooting depth to enhance agronomic productivity, accentuate aesthetic values and minimize risks of environmental degradation. Soil management for sustainable use should integrate more than one of the following (a) enhancement of soil structure through soil surface management for minimizing risks of degradation of soil structure; (b) soil water conservation and management including drainage, irrigation and runoff management; (c) soil temperature management; (d) nutrient capital enhancement and management and alleviation of nutrient deficiency and toxicity constraints; and (e) enhancement and management of soil organic matter content and activity and species diversity of soil fauna, including biomass carbon.

While much work has been done on soil nutrient manipulations, little has been done on assessment of activity and species diversity of soil fauna and flora. Little has also been done on routine methods to determine soil health in terms of biodiversity. Nevertheless field experience demonstrates that farmers fields with high organic matter and a lot of biological activity are the most productive. The majority of farmer soil management methods are centered on practices that improve soil organic matter and hence biodiversity for production. Conversely research has for a long time concentrated on soil nutrient improvement, rather than organic matter management. Approaches for soil management to improve soil biodiversity need to be more addressed than before and account for soil biodiversity's contribution to soil productivity and plant production.

In order to achieve widespread adoption of developed sustainable resource management technologies, identification of existing farmer's successful resource management techniques must be identified. The envisaged improved technologies may be integrated into existing farmer's successful models, further tested and demonstrated by farmers themselves to other farmers with facilitation of experts. The process involves in-situ assessment of technologies by farmers followed by whole sale adoption, modification and/or rejection. Through full farmer empowerment, adoption and dissemination of the developed technology is faster than several current participatory technology development and dissemination methods.

THE CHALLENGE PROGRAM ON BIOLOGICAL NITROGEN FIXATION (CPBNF)

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A Challenge Program on Biological Nitrogen Fixation (CPBNF) was proposed by the International Crops Research Institute for the Semi Arid Tropics (ICRISAT), as part of the new global initiative taken by the CGIAR. The interim Science Council of the CGIAR (iSC) has recently selected the concept note for development into aprepoposal for the Challenge Program pre-proposal.

The overall goal would be to harness some of the most recent breakthroughs in BNF technologies and research on legume-rhizobium symbiosis, where it is most needed, i.e., to mitigate the downward spiral of soil fertility loss, food insecurity, poverty and malnutrition in developing countries. The current plan is to build a large stakeholder consortium, based on a recent initiative taken by FAO, to promote BNF technologies in developing countries with a major focus on most vulnerable areas. A concerted effort in this field could build synergies among CGIAR centers (CIAT, IITA, ICRISAT, ICARDA), Advanced Research Institutes, international agencies, NGOs and NARS, for the promotion of legume crops and sustainable agriculture, and consequent impacts on soil fertility, food security and poverty alleviation.

LIVING SOIL TRAINING FOR FARMERS: IMPROVING KNOWLEDGE AND SKILLS IN SOIL NUTRITION MANAGEMENT

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The excessive use of chemical fertilizers without additional organic matters can cause serious problems to soil health, the environment and agricultural production. Farmers were always recommended to apply fertilizers without understanding the soil system of how it can be improved to feed the crops for better yield. It this assumes that farmers do not know about soil nutrient management and are not able to change their behavior. Some studies, however, show that farmers in general are aware that organic matter is important for their soil, but this knowledge is not sufficient to change their behavior. There are often reasons that override farmers' habit concerns in carrying out appropriate practices in applying fertilizers. Moreover, the recommendations are often based on the assumption that only chemical fertilizer applications are necessary for high crop yields when, in fact, they are part of the problem. Application of only chemical fertilizers not only affects the soil system but crops often also have not enough nutrients to produce a higher yield with good quality. To avoid many of the adverse effects to soil systems, means of farmers' education should be explored, including both the education on soil systems as well as soil nutrient management.

Helping farmers to learn through an ecologically based, farmer-centered approach will highly contribute to the development of sustainable agriculture. Interdisciplinary approaches are important to seek solutions to soil nutrient problems. Farmers often are more concerned about losing their crops than they are about damaging their soil system.

For interventions to be effective, farmers must have an opportunity to find out themselves what soil is, why "living soil", how it is living and how it relates to healthy crop production.

The “Living Soil” Training in Cambodia was introduced by the FAO Community Integrated Pest Management Programme in 2001(*). The training provides a tool to help farmers learn about soil ecology. The training has been introduced into the Farmer Field School Programme in IPM and follow-up training for farmers. The purpose of the training is to upgrade farmers’ understanding of soil eco-system sand integrated soil nutrient management.

* training manual on “Living Soil”, FAO Community IPM by Dr. William Settle

DO WE NEED AN INTER-GOVERNMENTAL PANEL ON LAND AND SOIL (IPLS)?

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Introduction

Looking into the development of international conventions in relation to climate change (FCCC), biodiversity (CBD) and the combat of desertification (CCD) as well as into other legal instruments, e.g. referring to the protection of forests and other environmental media, it becomes increasingly important to create and to harmonize opinions on a world wide level, in order to draft an international soil policy in relation to world-wide developments, especially in the field of protection of land and soils as a non-renewable resource of humankind. In this context, the question arises if the community of soil scientists is willing to support an intergovernmental panel on land and soil (IPLS), in order to foster soil issues of world-wide concern.

Importance of global land and soil resources

Feeding the burgeoning population, while preserving or enhancing the quality of the global land and soil resources is becoming a daunting task, particularly in developing countries. To ensure political stability and sustainable development, decision makers recognize food security as a primary concern. - In the industrialized countries, there are a number of further problems that limit agriculture, and an important one relates to the rate at which land and soil is permanently taken out of agriculture through the development of technical and socio-economic infrastructures, thus sealing soil and land. Besides land and soil quality also the quantity and quality of water raises increasing concern in many countries. Moreover, the maintenance of biodiversity is of paramount importance.

It is estimated that there are about 7.1 million km^2 of land and soil under low risk of human induced desertification, 8.6 million km^2 at moderate risk, 15.6 million km^2 at high risk, and 11.9 km^2 under very high risk, which means that about 33% of the global land surface are affected by desertification, thus endangering more than 1.4 billion people, half of whom living in Africa.

Due to erosion and desertification the productivity of land and soil has declined significantly. This becomes evident by yield reduction in Africa, due to soil erosion, ranging from 2-40%, with a mean loss of 8.2% for the continent. In South Asia, annual losses in productivity are estimated at 36 million tons of cereal. General estimations at a global scale indicate that the annual loss of 75 billion tons of soil costs the world about 400 billion US$ per year.

However, until today, land use and soil management still are a secondary environmental topic. Despite progress related to dry lands, e.g. the United Nations Convention to Combat Desertification (UNCCD), the full scope of land and soil related environmental issues have not yet been accordingly addressed. The UNCCD by extending its mandate to Central and Eastern European Countries (see Annex 5, as adopted by COP4, 2000) demonstrated the need for including the variety of land degradation issues into the international agenda.

A global clearing house for land and soil

There exists a broad range of relevant knowledge on land and soil degradation, but no co-ordinated contribution of the international scientific community to the needs of policy makers. The knowledge on states, degradation dynamics and potential consequences is still very patchy or entirely absent (hot spots of land and soil degradation). Monitoring of land and soil quality is non-existent in most countries of the world, and even in the industrialized countries a systematic programme of monitoring is recent. There is a need for standardization of methods and harmonization of information, so that more reliable assessments can be made.

Basically, there is no sufficient understanding of the state of global land and soil resources and their regulatory function in the global environment. There is even less information on areas or regions which may succumb to ecological collapse if mitigating technologies are not introduced. Therefore, regular scientific stock-taking exercises are an essential prerequisite for concretizing treaty commitments, for instance through using a baseline catalogue of global indicators, which yet needs to be developed.

There is also a need for a cross-cutting analysis of the pivotal themes of land degradation and desertification and identifying “safety margins” or “guard rails” in order to inform the international community, in as timely a manner as possible, about hazardous developments. In this context, indicators on biodiversity, especially soil biodiversity, could play an important role.

Guard rails indicating the limits of absolute non-sustainability would provide a scientifically underpinned basis upon which to determine abatement or conservation goals for combating land degradation and desertification.

It is thus timely to consider the creation of an international institution, which has:

1. To serve as a clearing house for issues on global land use and soil management and degradation.
2. To assess and synthesize the scientific, technical and socio-economic information relevant for the understanding of the risk of human-induced land and soil quality change and show the pivotal role of land use and soil management in ecosystem services at all scales;
3. To address the variety of land use and soil management issues as relating to sustainable development, poverty alleviation and multilateral environmental agreements.
4. To stimulate and involve the scientific community to develop the science of land use and soil management in a multi-disciplinary and pluri-disciplinary manner;

5. To assist actively national, regional, and global decision makers in developing policies to assess, monitor, and mitigate negative impacts on land and soil.

In view of the complexity of global soil and land degradation, systematic dissemination of scientific findings and early recognition of strategies to governments and international political regulatory bodies such as United Nations Environment Programme (UNEP), Food and Agriculture Organisation (FAO) and the United Nations Convention to Combat Desertification (UNCCD) is crucial.

Moreover, intensive co-operation with further existing UN conventions, such as the UN Convention on Climate Change and the UN Convention on Biodiversity are desirable.

Improving scientific policy advice

The UNCCD incorporates a body charged with providing scientific advice, the Committee on Science and Technology (CST). However, with respect to global soil and land protection policy, there is still need for an institution that provides scientific advice and informs UNCCD on progress or lack of it in areas that impact its work. The role and function of this body is expected to be similar to the Intergovernmental Panel on Climate Change (IPCC), making its recommendation accessible to the international scientific community, the parties and all stake holders.

The function of the CST is to call for and evaluate expert scientific opinions at the specific request of the Conference of the Parties (COP). In its capacity as a subsidiary, instruction-bound body of the COP, the CST is closely linked to their programmes of work and cannot be a substitute for an independent scientific assessment of global land and soil degradation. Moreover, an International Panel on Land and Soil (IPLS) would support the CST and could provide scientific assessment reports on global soil and land degradation.

Building upon the IPCC experience, the establishment of a comparable scientific body or panel to provide advice and support is recommended.

In an Inter-Governmental Panel on Land and Soils (IPLS), recognized scientists could be brought together, who could work on an ongoing and independent basis and provide scientific policy advice. An Inter-Governmental Panel on Land and Soils (IPLS) would prepare the scientific base for decisions for e.g. UNCCD and UNEP. In general, the contributions provided by this panel could give greater weight to the problems associated with land degradation and desertification and stimulate awareness for the importance of the problem. A further aspect is that such a panel could provide the parties and all stakeholders with scientific policy advice on current issues and problems in the political process and, moreover, highlight topics neglected in the policy arena.

PROTECTION AND SUSTAINABLE USE OF THE BIODIVERSITY OF SOILS

To: The Signatory Nations of the Rio Biodiversity Convention
From: The Members of the XIIth International Colloquium on Soil Zoology

The Biodiversity Convention has concentrated upon the visible world, but a considerable part of biodiversity is situated in the soil. Soil contains some of the most intricate and species rich communities of the globe. Its fauna and microflora represent a major part of our natural heritage but are often neglected in conservation management plans. Yet soil biological processes are fundamental for the functioning of natural and managed ecosystems and so are vital for human needs. Consequently consideration of the biodiversity of soil must be included in national plans drawn up to comply with the Biodiversity Convention.

Signed by Professor Dennis Parkinson, Chairman Subcommission D (Soil Zoology), International Society of Soil Science (IUSS).

Annex

SOIL BIODIVERSITY AND SUSTAINABLE AGRICULTURE: AN OVERVIEW[1]

I. Introduction

1. The Conference of the Parties to the Convention on Biological Diversity (COP/CBD) has identified soil biodiversity as an area requiring particular attention in regard to agricultural biodiversity (COP decisions III/11, IV/6 and V/5). Most recently, the 7th meeting of the Subsidiary Body for Scientific, Technical and Technological Advice (SBSTTA-7, Montreal, November 2001), recommended, *inter alia*, that COP, at its 6th meeting: *"consider establishing a cross-cutting International Initiative for the Conservation and Sustainable Use of Soil Biodiversity within the programme of work on agricultural biodiversity. Noting that this should take into account case studies on the full range of ecosystem services provided by soil biodiversity and associated socio-economic factors, and inviting the Food and Agriculture Organization of the United Nations (FAO), and other relevant organizations, to facilitate and coordinate this initiative"* (SBSTTA Recommendation VII/8).
2. This note aims to provide background information to assist the COP in its consideration of the establishment of the proposed **International Initiative for the Conservation and Sustainable Use of Soil Biodiversity**. It is also intended to help promote further adoption of strategies that enhance the important roles and functions of soil biodiversity for sustainable and productive agriculture and to encourage integrated soil biodiversity management. It draws on lessons learned from case studies and the key messages outlined

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[1] *A Contribution to the Implementation of the Agricultural Biodiversity Programme of Work under the Convention on Biological Diversity by the Food and Agriculture Organization of the United Nations (FAO)*

in Information note UNEP/CBD/SBSTTA/7/INF/11, that was considered by SBSTTA at its seventh session in November 2001, notably in regard to expertise, knowledge, technologies, progress and opportunities. Finally, this note sets out some suggested activities for the proposed International Initiative, highlighting the need to adapt and use integrated ecosystem management approaches in order to harness the economic, environmental and food security benefits from better management of soil life.

II. Recent activities on soil biodiversity of FAO and other organizations

3. Under its joint programme of work with the CBD Secretariat, and with the support of the FAO-Netherlands Partnership Programme (FNPP), FAO is working on the conservation and sustainable use of agricultural biodiversity within sustainable and productive ecosystems and its contribution to global food security. One of the four main areas of attention of this programme is on improving understanding and implementation of the ecosystem approach, including adaptive management and best practices. In this regard, the sub-component on soil biodiversity aims, firstly, to generate increased awareness of the importance of soil biodiversity, a seriously neglected but vital aspect of land resources management and sustainable agriculture systems. Secondly, it aims to expand cooperation among interested partners in improving management of soil biodiversity, as invited by COP decision V/5.
4. In collaboration with other programmes, scientific institutes and resource experts, FAO is making available knowledge on the categories and functions of soil biodiversity and on specific technologies for improved soil biological management. Through the preparation of case studies, bioindicators, training materials and participatory technology development approaches, it is piloting applied work on soil biological management in the agricultural and land sectors. The information compiled by FAO through contacts

with partner organizations is available at the web site http://www.fao.org/ag/AGL/agll/soilbiod/

5. Linkages are being identified with ongoing programmes and networks, with a view to establishing partnerships, for example with:
    - The GEF/UNEP project and research network on the Conservation and Sustainable Management of Below-Ground Biodiversity hosted by the Tropical Soil Biodiversity and Fertility Institute (TSBF) of CIAT.
    - Networks including the IBOY and CYTED Macro-fauna networks, and various mycorrhiza and rhizobia networks such as the "Asociación Latino Americana de Rhizobiología" (ALAR), the "Caribbean Mycorrhizal Network" (CARIVAM) in Latin America.
    - Research bodies, such as the Institut de Recherche et Developpement (IRD-UR) in France, which hosts an active research network on Biodiversity and Soil Functioning**;** the NERC Soil Biodiversity Program and CABI in the UK; the CLUE project and the Wageningen simulation project on biodiversity, which is assessing the impact of soil biodiversity on ecosystem functioning, in The Netherlands.
    - Agro-biology/ecology bodies, such as Centro de Pesquisa em Agrobiologia of Embrapa, Brazil and University of Padova Agroecology Laboratory; as well as,
    - Soil biodiversity projects such as CYTED (Latin America) and SHIFT (GTZ-Embrapa), Manaus, Brazil; the EU Soil Biodiversity and Ecosystem Functioning Program; and the UNU People Land Management and Environmental Change Project (PLEC), which is concerned with indigenous approaches to above- and below-ground agrobiodiversity.
6. An International Technical Workshop on "Integrated Soil Biological Management and Sustainable Agriculture", is being organised during the period 24-27 June 2002, with the support of the FNPP project and to be hosted by Embrapa Soybean in Londrina. The aim is, in collaboration with technical partners, to further review the state

of the art, with a focus on practical experiences, and to help identify priorities for action. This review process should take into account the crucial role of soil biodiversity in agricultural production and in providing wider ecosystem services and the need for appropriate management technologies, building on local knowledge systems and ensuring integrated approaches.

III. Rationale for integrated soil biological management in the agricultural sector

A. Soil Biodiversity - the Root of Sustainable Agriculture

7. Given escalating population growth, land degradation and increasing demands for food, achieving **sustainable agriculture** and viable agricultural systems is critical to the issue of food security and poverty alleviation in most, if not all, developing countries. It is fundamental to the sustained productivity and viability of agricultural systems worldwide.

8. Sustainable agriculture (including forestry) involves the successful management of agricultural resources to satisfy human needs while maintaining or enhancing environmental quality and conserving natural resources for future generations. Improvement in agricultural sustainability requires, alongside effective water and crop management, the optimal use and management of soil fertility and soil physical properties. Both rely on soil biological processes and soil biodiversity. This calls for the widespread adoption of management practices that enhance soil biological activity and thereby build up long-term soil productivity and health.

9. Soils contain enormous numbers of diverse living organisms assembled in complex and varied communities. Soil biodiversity reflects the variability among living organisms in the soil – ranging from the myriad of invisible microbes, bacteria and fungi to the more familiar macro-fauna such as earthworms and termites. Plant roots can also be considered as soil organisms in view of their

symbiotic relationships and interactions with other soil components. These diverse organisms interact with one another and with the various plants and animals in the ecosystem, forming a complex web of biological activity. Environmental factors, such as temperature, moisture and acidity, as well as anthropogenic actions, in particular, agricultural and forestry management practices, affect to different extents soil biological communities and their functions.

10. Soil organisms are an integral part of agricultural and forestry ecosystems and they play a critical role in maintaining soil health, ecosystem functions and productivity. Each organism has a specific role in the complex web of life in the soil:

    - The activities of certain organisms affect soil structure - especially the so-called “soil engineers” such as worms and termites - through mixing soil horizons and organic matter and increasing porosity. This directly determines resilience to soil erosion and availability of the soil profile to plants.
    - The functions of soil biota are central to decomposition processes and nutrient cycling. They therefore affect plant growth and productivity, as well as the release of pollutants in the environment, for example, the leaching of nitrates into water resources.
    - Certain soil organisms can be detrimental to plant growth, for example, the build up of nematodes under certain cropping practices. However, they can also protect crops from pest and disease outbreaks through biological control and reduced susceptibility.
    - The activities of certain organisms determine the carbon cycle - the rates of carbon sequestration and gaseous emissions and soil organic matter transformation.
    - Plant roots, through their interactions with other soil components and symbiotic relationships, especially *Rhizobium* bacteria and *Mycorrhiza*, play a key role in the uptake of nutrients and water, and contribute, through their growth and biomass, to soil quality and organic matter content.

- Certain soil organisms can also be used to reduce or eliminate environmental hazards resulting from accumulations of toxic chemicals or other hazardous wastes. This action is known as bioremediation.

11. There is a recognised need to bring together experience and technologies on the management of agricultural biodiversity in agricultural ecosystems, and, through international and national biodiversity strategies and action plans and harmonised policies, to bring about a transformation of unsustainable agricultural practices and land use systems to sustainable practices and systems. Nonetheless, the fundamental role of soil biodiversity in maintaining sustainable and efficient agricultural systems is still largely neglected in this process and in the majority of related agricultural and environmental initiatives.

B. Survey of Soil Biodiversity Expertise, Projects and Initiatives

12. In response to a Survey of soil biodiversity expertise, projects and initiatives, commissioned by FAO in 2001, over 100 projects were reported worldwide, either ongoing or being developed by private and public agencies, universities, research organisations and consortia. These address various soil biodiversity issues, including: (i) the significance of ecosystem complexity in maintaining soil organism diversity; (ii) the effects of agricultural management on soil organisms; and (iii) the role of soil biodiversity and specific soil taxa on various ecosystem functions.

13. The responses from some 123 soil biodiversity experts, from research, extension and projects from around the world, provided information on professional backgrounds, the location and conditions of field investigations, as well as the soil organisms, soil properties and processes and the agricultural management practices and their effects that are under investigation. A broad ecological approach was reflected by those with intersecting expertise in ecology, soil science and zoology, compared to the often narrower scope of microbiology, entomology, agronomy and botany specialists. There

was, however, a notable lack of soil biota specialists with expertise in natural resource management, rural/ community development and plant pathology, which could hinder their interactions with local farming populations.

14. Work is ongoing in a variety of field sites, in both agricultural lands and natural undisturbed areas and under a range of climatic and land use conditions. However, subtropical and arid regions are strongly under-represented and relatively more work is ongoing in forests and grasslands than other vegetation types. South-South cooperation and work could be encouraged in subtropical climates and semi-arid regions, and in range and pastoral systems, in order to strengthen the knowledge base and facilitate knowledge and technology transfer to these often marginalised agricultural production zones.
15. A wide variety of soil organisms and soil processes are being studied, though specialists on earthworms, soil and litter arthropods, roots, nematodes and mycorrhizal fungi are more common. Much work is ongoing in the area of organic matter inputs, including decomposition rates, enhanced bio-availability, nutrient pools and transformations and soil physical properties. On the other hand, relatively less work was reported on soil and litter fungi, rhizobial bacteria and nitrogen fixation, on fungal root pathogens and soil physical processes, as well as on soil biota interactions in regard to inoculants, tillage, inorganic fertilisers, pesticides and pH adjustments.
16. From the findings, there is a clear need to identify and facilitate the transfer of soil biodiversity research and its application in the agricultural development context. Firstly, because the perceived gap in work (though this could reflect survey bias) concerns the crucial and unique symbiotic relationships (plant-soil organisms) that either facilitate nutrient uptake (mycorrhizal fungi) or convert atmospheric nitrogen to readily utilisable forms - a vital area for agricultural productivity. Secondly, it may reflect a gap in understanding of effects of certain agricultural practices, especially

the use of certain agrochemical and biological inputs, on soil biological functioning and health.

17. National reports to the COP and reports by international agencies supporting the CBD provide a means to assess progress made. In this regard, from an overview of national reports it is observed that, in general, countries report more on natural ecosystems than on agricultural ecosystems. Moreover, within agricultural systems the emphasis is on plant and animal genetic resources and often little or no information is given on soil biological diversity. Some reports stress research and monitoring, while others place more emphasis on conservation actions, but the overriding message is that almost everywhere there is a need for and there are relevant initiatives upon which to build.

C. Soil Biological Management and Farmer Practices: How to Harness the Benefits

17. The central paradigm for the biological management of soil fertility is to utilise farmers' management practices to influence soil biological populations and processes in such a way as to improve and sustain land productivity. Biological populations and processes influence soil fertility and structure in a variety of ways, each of which can have an ameliorating effect on the main soil-based constraints to productivity. The means to create a more favourable environment within the soil and soil biological community for crop production involves site-specific decisions concerning crop selection and rotations, tillage, fertiliser and planting practices, crop residues and livestock grazing. These and many other factors influence ecological interactions and ecosystem function.

18. Capturing the benefits of soil biological activity for sustainable and productive agriculture requires a better understanding of the linkages among soil life and ecosystem function and the impacts of human interventions. The complex interaction among soil, plant and animal life, environmental factors and human actions must be effectively managed as an integrated system. Greater attention to the

management of soil biological resources - a hitherto neglected area in mainstream agriculture - will require a collaborative effort among scientists and farmers', and across ecological zones and countries, building on successful experiences.

19. As noted above, soil organisms contribute a wide range of essential services to the sustainable functioning of all ecosystems. They act as the primary driving agents of nutrient cycling, regulating the dynamics of soil organic matter, soil carbon sequestration and greenhouse gas emissions; modifying soil physical structure and water regimes; enhancing the amount and efficiency of nutrient acquisition by the vegetation; and enhancing plant health. These services are not only critical to the functioning of natural ecosystems but constitute an important resource for sustainable agricultural systems.
20. Direct and indirect benefits of improving soil biological management in agricultural systems include economic, environmental and food security benefits:
    - **Economic benefits:** Soil biological management reduces input costs by enhancing resource use efficiency (especially decomposition and nutrient cycling, nitrogen fixation and water storage and movement). Less fertiliser may be needed if nutrient cycling becomes more efficient and less fertiliser is leached from the rooting zone. Fewer pesticides are needed where a diverse set of pest-control organisms is active. As soil structure improves, the availability of water and nutrients to plants also improves. It is estimated that the value of "ecosystem services" (e.g. organic waste disposal, soil formation, bioremediation, N_2 fixation and biocontrol) provided each year by soil biota in agricultural systems worldwide may exceed US$ 1,542 billion.[2]
    - **Environmental protection:** Soil organisms filter and detoxify chemicals and absorb the excess nutrients that would otherwise become pollutants when they reach groundwater or surface water.

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[2] *Pimentel, D. et. al., 1997. BioScience, 47(11), 747-757.*

The conservation and management of soil biota help to prevent pollution and land degradation, especially through minimising the use of agro-chemicals and maintaining or enhancing soil structure and cation exchange capacity (CEC). Excessive reduction in soil biodiversity, especially the loss of keystone species or species with unique functions, for example, as a result of excess chemicals, compaction or disturbance, may have catastrophic ecological effects leading to loss of agricultural productive capacity.

- **Food security:** Soil biological management can improve crop yield and quality, especially through controlling pests and diseases and enhancing plant growth. Below-ground biodiversity determines resource use efficiency, as well as the sustainability and resilience of low-input agro-ecological systems, which ensure the food security of much of the world's population, especially the poor. In addition, some soil organisms are consumed as an important source of protein by different cultures and others are used for medicinal purposes. At least 32 Amerindian groups in the Amazon basin use terrestrial invertebrates as food, and especially, as sources of animal protein - a strategy that takes advantage of the abundance of these highly renewable elements of the rainforest ecosystem.[3]

21. The improved management of soil biota and its diversity contributes both to the needs of farmers', especially in maintaining productivity and increasing returns from labour and other inputs, and to national interests through maintaining a healthy and well functioning ecosystem in terms of water quality (hydrological cycle) and preventing soil erosion and land degradation (nutrient and carbon cycles). There is a need to improve recognition of these multiple benefits and to promote actions that maintain/enhance soil biodiversity and its vital and valuable functions.

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[3] *Paoletti, M G. et. al., 2000. Proceedings R. Soc. Lond. B. 267, 2247-2252.*

22. Soil organisms may have beneficial, neutral or detrimental effects on plant growth, depending on their populations and effects on the ecosystem. Thus, soil biota and their ecological interactions must be effectively managed for maximum productivity. Land managers need unbiased information that will enable them to develop biologically-based management strategies to control or manipulate soil stability, nutrient cycling, crop diseases, pest infestations and detoxification of natural and manmade contaminants. These strategies will require improved understanding of the effects on soil biota of habitats, food sources, host interactions, and the soil physical and chemical environment. Understanding the ecology regulating both beneficial and detrimental efects of certain organisms is essential to harnessing and controlling their activity in agro-ecosystems with a view to promoting viable, productive and sustainable systems.
23. If farmers' understand the effects of their different management practices on key categories of soil biota and their functions, and if they know how to observe and assess what is happening in the soil, then they can more successfully develop and adopt beneficial practices. However, it is not only the biophysical factors that affect farmers' decisions but also socio-economic considerations. Common constraints to the use of different soil biological management practices include the labour and time costs, monetary cost, availability of inputs (for example, planting material, inoculants and capacities) as well as social acceptability.

D. Agricultural Practices that Enhance Soil Biological Activity

24. Capturing the benefits of soil biological activity for agricultural production requires adhering to the following **ecological principles**:
    - **Supply organic matter:** Each type of soil organism occupies a different niche in the web of life and favours a different substrate and nutrient source. Most soil organisms rely on organic matter for food; thus a rich supply and varied source of organic matter will generally support a wider variety of organisms.

- **Increase plant varieties:** Crops should be mixed and their spatial-temporal distribution varied, to create a greater diversity of niches and resources that stimulate soil biodiversity. For example diverse habitats support complex mixes of soil organisms, and through crop rotation or intercropping, it is possible to encourage the presence of a wider variety of organisms, improve nutrient cycling and natural processes of pest and disease control.
- **Protect the habitat of soil organisms:** The activity of soil biodiversity can be stimulated by improving soil living conditions, such as aeration, temperature, moisture, and nutrient quantity and quality. In this regard, reduced soil tillage and minimized compaction are of particular note.

25. The ecosystem approach: Adaptation and further development of integrated soil biodiversity management into sustainable land management practices requires solutions that pay adequate consideration to the synergies between the soil ecosystem and its productive capacity and agroecosystem health. There are several practical examples of holistic agricultural management systems that promote and enhance agroecosystem health, including biodiversity, biological cycles and soil biological activity. The following paragraphs illustrate selected approaches and strategies for integrated soil biological management.
26. Integrated Pest Management (IPM) is the recognised alternative to non-sustainable crop protection practices, in particular, the mis- and over-use of pesticides. Ecological concepts were initially developed in cotton, oil palm, cocoa and other crops and then applied for rice systems in Asia and more recently in a range of cropping systems, including vegetables, legumes and maize. IPM improves environmental sustainability as it conserves essential ecological functions through the use of pest resistant varieties, the actions of natural enemies and cultural control. It improves socio-economic sustainability as it is a farmer-driven process that is institutionalised at the level of the farming community and local

government and reduces farmers' dependence on procured inputs. It offers an entry point, through the Farmers' Field School approach, to address other farming situations and extension problems. In this regard, soil-borne pathogens and other soil organisms are key elements of crop health and yield constraints along with soil health and fertility. Cropping practices, land management and plant and animal biodiversity, directly or indirectly influence the ecological role, as well as the predator-prey interaction of these pathogens within the agricultural system. Soil organic matter content, for example, interacts strongly with soil micro-biota, with the population of saprobes and antagonists within a soil being determined by the nutrient sources available within the soil. Soil biodiversity has important interrelations with crop and livestock associated diversity and management. In accordance with the expanded scope of certain field programmes to Integrated Production and Pest Management (IPPM), there are opportunities for better understanding and management of soil biota interactions and associated biodiversity.

27. **Organic Agriculture** manages locally available resources to optimise competition for food and space between different plant and animal species. The manipulation of the temporal and spatial distribution of biodiversity is the main productive "input" of organic farmers. By refraining from using mineral fertilizers and synthetic pesticides, pharmaceuticals and genetically-modified seeds and breeds, biodiversity is relied upon to maintain soil fertility and to prevent pests and diseases. Twenty years of scientific research has demonstrated that Organic Agriculture significantly increases the density and species richness of indigenous invertebrates, specialized endangered soil species, beneficial arthropods, earthworms, symbionts and microbes[4]. Suitable conditions for soil fauna and flora, as well as soil forming and conditioning and nutrient cycling are encouraged by organic practices such as: manipulation of crop rotations and strip-cropping; green manuring and organic fertilization

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[4] *Organic Agriculture Farming Enhances Soil Fertility and Biodiversity: Results from a 21 Year Old Field Trial. Research Institute of Organic Farming (FBL). Frick. Switzerland, 2000.*

(animal manure, compost, crop residues); minimum tillage; and of course, avoidance of synthetic pesticide and herbicide use.

28. **Conservation Agriculture** aims to maintain and improve crop yields and resilience against drought and other hazards, while at the same time protecting and stimulating the biological functioning of the soil. Essential principles of Conservation Agriculture are no-tillage (and direct seeding), the maintenance of a cover of live or dead vegetal material on the soil surface and the use of crop rotations. Crop sequences are planned over several seasons to minimize the build-up of pests or diseases and to optimize plant nutrient use by synergy between different crop types. Management practices that affect the placement and incorporation of residues influence the capacity of soil organisms to recycle nutrients. Tillage for example, affects soil porosity and the placement of residues. It collapses the pores and funnels that were constructed by soil animals, affecting the water holding, gas and nutrient exchange capacities of the soil. The placement of residues influences soil surface temperature, rate of evaporation and water content and nutrient loading and rate of decay. Conservation tillage, and particularly no tillage, reduce soil disturbance, increase organic matter content, improve soil structure, buffer soil temperatures and allow soils to trap and retain more rainwater. These soils are more biologically active and biologically diverse, have higher nutrient loading capacities and release nutrients more continuously[5].

29. The benefits towards which alternative management aims, beyond conventional systems, include, *inter alia*: abundance and activity of beneficial arthropods and earthworms, including predators; high occurrence of root symbionts and of fungi, bacteria and other microorganisms; high levels of microbial activity and high-energy efficiency, as well as erosion control. Energy efficiency is enhanced through a closed (or semi-closed) nutrient cycle and more effective turnover of organic matter, including faster mineralization and

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[5] *References from the Ist World Congress on Conservation Agriculture, Madrid, 2001 including those of J. Epperlein and of A.M.R. Cassiolato, et al, respectively*

delivery of plant nutrients and build-up of stable soil humus. Soil erosion is one of the most serious environmental problems of agriculture. Reduction of soil erosion and nutrient leaching in such systems is a consequence of better aggregate stability, a greater soil cover (mulch or cover crops), higher total available carbon and microbial biomass in the topsoil and increased activity of soil engineers. An additional benefit of alternative systems may be the greater occurence and diversity of wild flora, including endangered varieties, for example in field margins and organic grasslands. Effective management of weed species has also been reported, to reduce incidence of aphids and to influence the diversity and abundance of arthropods, pollinators and parasitoids.

25. FAO, with many partners, is actively working on the development and dissemination of the above technologies and practices, for example, enhancing knowledge through inter-disciplinary working groups and field programmes and projects. Compared with soil physical and chemical considerations soil biodiversity has been particularly neglected as a crucial aspect of soil fertility. FAO has therefore been promoting greater recognition of the importance of **integrated soil productivity management** strategies and technologies for enhanced and sustainable agricultural production systems. In Africa, the multi-partner Soil Fertility Initiative, which was launched in some 20 countries, and the follow-up piloting of **Farmer Field School (FFS) approaches** for soil productivity improvement and conservation agriculture approaches, (for example in Eritrea, Tanzania, Uganda, Zimbabwe and Kenya), are helping to identify farmer constraints and opportunities and entry points for intervention. They are also allowing the development of appropriate training materials and enhancing national capacities for wider adoption of such integrated and farmer-driven approaches.

26. Recalling the COP’s call for case studies on soil biodiversity under the programme of work on agricultural biodiversity, the above success stories of sustainable and integrated agricultural management systems – conservation agriculture, organic agriculture

and IPM - are being further reviewed by FAO for presentation as illustrative case studies for consideration by SBSTTA and for use by international and national fora. These will illustrate, among others, the need for development approaches to integrate the biotic and abiotic aspects of soils, nutrients, water, crops, pastures, livestock and other living organisms, tailored to a particular cropping or farming system. The **Farming System approach**, which advocates the need to better understand the agro-ecological, physical, economic and cultural environment within which farming households live, has been given greater recognition with the joint FAO-World Bank publication and website in 2001 on Farming systems and Poverty: Improving Farmers' Livelihoods in a Changing World, see http://www.fao.org/farmingsystems/

E. Considerations for an Integrated Soil Biological Management Process

27. Soil biologists and agriculturists are challenged to address a major global concern: "How to provide greater food security for all nations on earth in a sustainable way?" In addressing soil biodiversity and relevant societal concerns, it is necessary to take an ecosystem approach and a multi-disciplinary approach in order to better understand biophysical and human interactions and the complexity of living systems. However, as below-ground biodiversity is incredibly complex, it may require an initial focus, for example, to assess specific ecological functions of soil biota in productive agro-ecosystems and impacts of specific farming systems, technologies and practices. Nonetheless, this should subsequently lead to the development of integrated soil biological management as a means to maintain renewable soil fertility and ecosystem services.

28. An Integrated Soil Biological Management (ISBM) process requires a **participatory approach** that involves the range of stakeholders in a flexible and iterative process of creating, sharing, and improving experiences of integrated soil biological management. Two main user groups are identified: i) Resource-poor farmers, small-scale

producers (men and women) and rural communities (especially those living on marginal and/or degraded lands as these are particularly amenable to soil biological management practices); and ii) Policy makers and promoters of sustainable agriculture in Low Income Food-Deficit Countries (LIFDCs), including research institutes, extension programmes, NGOs and international funding partners.

29. Soil biota provide key ecosystem services that are responsible for naturally renewable soil fertility, for mediating carbon sinks in the soil and many other functions. The conservation of healthy communities of soil biota and prudent use of specific soil organisms through biological soil management can be used to maintain and enhance soil fertility and ensure productive and sustainable agricultural systems[6]. Moreover, the consequences of neglecting or abusing soil life will weaken soil functions and contribute to greater loss of fertile lands and an over-reliance on chemical means for maintaining agricultural production. This important relationship between soil life and agricultural productivity emphasises the need to enhance collaboration among soil biology specialists and agricultural practitioners, those concerned with land degradation and other stakeholders, in promoting improved soil biological management. It also highlights the need to promote coordinated actions and concerted attention on soil biodiversity with a view to enhancing its contributions to agricultural productivity and sustainability and to combating land degradation, including, as appropriate, the biological restoration of soil fertility. For example, in fragile areas such as dryland, coastal and mountain environments and with resource-poor populations to reduce their vulnerability and food insecurity.

30. A focus should be placed on building on **existing opportunities** through the identification and refinement of direct and indirect management interventions for different biophysical and socio-

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[6] *Matson, P.A., W.J. Parton, A.G. Power, and M.J. Swift. 1997. Agricultural intensification and ecosystem properties.Science, 277, 504-509.*

economic conditions, and their integration with other management strategies (soil and water, crop and livestock, integrated pest management, etc.). The challenge will be to identify and promote integrated systems that are economically viable, environmentally sustainable and appropriate both socially and culturally. This could be initiated **through pilot-level experimentation and technology development** projects, with subsequent scaling-up processes through global and regional programmes and in collaboration with partners (CGIAR, TSBF, NGOs and others). Work is ongoing by FAO and partners in reviewing and compiling case studies, including experiences of the above-mentioned integrated management strategies. Case studies could be further developed into training materials and management guidelines and, through applied research, these could be targeted for particular agro-ecological zones and for farmers, extension agents and technicians at various levels and of various economic means (i.e. low medium and high-input farmers).

IV. Suggestions for the international initiative for the conservation and sustainable use of soil biodiversity

21. An International Initiative for the Conservation and Sustainable Use of Soil Biodiversity, as recommended by SBSTTA, could encourage country Parties to the CBD and FAO Member Nations to make progress, especially in the areas of technical assessments, adaptive management of soil biota, capacity-building and mainstreaming of relevant soil biology issues into various institutions and processes. Specific objectives could include, in particular:

a) Promoting **technical assessments**, for example, on the roles and importance of diverse soil organisms in providing key goods and services and on the positive and negative impacts of existing and new agricultural technologies and management practices. This should further the development of appropriate guidance for field practitioners and technicians and for national and international priority setting and policies.

b) Strengthening **capacities and partnerships** among farmers/land resource users, researchers and development programmes, for example: for monitoring and assessment of different farming systems, technologies and management practices in regard to their effects on soil biodiversity and its functions; for integrating soil biodiversity issues into training materials and agricultural programmes and policies (guidelines, compendia of "best practices", etc.); and, facilitating participatory research and technology development on soil biodiversity/biological management, with a view to promoting sustainable agriculture and improved land management.

c) **Sharing of knowledge and information and awareness raising**, including on the outcome of the above assessment and adaptive management activities in specific agro-ecosystems and farming systems. In this regard, it is opportune to encourage further contributions in response to the COP's call for case studies illustrating experiences in the conservation and sustainable use of soil biodiversity, from all concerned actors in the agriculture and environment sectors. This is intended to facilitate the review and prioritisation process for further work.

d) **Mainstreaming** soil biodiversity/biological management into agricultural and land management and rehabilitation programmes and strengthening **collaboration** among relevant programmes, networks, research institutes and national and international bodies on soil biological management. This could include: firstly, the identification and application of soil bio-indicators and field methodologies for monitoring and assessing soil biodiversity and its functions and the effects of land use/management practices on soil quality and health; and secondly, the identification and promotion of integrated soil biological management practices for different agro-ecological and socio-economic conditions.

32. The COP is invited to consider the above findings and suggestions in its consideration of SBSTTA's recommendations on the programme of work on agricultural biodiversity.

Cases Studies

PLANT PARASITIC NEMATODES ASSOCIATED WITH COMMON BEAN (*PHASEOLUS VULGARIS L.*) AND INTEGRATED MANAGEMENT APPROACHES

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Introduction

Common bean (*Phaseolus vulgaris* L.) is the most important legume crop in Kenya and is cultivated on an estimated 700,000 ha. A low average yield of 750 kg/ha is realized, against a potential of 1500 kg/ ha (Rheenen *et al.,* 1981). The major constraints to bean production are diseases, soil fertility, insect pest and low erratic rainfall (Otsyula *et al.,* 1998). Common bean is plagued by a wide range of plant parasitic nematodes, but only *Meloidogyne* spp. are of economic importance, causing up to 60% losses in yield (Ngundo and Taylor, 1974, Kimenju *et al.,* 1999). Apart from the direct losses resulting from root deformation, nematode infection is also known to break host resistance to other pathogens and to suppress nodulation. Several strategies have been developed for the control of root-knot nematode but their adoption level by smallhold farmers is limited (Table 1).

This study was undertaken with ultimate aim of developing an integrated strategy of managing root-knot nematodes on beans.

Materials and Methods

- Sample collection and nematode extraction

A survey of nematodes associated with common bean (*Phaseolus vulgaris* L.) was carried out in Kakamega, Kiambu, Machakos and Siaya districts. Twenty soil and bean root samples were collected from each of the 25 randomly selected farms in each district. Plants were gently

TABLE 1. Strategies of nematode control and their limitations

Strategies	Major limitations	Reference
Biological control	A viable alternative to chemicals	Sikora (1992)
Organic amendments	Too large quantities required	Rodriquez-Kabana (1986)
Crop rotation	Wide host range of *Meloidogyne* spp.	Thomason and Caswell (1987)
Resistant cultivars	Unavailable to farmers	Ngundo (1977)
Chemical Control	Uneconomical on common bean	Hague and Gowen (1987)

uprooted and a trowel was used to dig out soil from the bean rhizosphere to an average depth of 25cm. All the roots obtained from each farm were placed in a polythene bag but only about 3kg of the composite soil sample from each farm was transported to the laboratory. Nematodes were extracted from soil and roots using the sieving/filtration and maceration/filtration techniques as described by Hooper, (1990). Identification of nematodes to genus level was done using an identification key and descriptions by Mai and Lyon (1975). Nematode population levels were determined from a counting slide under a compound microscope and expressed either as number per 200cm^3 soil or 5g roots.

❖ Isolation and screening of *Bacillus* spp. against root knot nematodes

Bacillus spp. were isolated from the surface of healthy bean roots grown on soil collected from Machakos, Kiambu and Thika districts of Kenya and used in a greenhouse experiment where effect of *Bacillus* spp. on root-knot nematode populations and galling in beans was assessed. Two hundred and fifty *Bacillus* isolates were evaluated in three batches to determine their effect on nematodes and plant growth. *Bacillus* isolates were grown on nutrient agar at 27°C for 48 h, harvested and inoculum concentration adjusted to ca 10^9 colony forming units (cfu)/ml. Clean sand was placed in Leonard jars and steam sterilized for 1 h. Three bean seeds were sown in each jar but thinning was done at emergence to leave one seedling per jar. The plants were inoculated by pipetting 2ml of the bacterial suspension, adjusted to 10^9 cfu/ml, and 10ml of a nematode suspension containing 500 eggs/ml into each jar at emergence. Control pots were treated with carbofuran (nematicide) or sterile distilled water. Treatments were arranged in a completely randomized design with eight replications. Eight weeks after emergence, plants were gently uprooted, and washed free of sand. Galling and egg masses were rated using a scale of 1-9 (Sharma *et al*., 1994). Second-stage juveniles (J_2) were extracted from 200cm^3 soil using the sieving and filtration technique and enumerated (Hooper, 1990). Twenty *Bacillus* isolates were selected from this experiment and further tested using sterile and non sterile soils.

❖ Effect of organic amendments on damage by root-knot nematodes on beans

A greenhouse experiment was conducted using chicken, cow manure, leaves of *Mucuna pruriens, Azadirachta indica* (neem) and *Tagetes minuta* (marigold) as organic amendments. The amendments were applied at the rate of 5% (w/w) to soil which was held in 5 kg pots. The pots were sown with beans (GLP-2) at the rate of 3 seeds/pot which were later thinned to two plants per pot. A nematicide (carbofuran), applied at the rate of 1g/kg soil, and soil alone were included as controls. The pots were infested with eggs and juveniles of *Meloidogyne* at the rate of 6000 eggs/pot. A non-inoculated control was included. The experimental design was completely randomized with 10 replicates. Sixty days after soil infestation with nematodes, the plants were uprooted and washed free of soil using tap water. Galling, egg mass indices were and juvenile numbers were assessed using the methods described above. Plant growth was assessed by dry shoot and root weight. The experiment was repeated once following the procedure described above but with 8 replicates instead of 10 to confirm repeatability of the experiment.

Results

Endoparasitic nematodes of the genera *Meloidogyne* and *Pratylenchus* and ectoparasitic species belonging to the genera *Scutellonema* and *Helicotylenchus* were frequently extracted from soil or bean roots (Table 2). The endoparasitic nematodes, *Meloidogyne* and *Pratylenchus* spp., were present in 86 and 61% of the root samples, respectively. Eighty and 59% of the soil samples haboured *Scuttellonema* and *Helicotylenchus* spp., respectively.

TABLE 2. Diversity and occurrence of plant parasitic nematodes in soil and bean roots collected from four districts in Kenya

Nematode genus	% frequency of nematode occurrence per district				Overall
	Kakamega	Kiambu	Machakos	Siaya	
Soil					
Meloidogyne	96	42	84	72	74
Pratylenchus	96	48	80	48	68
Scutellonema	100	80	64	76	80
Helicotylenchus	76	80	24	56	59
Tylenchorhynchus	12	36	52	32	33
Tylenchus	4	8	12	0	6
Criconemella	0	0	8	0	2
Aphelenchus	0	8	4	0	3
Hemicycliophora	0	44	0	0	11
Trichodorus	0	8	0	0	2
Roots					
Meloidogyne	96	80	88	80	86
Pratylenchus	76	32	76	60	61

❖ Effect of *Bacillus* spp on root-knot nematodes and plant growth

The effects of *Bacillus* spp. on plant growth and root-knot nematode infection differed significantly ($P < 0.05$) among the isolates. Out of the 250 *Bacillus* isolates that were tested against root-knot nematodes, 93% reduced galling when compared to the control (water) while 12% were more effective in reducing galling and egg mass indices than carbofuran. One hundred and thirty five (54%) isolates were found to be as effective as carbofuran. Fifty (20%) isolates were found to promote plant growth. One hundred and fifty six isolates had no effect on plant growth while 44 isolates suppressed growth. In the repeat experiment, the isolates showed a pattern that was consistent with the first experiment.

The effect of *Bacillus* isolates on root-knot nematodes was assessed using selected strains in sterile and non-sterile soils as shown in Table 3. Generally, the isolates were found to perform better in sterile than in non-sterile soil. Galling index was lowest in bean plants treated with K61 and K67 in sterile soil while in non-sterile soil K48 had the lowest galling. Similarly, egg mass index was lowest in plants treated with isolates K67 in sterile soil and K48 in non-sterile soil. The highest galling was recorded in plants treated with *Bacillus* isolates K78 and K236 in sterile soil and non-sterile soil, respectively. The number of *Meloidogyne* juveniles was significantly ($P = 0.05$) different among treatments in sterile and non-sterile soil (Table 4). Numbers of second-stage juveniles (J_2) were higher in non-sterile soil than in sterile soil. Juvenile numbers were lowest in sterile soil treated with *Bacillus* isolate K78 and in non-sterile soil treated with *Bacillus* isolates K194 and K227. The highest number of juveniles was recorded in soil treated with *Bacillus* isolates K61 and K100 under sterile and non-sterile soil conditions, respectively.

Application of organic amendments resulted in reduced galling, egg masses, juveniles and improved growth of bean plants (Table 4). Chicken manure had significantly ($P = 0.05$) different effects in all the parameters measured compared to the other amendments.

Chicken manure followed by neem and Tagetes was the most effective amendment. Cow manure which is commonly used by farmers was least effective. The nematicide (carbofuran) that is widely used by farmers in the control of nematodes especially in vegetable production had no effect on nematodes.

TABLE 3. Galling index, egg mass index and J_2 count of bean plants inoculated with *Bacillus* isolates

***Bacillus* isolate**	**Galling index**			**Egg mass index**			**J_2 count/200 cm^3 soil**		
	S	**NS**	**Mean**	**S**	**NS**	**Mean**	**S**	**NS**	**Mean**
K9	4.5	5.0	4.8	5.5	5.5	5.5	145	323	234
K33	4.5	6.3	5.4	5.8	6.8	6.3	173	193	183
K34	5.8	5.8	5.8	7.0	6.3	6.6	141	260	201
K48	4.0	3.5	3.8	4.3	4.3	4.3	81	271	176
K51	4.0	4.8	4.4	4.3	5.0	4.6	450	205	327
K61	2.5	4.0	3.3	2.8	5.0	3.9	488	505	496
K66	2.8	4.8	3.8	3.3	5.0	4.1	160	223	191
K67	2.5	4.8	3.6	2.3	5.0	3.9	126	272	199
K78	7.0	5.5	6.3	7.5	6.0	6.8	42	190	116
K86	4.3	7.0	5.6	4.8	7.8	6.3	126	696	411
K89	4.3	5.5	4.9	4.3	6.3	5.3	109	157	133
K100	5.5	6.0	5.8	6.8	6.3	6.5	180	788	484
K158	3.5	2.8	4.1	4.3	5.3	4.8	90	182	136
K194	3.0	3.8	3.4	3.0	3.8	3.4	194	109	151
K227	4.3	3.8	4.0	5.0	3.8	4.4	465	132	299
K228	4.5	5.0	4.8	5.3	5.5	5.4	291	418	355
K236	3.3	7.3	5.3	4.5	7.0	5.8	141	531	336
K269	4.3	4.5	4.4	4.5	5.3	4.9	145	604	374
K270	2.5	5.5	4.0	3.0	6.0	4.5	165	404	284
K273	4.3	4.3	4.3	5.3	5.3	5.3	162	522	342
CB4	4.5	5.5	5.0	5.3	6.0	5.6	409	522	465
Water	8.3	9.0	8.6	9.0	9.0	9.0	525	596	561
Carbofuran	5.3	5.8	5.5	5.8	6.5	6.1	137	193	165
Mean	4.3	5.3		4.9	5.8		215	361	
SE	0.8			0.8			38.1		
CV (%)	16.7			15.7			13.2		
LSD $_{0.05}$									
Bacillus	0.8			0.8			37.7		
Soil condition	0.2			0.2			11.1		
Bacillus vs soil condition	1.1			1.2			58.3		

S = Sterile soil, NS = Non-sterile soil

TABLE 4. Effect of organic amendments on root knot nematode damage on beans root and bean biomass production

Amendment	Galling index	Egg mass index	Juveniles 200cm^3 soil^{-1}	Shoot dry weight	Root dry weight
Tagetes	*3.5*	4.8	133	5.6	1.0
Neem (*A. indica*)	3.5	5.4	174	7.4	1.1
Mucuna sp.	4.2	4.5	213	7.2	0.8
Chicken manure	2.1	3.3	83	11.1	1.4
Cow manure	4.6	7.8	521	5.4	0.7
Carbofuran	6.8	7.9	1192	3.0	0.5
Control	6.5	8.1	1112	2.2	0.2
L.S.D. ($P = 0.05$)	0.7	0.8	86	1.2	0.3

Discussion

Nematodes in the genera *Meloidogyne, Pratylenchus*, *Scutellonema* and *Helicotylenchus* are widely distributed in bean fields in Kenya. Diversity and frequency of occurrence of nematodes in the four genera were highest in Kakamega district. Warm and wet conditions prevailing in the district (Jaetzold and Schmidt, 1983), coupled with a high cropping intensity of *P. vulgaris* are ideal for plant parasitic nematode population build-up. Incidence and population densities of the predominant nematodes were, however, low in Kiambu district in spite of high cropping intensities in the district. This could be attributed to frequent use of cow manure for soil fertility improvement by most farmers in this district (Woomer *et al*., 1998). *Pratylenchus* spp. are common inhabitants of the rhizosphere of bean plants. Lesion nematodes, especially *P. zeae*, are a serious pest on maize in Kenya (Kimenju *et al*., 1998) where maize and beans are grown as intercrops by the small-holder farming communities in Kenya (Wortmann and Allen, 1994; Gethi *et al.,* 1997).

Locally isolated *Bacillus* strains showed potential for use as biocontrol agents of root-knot nematodes on beans. Out of 250 isolates that were tested, 12% of them caused a reduction in galling. This percentage was greater than that reported by Oostendorp and Sikora (1989) and Sikora (1988) on sugar beets and cotton, respectively. Zavaleta-Mejia and Van Gundy (1982) detected that 12% of the isolates were effective while Becker *et al*., 1988 reported that 20% of bacteria were antagonistic to root-knot nematodes in cucumber. The isolates were found to protect plants against plant parasitic nematodes as reported by Becker *et al*. (1988); Bowmann *et al*. (1993); and Oka *et al*. (1993). The ability of *Bacillus* isolates to suppress nematodes can be attributed to reduced egg hatching and modification of root exudates which interferes with the host finding processes of the nematodes or production of metabolites that are toxic to the nematodes (Sikora and Hoffman-Hergarten, 1992; Mankau 1995; Hallmann *et al*., 1998).

A remarkable reduction in activity and/or mobility was observed when second-stage *Meloidogyne* juveniles were treated with extracts from organic amendments suggesting that substances released by decomposing amendments had nematostatic effects (Miano, 1999). Extracts from chicken manure, *Tagetes*, *Mucuna* and Neem (*A. indica*) appear to have strong nematicidal properties. Several workers have reported this aspect (Padma *et al.*, 1997; Kaplan and Noe, 1993).

The ability of chicken manure to reduce nematode damage and populations in amended soils is well documented (Kaplan and Noe, 1993; Akhtar and Mahmood 1997; Miano,1999). Extracts from *Mucuna* spp. were found to reduce the activity of *Meloidogyne* juveniles (Marisa *et al.*, 1996). This was attributed to aliphatic alcohol and esters released during decomposition. *Mucuna* has also been used as a soil amendment in the management of plant parasitic nematodes (Chavarria-Carvajal and Rodriguez- Kabana, 1998).

Conclusions

Root knot nematodes are widely distributed and cause substantial yield losses of common bean in Kenya. The potential of organic amendments to suppress root knot nematodes and to increase bean yield was demonstrated. This study further demonstrated that *Bacillus spp*. are a viable component of integrated nematode management packages.

Further work is however required to test the efficacy of the *Bacillus* isolates under field conditions and to develop a cost effective mode of application, preferably leading to a method whereby *Bacillus spp*. and *Rhizobium* inoculant would be packaged together.

Acknowledgements

This study was supported by The Rockefeller Foundation Forum on Agricultural Resource Husbandry.

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AGROTECHNOLOGICAL TRANSFER OF LEGUME INOCULANTS IN EASTERN AND SOUTHERN AFRICA

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Introduction

In sub-Saharan Africa, the per capita food production of food grains over the period 1960 to the early 2000s has stagnated and finally declined. Evidence for this food insecurity is clearly manifested in food imports and food relief operations directed to this region. Several factors leading to frequent food shortages include: poverty, which significantly limits the small holder farmer to purchase fertilizers and other agricultural inputs needed to raise and sustain the levels of high crop productivity and the rising population which has had implications on diminishing agricultural land sizes and continuous cultivation of land with negligible or no nutrient returns, while the policies on the economics of use of agricultural inputs do not favor the purchases of these inputs. The importance of BNF to world food security is unquestionable. Most tropical soils are fragile in structure, are of low soil fertility, and inappropriate farming technologies have resulted in land degradation. Even though smallholder cropping systems in Eastern and Southern Africa are mainly maize-based, the cultivation of legumes is also widespread and their exploitation is designed to meet a wide range of needs including human nutrition, livestock feed, fuelwood, structural materials, soil erosion and fertility management. Maximization of the benefits accrued from legumes is limited by widespread deficiency of P in croplands which are mostly associated with low pH coupled by high aluminium and manganese toxicities (Sanchez and Euhara, 1980). The presence of high populations of indigenous *Bradyrhizobia* spp. in tropical soils that nodulate with commonly grown legumes has also acted negatively on the response of cultivated plants to rhizobia inoculation (Karanja et al., 1997).

Is the technology available?

Legume-*Rhizobium* technology has been in existence in the region for over two decades (Karanja and Woomer, 1998), and in many countries in the region rhizobial inoculant production effort has led to surpluses of inoculants. For instance, approximately 1.5 ton/year are produced and distributed in Kenya and Uganda, 16 tons and 6 tons are produced in Zambia and Zimbabwe respectively. A summary of legume inoculant production and other relevant details are presented in Table 1.

Constraints in the agrotechnological transfer to smallhold farmers range from pricing and marketing, farmer awareness, research and development, linkages between public institutions and industry, and policy. For instance a survey carried out in 8 countries in Eastern and Southern Africa revealed that farmer's perception to the use of rhizobium technology was varied (Figure 1). Whereas 95% of farmers were familiar with root nodules, only 26% considered nodules to have beneficial effects, and less than 10% had ever used legume inoculants (Woomer et al., 1998). All inoculant production units listed in Table 1 are based

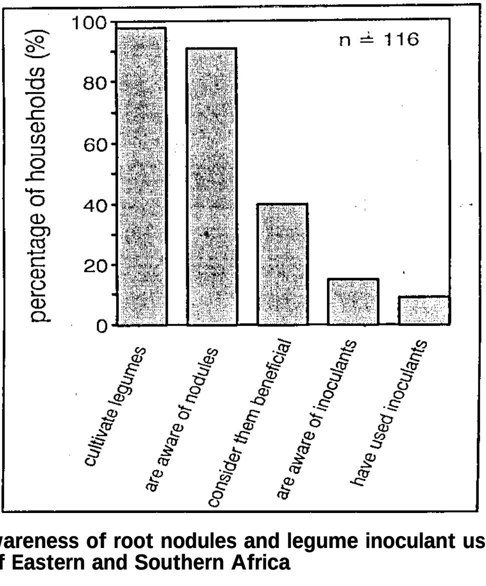

Figure 1. Farmers awareness of root nodules and legume inoculant use in selected countries of Eastern and Southern Africa

TABLE 1. Legume inoculant production in Eastern and Southern Africa

Country producer	Product name	Quantity (kg)	Carrier	Retail quantity (g)	Price ($)	Inoculant
Kenya: MIRCEN, University of Nairobi	Biofix	500-1000	Filtermud	100	1.25	Lablab, soybean, beans, Alfalfa, *Desmodium*, Pigeonpea
South Africa Pretoria	Stimuplant	12,500	Irradiated peat	250	1.75	Soybean, groundnuts, cowpeas, Lucerne, clovers, beans, peas, Lotus, *Desmodium*, Medicago
Uganda: Makerere University, Kampala	Bio-N-Fixer	8000	Peat	250	1.15	Glycine, Lucerne, beans, soybeans, *Calliandra*
Zambia: Mt. Makulu Research Station	Nitrozam	16000	Peat	250	0.50	Soybean 90%, Lucerne, beans
Zimbabwe: DRCC, Marondera	–	6000	Sterile bagasse	50	0.25	Soybean 90%, beans, pea Lentil, Cloves, Lucerne, *Desmodium*. Groundnuts, *Stylosanthes*, *Crotalaria*
Sudan: ENRRI	Okadin	2000	Unsterile charcoal dust	500	–	Soybean, groundnut, *Lucerne*, Guar, Fababean, Chickpea and Beans

either in National Agricultural Research Stations (NARS) or in microbiology laboratories in public Universities. The focus of all these institutions is not for commercial purposes, hence this non-industrial production approach has meant that inoculant prices are high per unit cost, leading to low farmer acceptance. Except in S.Africa, Zambia and Zimbabwe, where proper distribution mechanisms have been developed through commodity based co-operatives, in other countries such as Kenya and Uganda, farmers are expected to contact or travel to the laboratory centers to purchase the inoculants. Coupled by this, legume inoculants are not included in the list of plant nutrient-replenishing products that are recommended to farmers by the ministries of agriculture and affiliated national institutions and hence are not commonly stocked in agrochemical retail shops. This has had a negative impact on the wide application of legume inoculants by the millions of small holder farmers in sub-Saharan Africa where soil nitrogen limits food production.

Possibilities for strengthening the impact of agrobiotechnologies to the smallholder farmers

- Establishment of a series of linkages of Government agricultural and planning ministries, National Universities, National Agricultural Research Laboratories (NARS), Agricultural extension activities, relevant local NGO’s and CBO’s, agricultural inputs, retailers and identification of model farmers and community leaders.
- Increase farmer's awareness through effective extension in explanation and demonstration of agricultural biotechnologies to the small-scale farmers. The extension agents and those CBO’s and NGO’s working directly with farmers would have to be exposed to those technologies through series of workshops and training courses.
- Legume inoculants are highly perishable and sensitive to abiotic factors such as temperature and sunlight improvement of the poor infrastructure in the rural farming areas of Africa that lack electricity to increase market penetration. Improvement of while the low input agriculture practiced by the subsistence farmers in the tropical soils

that contain high populations of indigenous *Bradyrhizobium* sp. which lower legume responses to rhizobia inoculants

- Strengthen collaboration and communication between international and national research institutes, universities and ministries investigating similar problems such as those concerned with sustainable soil fertility management, legume germplasm improvement, agroforestry projects and biodiversity initiatives.

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RESTORING SOIL FERTILITY AND ENHANCING PRODUCTIVITY IN INDIAN TEA PLANTATIONS WITH EARTHWORMS AND ORGANIC FERTILIZERS*

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Overview

The long-term exploitation of soil under the tea gardens in Southern India (where many estates are >100 years old) has led to impoverishment of soil fertility and stabilization of yields, despite increasing application of external inputs such as fertilizers and pesticides. Some of the soil degradative processes include:

- decreasing organic matter contents
- lower cation exchange
- reduced water-holding capacity
- loss in important soil biota (reduced up to 70%)
- acidification (pH down to 3.8)
- increases in toxic aluminum concentrations
- compaction of the soil surface
- soil erosion
- leaching of nutrients
- accumulation of toxins (polyphenols) from tea leaves.

On invitation from Parry Agro Industries Pvt. Ltd. (ex- C.W.S. India Ltd.), Prof. Patrick Lavelle from IRD (ex-ORSTOM) and Dr. Bikram K.

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* *Case study also available from the Soil Biodiversity Portal at http:/www.fao.org/agl/agll/soilbiol/*

Senapati from Sambalpur University began several joint projects in 1991 seeking to restore soil fertility and enhance tea production in six private tea estates of the Parry Agro-Industries Ltd., in the state of Tamil Nadu, India. These experiments showed that:

- a mixture of tea prunings, high quality organic matter and earthworms was very effective at raising tea yields (more than application of fertilizers alone) due to its favorable effects on physical and biological soil properties; a bio-organic fertilization technique increased yields from 79.5-276%
- the increase in yields by using a bio-organic fertilization technique ranged from 75.9-282%, representing a profit gain of up to US$5500 per hectare per year compared to conventional techniques
- despite soil faunal depletion in intensive tea plantations, there is a potential for recovering their population and activities by applying various organic materials
- with optimal limitation, there is a significant relationship between the earthworm populations present in the field and total green leaf tea yields
- the termite: earthworm ratio may be a good indicator for assessing soil degradation status.

The combined inter-disciplinary effort of scientists from two research/ teaching institutions, and Parry Agro-Industries Ltd., led to the discovery of a practical, economical and conservation-minded solution, that has now been patented and is being spread to other sites in India and to other countries. The bio-organic fertilization technique and the principles of biological management of soil fertility with soil biota and organic matter, have great potential for widespread application, particularly in agro-forestry systems and where soil biological and physical health have been degraded due to intensive or long-term agricultural activities.

The Problem: Soil degradation under intensive tea plantations

Tea is an economically important, high-value plantation crop in India with an old history (*Photo* 1); many estates are more than 100 years

Photo 1. A privately-owned (Parry Agro Industries Ltd.) intensive tea plantation in the southern Indian state of Tamil Nadu (photo P. Lavelle). Note the aerial dispersal of pesticides (center).

old. Tea production levels in India were about 1000 kg ha^{-1} during the 1950’s and these increased up to about 1800 kg ha^{-1} in the mid 1980’s, due to the introduction of green-revolution technologies such as external chemical inputs (Senapati *et al*., 1994a). Nevertheless, no further yield increases have been obtained in average tea yields, despite increasing application of external inputs such as fertilizers and pesticides (*Photo* 2), and even spraying of plant growth hormones. Reasons for this stabilization are linked to chemical, physical and biological impoverishment of soil fertility under intensive tea production (Panigrahi, 1993).

Evidence of this degradation can be seen in the low soil organic matter content, cation exchange and water-holding capacity, poor and little diverse soil fauna populations and highly acidic pH, and in the high soil compaction, erosion, nutrient leaching, accumulation of xenobiotics and toxic aluminum present under high input, intensive teal plantations (Pahigrahi, 1993; Senapati *et al*., 1994a; 1999). All these soil features reduce plant root growth and plant health, limiting any potential benefits of chemically-based recovery of soil fertility (e.g., with high fertilizer applications).

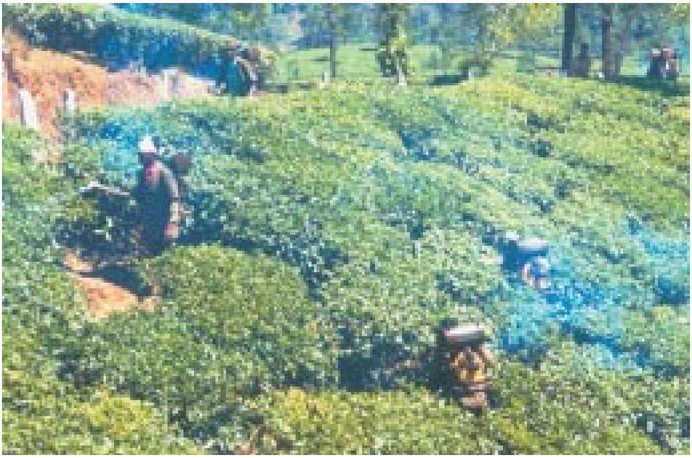

Photo 2. Application of external inputs in intensive tea plantations is very high and has led to considerable soil biological, physical and chemical degradation (photo P. Lavelle).

Intensive tea production and soil biodiversity

The soil conditions under intensive tea plantations are not conducive to high soil fauna populations and activity. Forest reserves dominated by native vegetation near three intensive tea plantations in Tamil Nadu showed a high biomass and density of various soil macro-fauna groups, which contrasted with the low biomass and density of most groups (except termites) in long-term tea plantations (Figures 1 and 2). Human-induced trampling of the soil during tea harvesting further reduced soil macrofauna populations, particularly their biomass (Figure 1). In contrast, abundance of termite pests increased in both trampled and non-trampled areas (Figure 2). The ratio of termite to earthworm populations calculated for several sites showed the potential use as an indicator of soil degradation (Figure 3).

Very few native earthworms were found in tea plantations, and most native species of both earthworms and other faunal groups probably disappeared after original forest was converted to tea plantations decades ago. However, these native animals were responsible for helping to regulate soil structure and organic matter incorporation, and this capacity was lost in conversion to tea.

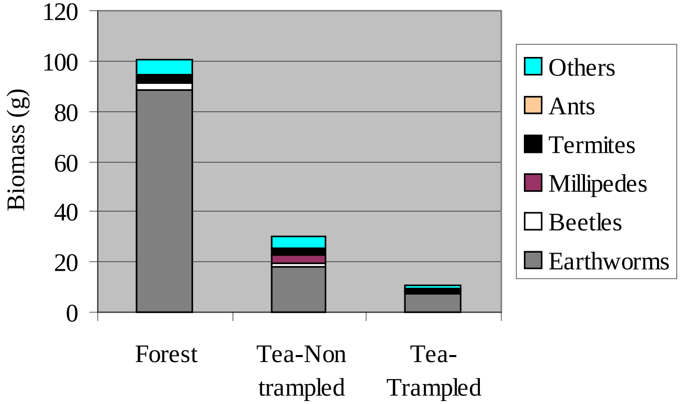

Figure 1. **Soil macrofauna biomass (average of three sites; values in g per m²) in natural forest reserves and nearby intensive tea plantations in Tamil Nadu, India. Trampled areas are zones within tea fields that were compacted by humans in harvesting activities (data from Senapati *et al.*, 1994a).**

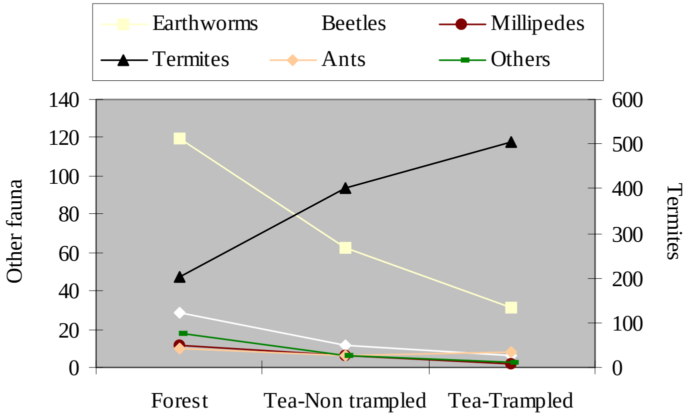

Figure 2. **Soil macrofauna abundance (average of three sites; values in number of individuals per m²) in natural forest reserves and nearby intensive tea plantations (trampled and non-trampled areas) in Tamil Nadu, India (data from Senapati *et al.*, 1994a).**

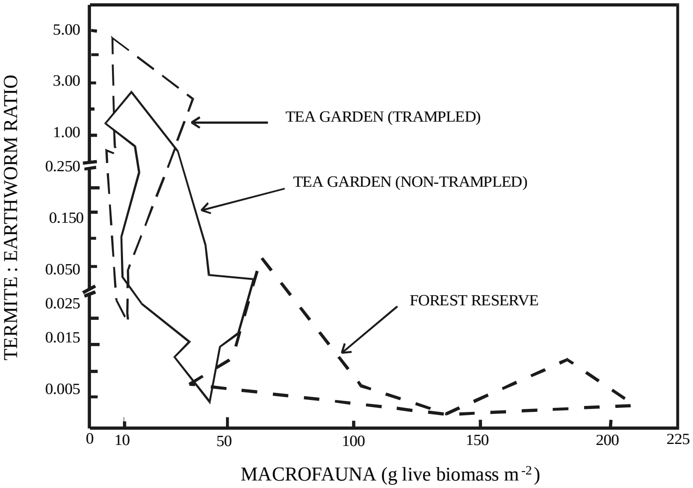

Figure 3. Termite to earthworm ratios in native forest reserves and tea plantations in Tamil Nadu, southern India (from Senapati *et al*., 1994b).

Restoring soil health and tea production using the principles and practices of *Bio-organic fertilization* (FBO)

Because agro-chemicals are unable to sustain production increases and cannot restore soil fertility, solutions must be found to recover the soil's original characteristics (as in the forest), i.e., its biological, physical and chemical properties, before it becomes degraded. The naturally regenerating properties of organic matter are well recognized, such as its ability to increase cation exchange, plant nutrient availability (depending on quality), soil fauna populations and microbial activity, soil structure (aggregation, porosity) and physical processes (infiltration, water holding capacity, erosion).

In a response to this challenge, four separate treatments were installed in 1991 at the Caroline Tea Estate (private tea plantation), in Tamil Nadu, to test the effect of organic matter applications on tea yields and the recovery of soil fauna populations. The four treatments were:

- no fertilization (zero organic and zero inorganic)
- 100% organic fertilization (no inorganic)
- 100% inorganic fertilization (no organic)

- 50% organic, 50% inorganic fertilization.

The organic fertilizer utilized was a commercial fertilizer derived from composted urban organic wastes, and the amount applied was calculated by its nitrogen fertilizer equivalents, so that the same amount of N was applied with 100% inorganic and 100% organic fertilization. The composition of the commercially available organic fertilizer and the tea residues used is given in Table 1.

TABLE 1. Chemical composition of the organic materials applied (commercial organic fertilizer and tea prunings) at Caroline and Lower Sheikalmudi Tea Estates, Tamil Nadu, India (Natesan and Ranganathan, 1990; Senapati *et al*., 1999).

	Commercial organic fertilizer	Tea leaf	Tea stem	Tea wood
pH	7.6	–	–	–
Electrical conductivity	0.34	–	–	–
%C	8.55	–	–	–
%N	0.67	3.2	1.37	1.04
C:N	12.8	–	–	–
%K	0.53	1.24	1.0	0.55
%P	1.0	0.1	0.07	0.03
%Ca	–	1.1	0.27	0.3
%Mg	–	0.17	0.09	0.06

The results showed that plots with 50% organic and inorganic fertilizers yielded 38, 32 and 31% more green tea leaf biomass in the first three years (1992-1994) compared to the conventional (100% inorganic fertilizer) treatment plots (Figure 4). Over 6 years (1992-1998), the average increase was 23%. The 100% organic fertilized plots also generally out-yielded the 100% inorganic, but to a lesser amount: 16, 17 and 13% in the first 3 years and 9% over the whole experiment (6 years). Cost benefit analyses over 3 years indicated that the 50:50 plots had a profit increase of 27-41% while the 100% organic plots had profits only 10-19% higher.

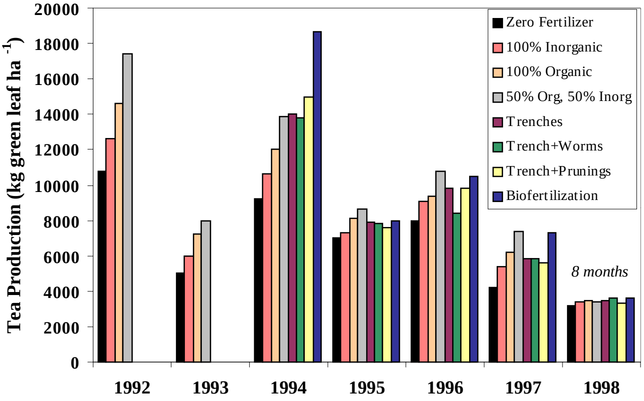

Figure 4. Effect of application of inorganic and/or organic fertilizers and earthworms alone or together with organic materials on annual green tea leaf production (total for year) during the period of 1992-1998, at Caroline Estate, Tamil Nadu (modified from Senapati *et al*., 1999). Data for 1998 represent the total for 8 months only.

Furthermore, the application of organic matter also helped raise soil faunal populations, particularly those of earthworms and other arthropods (excluding termites) (Figure 5). The termite:earthworm ratio simultaneously decreased, indicating soil restoration was occurring. In

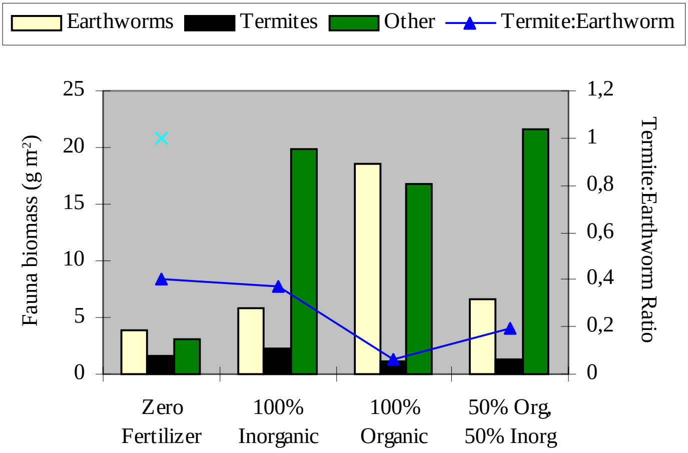

Figure 5. Soil macrofauna biomass (g m^{-2}) and termite-to-earthworm ratios as affected by organic and/or inorganic fertilization in an intensive long-term tea plantation at Caroline Estate, Tamil Nadu (data from Senapati *et al*., 1994a).

fact, improvements in macroaggregate status and soil available P contents were observed, probably due to an organic matter-induced reduction in Al saturation and higher soil fauna activity.

A second project was undertaken beginning in 1993, with support from the European Economic Community (EEC) and Parry Agro to evaluate the effect of digging trenches into the soil and incorporating or not tea prunings (tea was pruned in 1993), other organic materials and/or earthworms. Trenching is an old practice that has for the most part been abandoned in plantation crops due to the increasing cost of human labor and the substitution for other management techniques (Grice, 1977). Trenches are dug to help minimize soil loss, and improve soil moisture and aeration. Trenches 1.8 m in length, 0.3 m in width and 0.45 m in depth were prepared between the tea rows in 1 hectare blocks at Caroline and Sheikalmudi Estates (*Photo* 3). All trenches

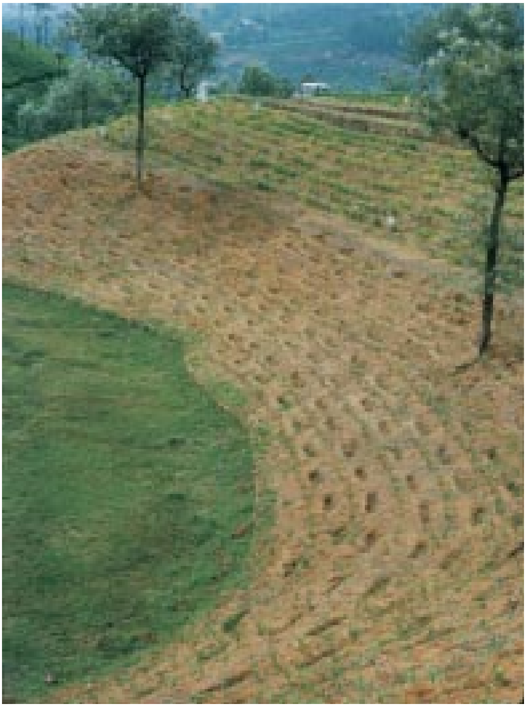

Photo 3. **The digging of trenches in between tea rows to incorporate various organic materials as a way to restore soil health and tea productivity (photo A. Chauvel).**

were fertilized with both inorganic fertilizers and the commercial organic fertilizer, in a 50:50 proportion.

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Earthworms were reproduced by vermicomposting in large covered beds (6 m x 0.9 m x 0.5 m depth) in the field with several earthworm species (*Pontoscolex corethrurus, Megascolex konkanensis*, *Amynthas corticis* and *Metaphire houlleti*), using a mixture of locally available organic materials and soil (*Photo* 4). This process permitted 1000 adult or sub-adult earthworms to rapidly reproduce and multiply up to 15 times in number, over a period of 90 days. *P. corethrurus* dominated in the beds and therefore represented 80% of the earthworms added to the trenches.

P. corethrurus is an exotic earthworm species often found in plantation crops in India and in the tea plantations studied, this earthworm species was initially found to be dominant over native earthworms species

Photo 4. Covered vermiculture beds used to produce earthworms 'en masse' for inoculation into trenches (photo P. Lavelle).

(Senapati *et al*., 1994a,b). However, inoculation of several species of earthworms and organic matter management at each site, helped rehabilitate native species over *P. corethrurus*. Various greenhouse and field trials have shown important increases in plant production when *P. corethrurus* is inoculated (Brown *et al*., 1999), but its long term impact has also been shown to be detrimental to the system under specific soil and climatic conditions, and in the absence of soil-decompacting earthworm species (Chauvel *et al*., 1999). Promotion of a single earthworm species or single inorganic/organic fertilizer was thus not a component or objective of the experimental conditions to be applied.

Choice of the quality, quantity and placement of organic materials to be used for earthworm production and organic fertilization of tea plantations was also a critical step in the use of these practices. The proper combination to apply was dependent on the status of soil degradation, local availability and its suitability to the ongoing crop culture practices. 'Diversity and dynamism as the key to sustainability and conservation' were followed as the motto during the whole process of development and application of the techniques and experiments here described.

Therefore, the treatments investigated were:

- trenches with (closed) or without (open) soil re-incorporated into the trench
- trenches with earthworms and their substrates (closed)
- trenches with incorporated organic materials varying in quality, quantity and placement
- trenches as above and earthworms (plus their substrates).

The principles and practices resulting from these experiments have created the technique called Bio-organic fertilization (‘FBO’ technology for short). FBO is an innovative package which is need-based, location-specific and synchronized as per the management practices of the individual (farmer or producer), institution or body. This innovation includes the following components:

- selection of different functional categories of earthworms
- mass scale production technology for vermiculture and primer
- selection of organic matter quality, quantity and placement
- application of inputs in ‘fertilization units’
- adaptable management practices.

At the Caroline Estate, tea yields throughout the experiment (Figure 4) were far above the national average and reached up to 19,000 kg ha^{-1} $year^{-1}$ with FBO the first year (1994). The corresponding profit increase in this treatment was 41% in 1994. The digging of trenches alone and trenches with different organic materials including tea prunings or earthworms by themselves led to significantly higher tea yields compared to the conventional treatment (100% inorganic fertilizers). However, these yields were not significantly higher than tea production levels in the 50% Organic + 50% Inorganic fertilizers treatment during the first year of the experiment. On the other hand, combination of earthworms and organic materials in the trenches, increased yields by 35% the first year compared with the mixed (50% Organic + 50%

Inorganic) fertilizer treatment and by 78% compared with the conventional treatment, although in subsequent years the benefits of this technique over the mixed treatment were less evident, with similar yields in most years. Thus, the combination of organic materials with or without earthworms into trenches and their impact on green tea leaf production indicate a particular dynamism of these innovative techniques with time.

At Sheikalmudi Estate, application of earthworms in the trenches with or without organic matter applications led to considerable increases over trenching with or without tea prunings and the conventional treatment (100% inorganic fertilization) (Figure 6, Table 2). Tea pruning is one of the locally available organic resources/materials that were incorporated along with other materials at this site. Application of 'FBO' technology increased yields more than 230%, and profits (Table 2) increased more than 3.5 times the base value (US\$2,000 ha^{-1}) in the conventional treatment, reaching up to more than US\$7,000 ha^{-1} in the first year of application. The profits obtained using FBO technology

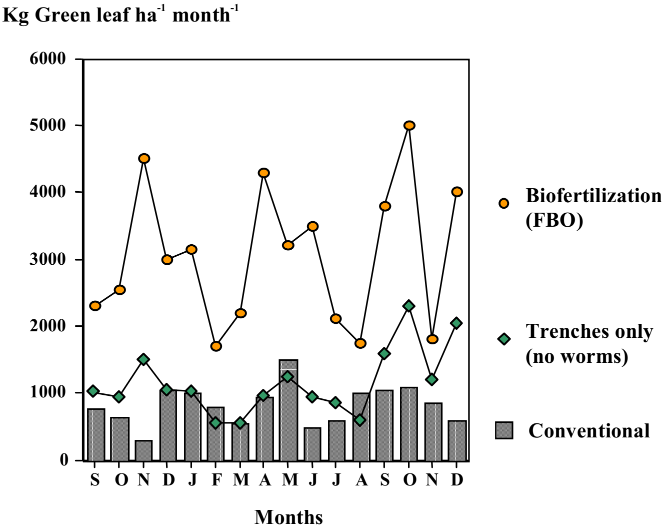

Figure 6. Effect of applying organic materials with or without earthworms into trenches, on green tea leaf production over a 16 month period at Lower Sheikalmudi Estate, Tamil Nadu (modified from Lavelle *et al*., 1998).

TABLE 2. Tea production and cost-benefit analysis evaluation of different management techniques implemented in at Sheikalmudi Estate (Parry Agro-Industries, Ltd.) (adapted from Lavelle *et al*., 1998). Conv = conventional with 100% inorganic fertilization and associated crop culture by Parry Agro; FBO = bio-organic fertilization technique, including earthworm selection, culture, primer preparation and their application along with organic matter quality, quantity and placement in bio-organic fertilization units.

	Management practices adopted				
	Conv.	**Trenches alone**	**Trench + worms**	**Trench + prunings**	**FBO**
Production (kg ha^{-1} yr^{-1})	2306	3104	8377	3132	8667
% increase	0	35	263	36	239
Income (US$ ha^{-1})	2537	3414	9215	3445	9534
Investment costs (US$ ha^{-1})					
Chemicals and manures	121	162	162	205	205
Manpower	419	573	1541	602	1600
Trench management	–	21	21	21	21
Earthworm management	–	–	114	312	114
Total costs	540	756	1837	828	1940
Profit (US$ ha^{-1})	1997	2568	7378	2617	7594
% increase	0	30	249	28	260

were more than three-fold higher despite the costs associated with applying these techniques.

Comparing the results obtained at both sites, it is apparent that the benefits of using earthworms and FBO were much greater at Sheikalmudi than at Caroline during the first year. The results that have been obtained from different experimental situations thus appear to vary in their response to the application of ‘FBO’ technology between sites as well as with time (at the same site), indicating a dynamism in this technique. This dynamism might be proportional to the recovery mechanisms from the original environmental degradation states, and the degree of response might be dependent on biogeographical regions, management practices and crop history, among other factors.

The ‘FBO’ technology must therefore be tailored to each specific site, and needs constant intervention of biologists to determine the optimum organic matter quality, quantity, combinations and placement, as well as to monitor the levels of macrofaunal diversity and density and production of biogenic structures (casts, burrows, nests, etc.).

Despite the different responses observed, the benefits of FBO technology alternatives, especially over the conventional treatment (100% inorganic), were clearly evident at both sites, providing evidence for a synergistic positive interaction on tea yields, of the presence of both earthworms and high and low quality organic materials in trenches. Extensive root growth observed near and in the trenches may be one of the main mechanisms for the enhanced benefits accrued with FBO (Giri, 1995). Other benefits of FBO come from bioturbating (burrowing, casting, soil loosening), priming (changes in soil microflora communities and activity) and mineralizing activities (nutrient mineralization and organic matter decomposition rates) of earthworms, and the ameliorating properties of organic matter application to soils (e.g., Al detoxification, soil aggregation, cation exchange).

In fact, earthworm biomass and other macrofaunal biomass were linearly related to green leaf production, with an optimal limit that varied with age of plantation, soil quality and degradation status (management practice). It has now been realized that beyond optimal limits, neither the earthworm nor the feeder root biomass continue to maintain linearity. Furthermore, the ratio of termite to earthworm biomass also served as a useful and significant synthetic index value to indicate system degradation and restoration.

Conclusion: The potential for Bio-organic fertilization

The current adoption of FBO techniques in very large scale applications can already assure positive responses of up to 50% enhancement in production. Furthermore, other benefits can accrue, such as land restoration, product quality improvement, soil conservation, landscape and aesthetics values; these have, in many cases not yet even been evaluated (and will certainly greatly amplify the benefits of FBO). This is an indication that in worst case-scenarios, even if production enhancement is insignificant, cumulative values of other components in the system will benefit from the innovation.

Based on the results obtained at Caroline and Sheikalmudi Estates using FBO, a patent was deposited to protect the technique associated with this treatment (selection of earthworms, large-scale vermiculture and primer preparation, selection of organic materials by quality, quantity and placement and their management and application into trenches as a bio-organic fertilization unit). The patent, entitled "Fertilisation Bio-Organique dans les Plantations Arborées" (FBO), was developed by Parry Agro Industries Ltd., in association with the French Institut de Recherche pour le Développement (IRD) and Sambalpur University (Orissa, India). Details of the methodology for its application are described in the patent document (ref. PCT/FR 97/01363).

The holistic system approach of the 'FBO' technology has now been extended to about 200 ha in different Estates of Parry Agro-Industries and to other countries and over 20 million earthworms are being produced each year (Senapati *et al*., 1999). The latest development in this technology include the signing of 'LOI' (Letter Of Intent) among three parties (IRD, Parry Agro and Sambalpur University) in Nov. 2000, for technology transfer to China and Australia for large scale implementation. Furthermore, the possible application and benefits of applying the FBO technique and its principles and practices in other tree/bush crops should be explored. This wider applicability could include adoption of FBO to conserve and/or restore soil fertility in degraded or degrading sites planted with crops or bushes and trees such as: coffee, citrus or banana, and even plantations of coconut, oil palm, Eucalyptus or Pine species, etc.

However, FBO techniques are being assimilated at a slower pace than desired, especially because of the deep-rooted tradition of conventional technologies, upheld by agrotechnologists who comprise a large majority of the farm managers in India. Other such impediments for adoption should be investigated and ways of publicizing FBO more widely, and promoting its adoption in other countries experiencing the same difficulties (stagnating or decreasing tea yields and/or degraded or degrading soil conditions), should be found and implemented. Finally, another major constraint presently affecting wide-spread adoption of FBO may be its high human labor demands and the associated availability and cost (*Photo* 5). It was estimated that, in tea plantations, the target sites for application of FBO must be re-inoculated and the trenches re-dug every 3-4 years to ensure that the benefits continue at high levels. Thus, for the technique to lead to highest benefits, an inexpensive and readily available labor source must be present. This is the case for some countries such as India, but not for others, where the cost would become prohibitive unless manual trench digging could be substituted by machine powered diggers (in an economically viable manner), and the cost of producing earthworms (still considerably dependent on human labor) could be minimized. Additionally, as vermiculture techniques modernize and improve, the potential for reducing earthworm

Photo 5. Tea is a crop that demands much human labor when machines are not available; the FBO technology currently also has high human labor demands, although these can be reduced with the development of appropriate machinery and technologies (photo P. Lavelle).

production costs for inoculation will increase, making FBO more feasible even in countries where human labor costs are high or few laborers are available.

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MANAGING TERMITES AND ORGANIC RESOURCES TO IMPROVE SOIL PRODUCTIVITY IN THE SAHEL[*†]

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Overview

Termites, widespread and abundant in drier areas in the tropics, are not only pests, but can also play an important beneficial role in recovering degraded ecosystems. They are a resource that can be used and managed, together with locally available organic resources, to counteract land degradation through their soil burrowing and feeding activities. Land degradation is a major agricultural problem in the Sahel, and one of the most spectacular demonstrations can be seen in the extension of completely bare and crusted soils. In this region, the combined effect of soil organic matter depletion, primary production decrease due to mismanagement of the fragile ecosystem, and the harsh climatic conditions has resulted in the expansion of crusted soils. These soils are characterized by:

- very low infiltration capacity
- nutrient imbalances
- reduced biodiversity and
- low to nil primary productivity.

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[*] *This case study is based on the results obtained by Dr. Abdoulaye Mando, as part of his PhD dissertation (Mando, 1997), under the direction of Drs. Leo Stroosnijder and Lijbert Brussaard, of the Agricultural University-Wageningen, Holland.*

[†] *Case study also available from the Soil Biodiversity Portal at http://www.fao.org/agl/agll/soilbiol/*

This situation has led to increasingly miserable social conditions such as:

- decrease in per capita availability of arable land
- decrease in per capita food production
- decline of human welfare and
- social crises due to ever increasing land shortage.

Soil rehabilitation efforts have been undertaken by governments of several Sahelian countries, however these are constrained by socio-economic conditions that limit the use of machinery and fertilizers, which are unavailable and expensive in most countries. An alternative practice for rehabilitating crusted soils is through the application of various organic mulches to the soil surface that attract termites and/or increase their activity. Their bioturbating activities in the crusted soils speeds their rehabilitation by:

- breaking up of surface crusts
- reducing soil compaction
- increasing soil porosity
- improving water infiltration into the soil and
- enhancing water holding capacity in the soil.

These activities create conditions that permit:

- root penetration into the soil
- recovery of a diverse vegetative cover and
- restoration of primary productivity.

Work performed by Dr. Mando in Burkina Faso has demonstrated that termites, far from being only traditionally-held pests in agroecosystems, can also be extremely important in soil rehabilitation efforts, in plant production and ecosystem function, and that it is possible to manage their activities for human benefit. In the denuded areas where mulch was applied and termites invaded, within 1 year native plants re-established themselves, and crops such as cowpea could be planted, yielding modest harvests (>1 T ha^{-1} grain).

The Problem: Soil degradation in the Sahel

Soil degradation and particularly crusting is a major agricultural problem in the Sahelian zone. The combined effect of extreme and difficult climatic conditions, overgrazing and trampling by cattle, continuous cultivation and other unsustainable management practices have resulted in the spreading of bare soils with a degraded structure and a sealed surface (crusts) that impede water infiltration and root growth (*Photo* 1). Such soils constitute a threat to Sahelian agriculture and restoration efforts must be undertaken if agricultural productivity is to be restored and sustained.

Photo 1. Bare plot in September 1994. The whole site was like this picture at the beginning of the experiment.

To solve the problems that confront rural areas in the Sahel, to secure food production, and to curtail further soil degradation, a variety of measures can be taken. These range from re-evaluating and adjusting macro-economic policies to the implementation of simple measures at the farm household level. Amongst others, this requires that the productivity of the arable land increase and also that the area of land under cultivation or pasture be extended at the expense of wasteland (Kaboré, 1994, Mando, 1997). However, because the Sahel is one of the world's poorest regions, any new techniques can only be adopted if they are cheap and easily accessible. Therefore, modern techniques often used in the developed countries, such as machinery and fertilizers are not feasible.

Alternative solutions: Mulch and termite activities

The stimulation of soil fauna, especially termites, in semi-arid regions is a viable option to improve soil structure (Mando *et al*., 1996). Termites can affect the soil by their burrowing and excavation activities in search of food, or the construction of living spaces or storage chambers in the soil or above-ground. In fact, soil structure, structural stability, porosity, decomposition processes and chemical fertility are altered to a large extent by termite activities. Based on this presupposition, the role of termites and mulch in the rehabilitation of crusted soil was examined. The main hypothesis was that application of organic material on crusted soil would trigger termite activity and that termite-mediated processes would promote the rehabilitation of the degraded soil.

Materials and methods

The study site was located in Bam Province, Northern Burkina Faso, in the Western African Sahel. Rainfall in the region is irregular (400-700 mm year^{-1}) and mean temperature ranges from 20-30º C, with great diurnal variation. Native vegetation consists mostly of annual herbs and shrubs, with few annual grasses. Soils in the region are ferric and haplic lixisols and chromic cambisols (FAO-UNESCO classification). Bare spots are abundant and human pressure on the environment is high. Termites are the predominant soil fauna in the region and consist mostly of the subterranean type, that do not create mounds on the soil surface. Three species of termites were found in the experimental field: *Odontotermes smeathmani* (Fuller), *Microtermes lepidus* (Sjöst) and *Macrotermes bellicosus* (Sjöst).

A split plot design with three replications was used to study the biological and physical role of mulch in the improvement of crusted soil and water balance during three consecutive years (1993-1995). Dieldrin (an insecticide) was used to obtain termite and non-termite infested plots. Four treatments with or without three different mulch types were randomly applied in subplots:

1. no mulch (bare plot)
2. straw of *Pennisetum pedicellatum,* at 3 tons ha^{-1}
3. woody material of *Pterocarpus lucens,* at 6 tons ha^{-1}
4. composite (woody material and straw) treatment, at 4 tons ha^{-1}.

Data on termite activity, organic matter decomposition, runoff, sediment accumulation, plant diversity and biomass of vegetation cover were collected on all plots.

In addition, another experiment with application of grass (*P. pedicellatum*) straw or cattle dung at 5 and 7 tons ha^{-1} mulch, respectively, was conducted to assess the effects of the presence/absence of mulch and/or termites on the growth and production of cowpea.

Results: Soil rehabilitation, restoration of vegetative diversity, primary productivity and agricultural potential is stimulated through termite activities

No other soil fauna besides termites was observed on the plots, and no termite activity was observed on the plots sprayed with the insecticide. On the plots without pesticides, the application of organic materials (mulch) to the soil surface triggered termite activity, and termite colonization occurred in a relatively short time. Termite activity was similar under the different mulch types.

Termites and soil structure

Odontotermes smeathmani was the species mainly responsible for the termite-created features observed. These features included:

1. transport of material to the soil surface to construct sheathings for protection while searching for food

2. opening up of large voids on the sealed surface of the soil and throughout the entire soil profile (*Photo* 2 and 3)
3. soil aggregation, particularly below 10 cm, through the construction of bridged grains, coatings and crumbs that form the infillings of voids.

Photo 2. Termite-created voids on crusted soil after mulch application.

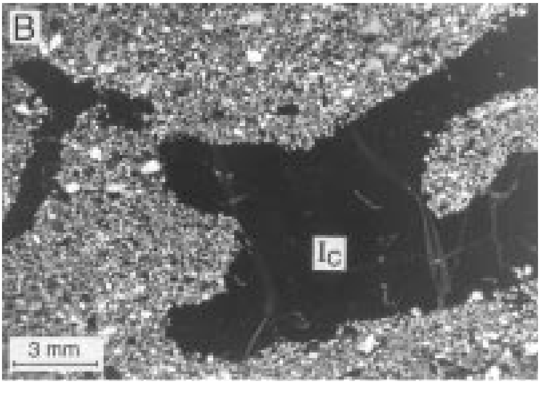

Photo 3. Cross polarized image of the microstructure of termite channels in the 0-10 cm layer of mulched plots. Note the interconnection of channels in the middle of the image (Ic).

All three features had a critical influence on soil properties and processes. The transport of material to the soil surface loosened the soil enabling water to infiltrate more rapidly (Figure 1). Both termites and mulch reduced runoff and increased soil water content (storage) throughout the plant growing period. The area occupied by the large termite-created voids represented up to 12% of the topsoil (0-7 cm horizon), and accounted for 60% of the macroporosity in that horizon.

The role of mulch in improving soil water status was achieved by protecting the soil against evaporation and increasing water infiltration through its many tiny barriers. However, the differences in soil structure between plots with and without termites showed that the application of mulch alone was of much less importance in crusted-soil rehabilitation, than the effect of termites feeding on and transporting the mulch materials.

In the bare plots, the results of previous termite activity (voids, macropores etc.) could be seen below 30 cm, although the top 10 cm of the soil showed a compact structure, with no aggregates, and a clear inability to permit adequate water infiltration (Photo 4).

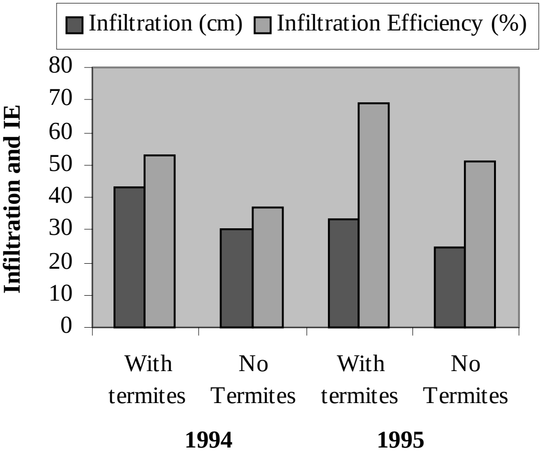

Figure 1. Effect of termites on soil water infiltration (cm) and infiltration efficiency (IE, %).

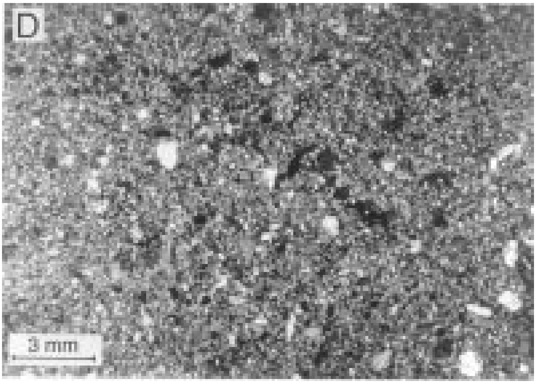

Photo 4. **Cross polarized image of a compact grain microstructure in the 0-10 cm layers of a bare plot.**

Termites and plant production

The mulching of a completely bare and crusted soil surface resulted, within one year, in the rehabilitation of primary production (*Photo* 5). However, plant diversity, plant cover and biomass and rainfall use

Photo 5. **Termite-straw plot (TS) in September 1994. Note that the straw that was applied as a mulch had disappeared due to termite consumption, but the productivity of the soil was restored.**

efficiency of plants growing in mulched plots with termite activity (*Photo* 5) were greater than in the plots without termite activity (*Photo* 6; Table 3). Woody species only established in plots with termites.

Photo 6. **Non-termite straw plot (NTS) in September 1994. Note that two years after the lay out of the experiment, the straw is still not decomposed and the vegetation did not perform well, despite mulch application.**

TABLE 3. Effect of termites and mulch on vegetation parameters.

Treatment	Biomass (T ha^{-1})		Number of plant species			Woody plants (ha^{-1})
	Year		Year			Year
	1994	1995	1993	1994	1995	1995
Straw + Termites	3.7	2.9	(3-13)	(11-25)	(26-35)	417
Wood + Termites	2.4	3.1	(1-15)	(5-11)	(18-30)	417
Composite mulch + Termites	3.3	3.9	(1-15)	(8-18)	(18-32)	665
Straw only	1.4	1.3	(1-8)	(6-10)	(8-21)	0
Wood only	1.2	0.5	(0-6)	(2-12)	(8-24)	0
Composite mulch only	1.4	1.1	(1-7)	(6-14)	(6-20)	0
Bare plot	0.0	0.0	0	13(0-2)	0	0

Plant performance was best when straw and composite-mulch were applied, moderate when woody mulch was used, and worst without mulch application (bare plots) in the first year of the experiment. During the consecutive years, the performance of the vegetation in termite plots increased but this phenomenon was more apparent in wood-mulched plots compared to those that were straw-mulched. Straw had a quicker but shorter effect on vegetation performance whereas woody material had a slower but longer-lasting effect. Bare plots remained bare throughout the experimental period (*Photo* 1).

Although mulching without termites did not significantly improve plant production in already crusted soils, it had some effect on the growth of native plants by improving soil microclimatic conditions and entrapping wind-blown sediments and improving rooting conditions for plants.

Crop (cowpea) growth and yields were far better in plots with termites than in no-termite plots (*Photos* 7 and 8), and termites greatly improved the performance of the cowpea. Yields reached 1 ton ha^{-1} where manure was added and termites were present, while no cowpea grain was harvested when only straw was applied in the absence of termites (Table 4).

Photo 7. Cowpea on termite plus cattle dung plots. Note that the termites had consumed all the cattle dung applied as a mulch without negative effects on the growing crop.

Photo 8. Cowpea on non-termite cattle dung plots. Note that 7 months after the lay out of the experiment, the cattle dung is still not decomposed and that the crop did not perform well, despite cattle dung application.

TABLE 4. Effect of termite addition to two different mulch types on cowpea yields, hydraulic conductivity and some chemical properties of a degraded Sahelian soil

Treatments	Yield (T ha^{-1})	Mineral N (mg kg^{-1})	K (mg kg^{-1})	Total P (mg kg^{-1})	K*sat** (10^{-5} ms^{-1})
Cowdung + termites	1.02	21.0	87.5	130.5	1.2
Straw + termites	0.6	10.0	26.0	106.5	1.7
Cowdung only	0.01	10.5	50.4	140.2	0.9
Straw only	0.0	10.1	29.6	75.7	0.5

*K*sat = Saturated hydraulic conductivity*

Termites thus played the preponderant role in primary productivity, affecting vegetation growth through two main processes:

1. improvement of soil structure and water infiltration; this was the most important mechanism of termite-mediated rehabilitation of the crusted-soils;
2. enhancement of nutrient release into the soil from the mulch due to termite activity (Table 4).

In semi-arid conditions termite activity plays a key role in nutrient cycling, and the timing of mulch application is critical to optimize termite foraging period and the weather conditions necessary to synchronize nutrient release with plant demands.

Conclusion: The potential for widespread biological soil remediation

The present study has shown how locally available organic resources (straw and woody materials, manure) can be applied to the surface of crusted soil to trigger regenerative termite activity within a few months. Despite the additional labour involved in gathering and spreading these materials (human constraints), the benefits are not only immediate, but also long-lasting. The major natural constraint on the wide-spread adoption of this technique however, would be the removal of plant material from one area to regenerate another. The amount of material removed must never reach a level where it causes degradation of the site it is being removed from or the activity defeats its purpose. But once the productive capacity of the ecosystem is restored, it is likely that the vegetation produced can act as the continuing source of food for the termites, who will then use the organic materials to continue their bioturbation activities critical to the maintenance of soil structure and plant production.

Termites, traditionally held to be pests in many occasions, can also be human friends. Termite activities repair the damage caused by soil degradation (crusting) through excavation across crusted surfaces, and the production of large voids that improve soil porosity and water infiltration into soil. Termites also enhance the decomposition of surface-applied organic materials stimulating nutrient release, which can then be used by growing plants. These results confirm that termites are not only pests, but can also be highly beneficial biological agents whose bioturbating and decomposing activities can be managed indirectly (with organic matter) to enhance primary production. Farmers in Burkina Faso and in other areas of West Africa are extensively making use of termite-mediated processes to enhance soil restoration and agricultural production in their farming systems (e.g., the zai/tassa system, where organic material is put into small holes in which termites enhance decomposition and increase water infiltration; see Roose *et al.*, 1992 and Mando *et al.*, 2000).

Finally, these results also show that soil structure degradation is the result of eradicating native soil fauna (termites in this case) that were responsible for constructing and opening voids near the soil surface (top 10 cm), and counteracting the degrading processes destroying these voids. In order to avoid future land degradation, and to recover currently degraded lands, organic resources should be applied in a continued manner, to feed termites and maintain and promote their populations and their soil and plant regenerative activities.

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OVERVIEW AND CASE STUDIES ON BIOLOGICAL NITROGEN FIXATION: PERSPECTIVES AND LIMITATIONS[†]

Adriana Montañez[*]

Problem statement

Biological Nitrogen Fixation and Sustainable Agriculture

Nitrogen is an essential plant nutrient. It is the nutrient that is most commonly deficient in soils, contributing to reduced agricultural yields throughout the world. Nitrogen can be supplied to crops by biological nitrogen fixation (BNF), a process which is becoming more important not only for reducing energy costs, but also in seeking more sustainable agricultural production. Nitrogen fixing micro-organisms could therefore be an important component of sustainable agricultural systems.

There are several significant reasons to seek alternatives to fertilisers that provide chemically fixed nitrogen:

- ❖ **Environmental**

  Nitrogen fertilisers affect the balance of the global nitrogen cycle, and may pollute groundwater, increase the risk of chemical spills, and increase atmospheric nitrous oxide (N_2O), a potent “greenhouse” gas.

- ❖ **Energy**

  The primary energy source for the manufacture of nitrogen fertiliser is natural gas, together with petroleum and coal. On the contrary, the energy requirements of BNF are met by renewable sources such as plant-synthesised carbohydrates rather than from non-renewable fossil fuels.

- ❖ **Sustainability**

  Long- term sustainability of agricultural systems must rely on the use and effective management of internal resources. The process of BNF offers an economically attractive and ecologically sound means

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[†] *Case study also available from the Soil Biodiversity Portal at http://www.fao.org/agl/agll/soilbiol/*

of reducing external nitrogen input and improving the quality and quantity of internal resources.

- **Nutrition**

  It is estimated that about 20% of food protein worldwide is derived from legumes. There are more than 13,000 described species of legumes and for only 3,000 species examined, more than 90% were found to form root nodules. Because few have been exploited for food, there is the prospect that the utilisation of legumes could be expanded substantially. It is anticipated that increasing demographic pressure and food demand will require the exploitation of BNF as a major source nitrogen for plant protein production.

Objective

The objective of this paper was to explore and discuss the possibilities for enhancing N_2 fixation by working on the plant host, the microbial symbiont and management of different agronomic methods. Examples will be taken from research work across different agro-ecological and socio-economic contexts that illustrate best practices and experiences for enhancing biological nitrogen fixation.

Strategies to enhance BNF in agricultural systems

There are several methods available to scientists working on enhancement of N_2 fixation:

1. Host plant management (breeding legumes for enhanced nitrogen fixation)
2. Selection of effective strains able to fix more nitrogen
3. Use of different agronomic methods that improve soil conditions for plant and microbial symbionts.
4. Inoculation methods

No one approach is better than the others; combining experience from various disciplines in inter-disciplinary research programmes should be pursued.

1. Host plant management

1.1. Plant selection

The amount of nitrogen fixed by legumes varies widely with host genotype, *Rhizobium* efficiency, soil and climatic conditions and, of course, the methodology used in assessing fixation.

The effectiveness of various legume species and their micro-symbionts has been provided in several publications[1]. The nitrogen fixing potential of a number of different legume species and their microsymbionts is showed in Figure 1.

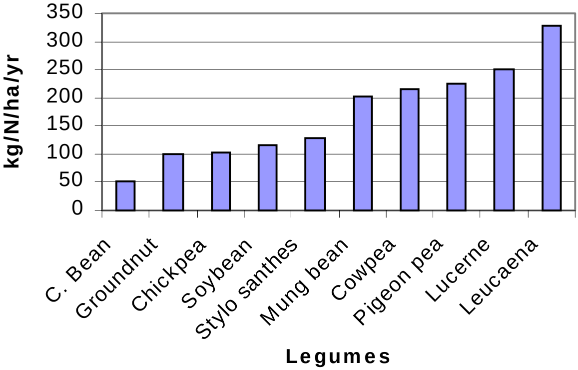

Figure 1. Average amounts of nitrogen fixed by various legumes (kg N/ha/yr)[2].

Case 1 illustrates that when effective rhizobial populations are present either naturally or from inoculation, and there are no other major yield-limiting factor, plant selection is a potential method to enhance BNF.

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[1] *Hardarson, G; Danso, SKA; Zapata F; 1987. Biological nitrogen fixation in field crops. In: Handbook of Plant Science in Agriculture (Eds.) BR. Christie. CRC Press Inc. Boca Raton, FL, pp 165-192*

[2] *FAO 1984. Legume Inoculation and Their Use. Food and Agriculture Organization of the United Nations. Rome 63 p.*

Case 1: Genotypic variation in BNF by Common Bean

(adapted from Hardarson et al., 1993)[3]

The objective of this study was to investigate the N_2 fixation potential of various cultivars and breeding lines of common bean and to identify lines which could be used as parents in breeding programmes to enhance N_2 fixation in this species.

Field experiments were performed in Austria, Brazil, Chile, Colombia, Guatemala, Mexico and Peru as part of an FAO/IAEA Co-ordinated Research Programme to investigate the nitrogen fixing potential of cultivars and breeding lines of common bean (*Phaseolus vulgaris* L.). Each experiment included different bean genotypes, which were compared using ^{15}N-isotope dilution method (Table 1).

TABLE 1. Data from the FAO/IAEA Co-ordinated Research Programme to investigate the nitrogen fixing potential of cultivars and breeding lines of common bean (*Phaseolus vulgaris* L)

Country	Common bean tested (N°)	Total N fixed (Kg.ha^{-1})	Selected cultivars
Austria (Seibersdorf)	29	25-165	Riz 44, Bat 322
Brazil (Goiania)	17	4-12	Honduras 35 Carioca
Chile	7	10-50	Red Mexican INIA Don Timoteo
Colombia (CIAT)	9	20-35	A268
Guatemala	10	92-125	ICTA San Martin ICTA Panamos ICTA Quenack-Ché
Mexico	18	0-70	Azufrado Negro Colima Negro Poblano
Peru - Summer Winter	20	12-59 19-59	Summer: Cabalero, Caraota, Blanco Winter: Bayo Normal, Canario G-62-2-6, Bayo G-7.5-9

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[3] *Hardarson, G., Bliss, F.A., Cigales-Rivera, M.R., Henson, R.A., Kipe-Nolt, J.A., Longeri, L., Manrique, A., Peña-Cabriales, J.J., Pereira, P., Sanabria, C.A., Tsai, S.M., 1993. Genotypic variation in biological nitrogen fixation by common bean. Plant Soil 152, 59-70.*

The results from the different countries showed that dry conditions and high temperatures contribute to low levels of fixation. Similar to other published results this study provides evidence for substantial genotype variability. The high values for nitrogen fixation were observed on adapted cultivars and breeding lines when the environmental conditions were favourable.

These can be used either directly as cultivars for production or in breeding programmes to enhance nitrogen fixation in their cultivars.

More effort in bean improvement programs should be placed on selection for increased nitrogen fixation under representative field conditions and involving improved inoculants when possible.

1.1. Plant improvements: roles for biotechnology

Although the direct molecular modification of a host plant or microsymbiont has yet to result in the improvement of N_2 fixation at the field level, several approaches offer promise. They include:

- **Host transformation to modify host range**. In a recent study transgenic *Lotus* plants transformed with the soybean lectin gene became susceptible to infection by *Bradyrhizobium japonicum*[4]
- **Host modification to synthesize opines**. Because *Rhizobium* strains vary in their ability to use opines, genetic engineering of legumes or other plants for opine synthesis may result in the enhanced growth of rhizosphere organisms with the ability to utilise this substrate[5].
- **Genetic transformation of plants for enhanced malate dehydrogenase (MDH) synthesis in roots and nodules**. Malate is the primary plant carbon source used by bacteroids, and is also a factor in plant adaptation to P and Al stress. Alfalfa transformed with a MDH gene having high efficiency in malate synthesis, exuded more organic material into the rhizosphere and fixed more N_2 than the wild type in initial studies (Temple *et al*., unpublished). Whether this also translates into enhanced P uptake and Al balance, remains to be determined.

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[4] *Van Rhijn, P., Goldberg, R.B., Hirsch, A.M., 1998.* Lotus corniculatus *nodulation specificity is changed by the presence of soybean lectin gene. Plant Cell 10, 1233-1249*

[5] *Savka, M.A., Farrand, S.K., 1997. Modification of rhizobacterial populations by engineering bacterium utilization of a novel plant produced resources. Nature (Biotech.) 15, 363-368.*

Case 2: Mutation breeding of grain legumes: an opportunity to enhance BNF (adapted from Micke, 1993)[6]

The Objective of this work is to help plant breeders to develop improved cultivars through the use of induced mutations.

For example many mutants varieties of common bean have been released that possess many different improved characters (Table 2. Adapted from Micke , 1993). Mutation breeding therefore appears to be an appripriate approach not only for genetic improvement of grain legumes in general but also for improving their symbiotic nitrogen fixation.

TABLE 2. Improved cultivars of common bean developed by mutation breeding

Species and name of cultivars	Country and year of release	Mutagen used	Improved characters
……………………………………… *Phaseolus vulgaris* L. (common bean) ………………………………………			
Universal	Germany, 1950	x-rays	Early maturing, higher yield, disease resistant
Sanilac	USA, 1956	x-rays	Bush type
Unima	Germany, 1957	x-ray & cross	Disease resistant
Seaway	USA, 1960	x-rays & cross	Bush type, short duration, virus resistant
Gratiot	USA, 1962	x-rays & cross	Bush type, stiffer stem, higher protein content
Saparke 75	USSR, 1967	Gamma rays	Higher yield, better disease resistant
Seafarer	USA, 1967	x-rays & cross	Very early maturing bush type, disease resistant
Pusa Parvati	India, 1970	x-rays	Early, bush type, higher yield
Alfa	CSFR, 1982	EMS	White seed colour, higher yield and protein content
Giza 80	Egypt, 1980	Gamma rays	Higher yield, larger grain, rust resistant
Muhranula	USSR, 1982	EI	Earlier
Ouray	USA, 1982	x-rays & cross	Bush type, better disease resistant
Markovskaya 8	USSR, 1985	Gamma rays	White seeds, earlier
Mogano	Italy, 1985	EMS	Uniform seed colour, dwarf type, high yield
Montalbano	Italy, 1985	EMS	Uniform yield colour, high yield
CAP 1070	Brazil, 1986	Gamma rays	Bush type, earlier maturity
Mitchell	Canada, 1986	x-rays & cross	Higher yield
Neptune	USA, 1986	x-rays & cross	Bush type

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[6] *Micke, A., 1993. Mutation breeding of grain legumes. Plant Soil 152, 81-85*

- **Host mutants with improved characters such as disease and insect pest resistant, earlier and later flowering, higher yield, higher protein content or less toxic compounds** (see Case 2)[7].

2. The effect of the micro-symbiont

There are several important characteristics to be considered for the selection of the rhizobial-symbiont.

- **Nitrogen fixation ability:**

  The rhizobia involved in nodulation can influence the percentage and amount of nitrogen fixed by the legume/*Rhizobium* symbiosis.

  There are several methods available to quantify and estimate N_2 fixation. Plant dry weight is usually well correlated to effectiveness in N_2 fixation, when N is the only limiting growth factor. ^{15}N-based methods[8] provide direct evidence for N_2 fixation and can be used by developing countries largely through collaborative arrangements with developed countries and agencies that have the resources. The International Atomic Energy Agency (IAEA) Vienna, Austria assists developing countries through co-ordinated BNF programs. Results of a Rhizobium screening programme in India is illustrated in Case 3.

- **Competitive ability:**

  The proportion of the nodules formed on a particular host is influenced by the competitive ability of an inoculated *Rhizobium* strain in comparison to indigenous strains, which may vary in their effectiveness.

- **Other important characteristics of rhizobial inoculants are:**

  i. Survival ability

  ii. Colonisation of the rhizosphere

  iii. Migration in the soil

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[7] *FAO/IAEA 1988. Improvement of Grain Legume Production Using Induced Mutations. IAEA, Vienna.*

[8] *Hardarson, G., Zapata, F., Danso, S.K.A., 1984. Field evaluation of symbiotic nitrogen fixation by rhizobial strains usin 15 methodology. Plant Soil 82, 369-375.*

Rhizobial inoculant for a particular legume species can be obtained either from other research laboratories, or through a selection programme. Selection of Rhizobia is justified only when no suitable strain is available from other sources.

Strain selection will be required for example:

- when the legume of interest is an uncommon species for which there is no recommended strain and,
- when inoculation with a recommended strain does not produce adequate nodulation and fixation.

Case 3: Outputs of the Rhizobium screening programme in India

(adapted from Khurana et al., 1998)[9]

Objective: to determine the effect of various factors such as the presence of a native homologous rhizobial population, soil mineral nitrogen, soil temperature and moisture, soil pH and interaction of rhizobia with other soil microbial communities on the response of legumes to rhizobial inoculation.

Efficient strains of rhizobia perform extremely well under controlled conditions, however, the response to inoculation under field conditions is highly variable.

Selection of native effective Rhizobium strains was performed from diverse geographic regions in India. The response of rhizobial inoculation on chickpea grain yield was tested under the All India Co-ordinated Project on Improvement of Pulses (AICPIP) under the aegis of the Indian Council of Agricultural Research (ICAR).

Data on the response of rhizobial inoculation on chickpea yield during three years 1993-95, 96 at 38 farmer's fields in seven states is summarised in Table 3 (Khurana *et al*., 1999).

In traditional chickpea-growing areas in India it was observed that about 18% of farmer's fields had < 102 rhizobia g^{-1} soil. Significantly improved yield due to rhizobia inoculation is expected when a field has < 102 rhizobia g^{-1} soil and other factors affecting BNF are optimum.

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[9] *Khurana, A.L., Dudeja, S.S., Sheoran, A., 1998. Biological nitrogen fixation in chickpea for sustainable agriculture. Prospects and limitations. Sust. Agric. Food, Energy, Ind.439-444.*

TABLE 3. Residual maximum likelihood estimates of grain yield in on-farm experiments on rhizobial inoculation in chickpea, 1993-1996, at various locations in India

Location	Year	N° farmers fields	Grain yield (kg ha^{-1})		Increase over control (kg ha^{-1})
			Noninoculated	Inoculated	
Maharashtra	1995-96	13	938	1026	88
Rajasthan	1993-94	5	1068	1212	144
	1994-95	3	1731	2120	339
	1995-96	6	897	1015	118
Karnataka	1994-94	1	840	1350	510
	1994-95	2	755	900	145
Haryana	1994-95	2	1100	1300	200
	1995-96	3	1367	1533	168
Punjab	1993-94	5	642	752	110
	1994-95	5	1750	2020	270
Uttar Pradesh	1993-94	1	847	1007	160

2. Factors, affecting BNF: Management decisions

Environmental factors affecting nitrogen fixation include temperature, moisture, acidity and several chemical components of the soil such as nitrogen, phosphorus, calcium and molybdenum content[3]. It is often difficult to isolate the effect of the above factors on inoculation success from their influence on symbiosis and nitrogen fixation. For example: acidity, as well as, calcium, aluminium and manganese concentrations will interact and affect both bacterial proliferation, root-hair infection and plant growth[3].

Numerous (micro)-climatic variables, soil physical properties and agronomic management factors also play a part in controlling N_2 fixation; however, none of those factors should be considered in isolation as all are interconnected in the control of N_2 fixation (Figure 2).

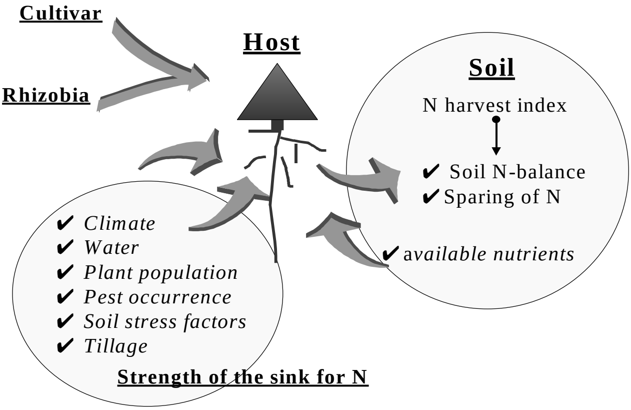

Figure 2. Conceptual model of the major factors that exercise a control on N_2 fixation of grain legumes in a cropping system (adapted from van Kessel & Harley, 2000)[10]

In addition to the competitiveness of the rhizobia in forming nodules and the effectiveness of the rhizobium-host plant to fix $N_{2,}$ a series of edaphic, chemical and biophysical factors exert a control on N_2 fixation. Management practices like the intensity of tillage or intercropping practices will alter those edaphic, chemical and biophysical factors and therefore influence BNF indirectly, as illustrated in Table 4.

3. Inoculation

Inoculum strains when applied to the target ecosystem have to compete with all of the negative and neutral microbes presented in the soil. This competition could reduce the efficacy of the final product and therefore methods and strategies to improve *Rhizobium* performance should be studied.

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TABLE 4. Factors Affecting Biological Nitrogen Fixation: a summary of some important factors limiting biological nitrogen fixation and possible recommendations

Factors affecting BNF	Effect	Recommendations
Temperature & moisture	• survival, of rhizobia in soil[11] • abilities to nodulate and fix nitrogen[12, 13] • inhibition of nitrogen fixation[14]	• placement of inoculum in deeper soil layers when top soil temperature are high[15] • Use of surface mulches may conserve moisture and reduce soil temperature[15]
Nitrogen Fertilisation	• Generally combined N delays or inhibits nodulation and nitrogen fixation. Because of this adverse effect, N fertilisation usually is not recommended for leguminous crops. However there may be situations where N has to be applied, such as to cereals in mixed cropping or rotations and then fertiliser may affect nitrogen fixation of the legume crop[16]	• the development of grain legumes which are less sensitive to mineral N should not be pursued unless there is increase in N-uptake and an improvement in the overall use efficiency of available N[16] • it is possible to apply small amounts of soil or foliar N fertiliser, which may increase yield without reducing the amount of nitrogen fixed[17, 18]
Pesticides, fungicides and insecticides	• The compatibility of rhizobia with pesticides is poorly understood except for fungicides[3, 19] • Insecticides have little adverse effect on nodulation when not directly applied on seed • The effect of herbicides on rhizobial survival is unknown	• due to the variability of the effect it is recommended to test the particular Rhizobium inoculum and its behaviour in respect to the product to be used, before application • the effect of pesticides on N fixation should be minimised by separate placement of rhizobia and pesticide
Intercropping	• Increase opportunities for N-use complimentarily, reducing the need for fertiliser-N, either by increasing the availability of soil N or by N transfer	• Several examples producing mixed results are showed in Case 4 **on Intercropping management**

Factors affecting BNF	Effect	Recommendations
Acid soils	• Acid soils constrain agricultural production and nitrogen fixation	• Use of acid-tolerant legume cultivars and rhizobium • Soil liming should be limited to achieving a pH at which available aluminium or manganese levels are no longer toxic
Tillage	• When tillage is minimised, lower rates of mineralization and nitrification, coupled with increased N immobilisation and a higher potential for denitrification will lead to a decrease in available N	• Limiting tillage can stimulate N demand and N_2 fixation. Conservation and zero tillage management practices will, therefore, lead to a stimulation of N_2 fixation, at least until a new equilibrium between residue input and the rate of decomposition is reached. Results from several field experiments are showed in Case 5 on **Tillage management**

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Case 4: Intercropping management

(adapted from van Kessel & Hartley, 2000)[20]

The total amount of N fixed per unit area in intercropped systems is often lower due to decreased legume population densities, and increased competition for light and nutrients by the non-legume. An increase in the total amount of N_2 fixed could occur when the intercropped legume uses more effectively limited resources.

TABLE 5. Variation in the N_2 fixation by grain legumes grown in monoculture (M) or intercropped (I) with non-legumes. (Cropping densities and fertilisation rates were not specified)

Cropping system	N_2 fixed (%)		N_2 fixed (kg ha^{-1})	
	M	I	M	I
Soybean/non-nodulating soybean[20]	42	23	71	17
Pea/barley[21]	62	84	115	81
Cowpea/maize[22]	28	34	22	10
Pea/mustard[23]	48	50	71	62
Pigeonpea/sorghum[24]	74	55	169	124
Pea/oats[25]	27	52	22	30
Lentil/flax[26]	77	85	14	8
Pea/rape[26]	38	33	41	27
Pea/mustard[26]	28	34	20	18
Pea/oats[26]	80	86	50	16
Pea/rape[26]	78	88	20	27
Ricebean/maize[27]	32	75	30	39
Cowpea/rice[28]	32	30	35	32
Fababean/barley[29]	74	92	79	71
Pea/barley[30]	68	84	213	74

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3.1. Determining the need for inoculation and the potential yield benefits (Case 6)[31]

In many soils, the nodule bacteria (*Rhizobium spp*) are not adequate in either number or quality. Under these conditions, it is necessary to inoculate the seed or soil with highly effective *Rhizobium* cultures.

1. Inoculation is almost always needed when certain new leguminous crops are introduced to new areas or regions. Host-specific rhizobia are frequently developed for new cultivars or varieties of legumes
2. Many soils are heavily infested with ineffective rhizobia capable of inducing nodulation without host benefit. Under such conditions, a very large inoculum of competitive and highly effective strain of rhizobia is needed to replace the ineffective native rhizobia.

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Case 5: Tillage management

(adapted from van Kessel & Hartley, 2000)[10]

Results from various field experiments with grain legumes are shown in Table 6 (adapted from van Kessel & Hartley, 2000).

TABLE 6. Influence of conventional (CT) and zero tillage/minimum tillage (ZT/MT) practices on N_2 fixation by grain legumes

Crop	N_2 fixed (%)		N_2 fixed (kg ha^{-1})	
	CT	ZT/MT	CT	ZT/MT
Chickpea[32]	34	28	32	27
Soybean[33]	73	88	180	232
Soybean[34]	73	88	91	156
Chickpea (1994)[35]	31	40	9	11
Chickpea (1995)[35]	12	17	4	5
Pea[35]	48	79	ND	ND
Lentil[36]	62	72	ND	ND
Soybean (Cultivar S12)[37]	87	91	33	47
Soybean (Cultivar S15)[37]	86	88	39	44

* ND: not determined.

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Case 6: The benefits of inoculation

(adapted from Singelthon et al., 1992)[31]

A comprehensive, five-year effort was made by NifTAL (Nitrogen Fixation in Tropical Agricultural Legumes) to determine the benefits of inoculation for agriculturally important legumes. The results showed clear benefits from inoculation.

In 228 standardised field experiments covering more than 20 countries and 19 species of legumes, the majority of the trials showed a significant response (< 1.0 S.D) to inoculation, both when the trials were conducted in farmers' fields and under more intensive management and higher inputs (Table 7).

TABLE 7. Rhizobial inoculation and the yield response of tropical legumes

Species	Total n° of trials	Significant response to inoculation (% of total)	
		Low input management	High input management
Peanut	26	50	46
Chickpea	31	48	55
Pigeonpea	8	13	13
Soybean	40	65	65
Lentil	27	48	41
Bean	10	10	30
Gram (black)	15	53	60
Mung bean	40	70	68
Cowpea	9	56	11

Clearly, there is a yield advantage to inoculation. However, the yield responses to inoculation were highly variable and affected by inherent field variability, even in the small-plot field experiments, and by differences in environmental and edaphic conditions.

Legume response to inoculation[37, 38] was largely dependent on:

- number of rhizobia already established in the soil
- availability of soil N
- demand for N by the crop
- The type of input management strategy used (Table 7)

3.2. Enhancing the effectiveness of inoculants

❖ **Inoculation technology**

The technology should aim at protecting the viability of the microorganisms and helping them to occupy the target niches and express their biological functions.

❖ **Examples**

- Microcapsulation techniques have been successfully used to entrap biofertilizer agents in biodegradable polymers, to protect them against storage conditions, oxidation, dryness, UV light and other environmental stresses[23]
- Sterile carriers (Gamma radiated or short wave) with lower water potential helped increase resistance of preconditioned biofertiliser inoculant to environmental stresses, as well as to support a higher microbial count with a longer expiration date[24]

❖ **Inoculation methods**

Methods of rhizobial inoculation can have great influence on the amount of N_2 fixed. There are several considerations to be taken into account when optimising inoculation methods and these have been reviewed for FAO, 1984.

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❖ Example

- It has been demonstrated that nodules on the lower part of the root system can fix more nitrogen over the whole growing season than the crown nodules, and they may contribute most of the nitrogen fixed by the legume plant[41]. Farmers applying inoculum on the seed can therefore not expect these bacteria to form nodules on the whole root system. It is likely that applied rhizobia form some or most of the nodules on the crown but other indigenous rhizobia in the soil may form the nodules at greater depth and distance from the crown. It should be possible to enhance N_2 fixation by promoting optimal production of nodules on lateral roots by selecting rhizobia not only for the effectiveness to fix N_2 but also for migration in the soil and along the root under a range of conditions.

❖ Associative biofertilizer inoculants (case 7)

Associative nitrogen fixation inoculants have also been developed and commercially produced for wheat, barley, cotton, canola, sugarcane, maize, and vegetables. The output of these inoculants has been inconsistent and more site and crop dependent. Thus, co-inoculants will require extensive in-vitro and in-situ investigations if the positive attributes associated with each organism are to be effectively exploited.

❖ Role of biotechnology in enhancing the efficacy of inoculants

Biotechnology and gene manipulation techniques were able to provide potential means to improve commercial inoculant strains. During the last 10 years, extensive studies revealed the genetic determinants and the regulation pathways of most of the microbial functions. Genes that control nodulation (*nod, ndv*), nitrogen fixation (*nif, fix*), host range (*nod, hsp*), surface polysaccharide (*exo*) and energy utilisation (*dct, hup*) have been identified. Inoculant strains were able to take advantage of these techniques to produce value-added inoculants.

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Case 7: Associative biofertilizer inoculants

TABLE 8. Output of some associative biofertiliser inoculants

Crop	Inoculant	Out put of application	Country
Soybean[42]	Rhizobium + phosphorus-solubilizing bacteria + P fertiliser	Increase seed protein	India
Acacia nilotica[43]	Rhizobium & Mycorrhiza	Enhanced ancillary characters	India
Rice[44]	Azolla, green manure	10% increase in straw yield by 3x incorporation of Azolla	Egypt
Wheat[45]	*A. lipoferum & B. polymxa*	6% increase in grain yield	Argentina
Wheat[46]	Composite of nitrogen fixers Gram negative	17% increase in grain yield in new sandy land	Egypt
Sorghum (forage)[47]	Composite of nitrogen fixers Gram negative	Increase in dry matter 3-21%	Egypt
Wheat[48]	Azorhizobium	8.85% increase in nitrogen content using N15	China
Oak Forest[49]	*Clostridium butyricum*	8.2 kg N/ha/year	England
Wheat[50]	A. brasilense	Enhancing the accumulation of trace elements	USA

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[42] *Sharma, K.N., Namdeo, K.N., 1999. Effect of biofertilisers and phosphorus on growth and yield of soybean* (Glycine max.*L).Crop Research 17, 160-163*

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4. Conclusions

Biological N_2 fixation is an important aspect of sustainable and environmentally-friendly food production and long-term crop productivity. However, if BNF is to be utilised, it must be optimised. In the near future, particularly in developing countries, tremendous opportunities exist for enhancing the BNF capacity of legumes.

There is no simple and easy approach to increase BNF in grain legumes grown as part of a cropping system, under realistic farm field conditions. Numerous (micro)-climatic variables, soil-physical properties, agronomic management, host-rhiozobia combination and socio-economic aspects play an important role in controlling BNF.

- The use of improved host-rhizobia combination has great potential to increase N_2 fixation. Interaction between a range of traits and N_2 fixing symbiosis will require particular care in breeding and selection programs aimed at alleviating environmental and management practices that reduce BNF.
    - Programmes for host plant selection
    - Programmes for *Rhizobium* selection
- Management practices that increase N demand by the host plant is a promising avenue to increase N_2 fixation in grain legumes in a cropping system. The most likely practices to have an impact on BNF are:
    - Improving pest management practices
    - Improving soil structure
    - Conversion from conventional tillage to zero or minimal tillage
    - Improving the overall fertility status of the soil, while maintaining low levels of available soil N.

There are several methods available to enhance BNF, as shown in the present paper. No one approach is better than all others, rather work on symbiosis combining experience from various disciplines in interdisciplinary research programmes should be pursued.

Usful contacts

❖ On going research and projects related to N_2 fixation

- International research institutes
    - Cowpea-Cereals Systems Improvement in the Dry Savannas http://www.cgiar.org/iita/research/parpt/project11.pdf
    - Improvement of Maize Grain Legume Production http://www.cgiar.org/iita/research/parpt/project12.pdf
    - FAO/IAEA Agriculture and Biotechnology Laboratory http://www.iaea.org/programmes/nafa/d1/
- Universities
    - University of Reading. Faculty of Agriculture and Food. Department of Soil Science http://www.rdg.ac.uk/AcaDepts/as/home.html

❖ Collection of nitrogen-fixing bacterial legume symbionts

- Agricultural Research Service (ARS) of the U.S. Department of Agriculture (USDA) http://bldg6.arsusda.gov/pberkum/Public/sarl/welcome.html

The Context

SOIL BIODIVERSITY AND SUSTAINABLE AGRICULTURE[1]

Soil organisms contribute a wide range of essential services to the sustainable function of all ecosystems, by acting as the primary driving agents of nutrient cycling, regulating the dynamics of soil organic matter, soil carbon sequestration and greenhouse gas emission; modifying soil physical structure and water regimes, enhancing the amount and efficiency of nutrient acquisition by the vegetation and enhancing plant health. These services are not only essential to the functioning of natural ecosystems but constitute an important resource for the sustainable management of agricultural systems.

I. Introduction

Soil Biodiversity and the Convention on Biological Diversity

1. Soil biodiversity has been identified as an area requiring particular attention under the programme of work on agricultural biodiversity of the Conference of the Parties (COP) to the Convention on Biological Diversity (CBD). This programme was initiated at COP-3 (decision III/11, Buenos Aires, 1996) to promote the positive and mitigate the negative impacts of agricultural activities on agricultural biological diversity; the conservation and sustainable use of genetic resources of actual or potential value for food and agriculture; and

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[1] *Background paper on soil biodiversity and sustainable agriculture prepared and submitted by the Food and Agriculture Organization of the United Nations for the information of participants in the seventh meeting of the Subsidiary Body on Scientific, Technical and Technological Advice (SBSTTA-7, Montreal, 12-16 November 2001). This information note supplements the progress report by the Executive Secretary on the implementation of the programme of work on agrobiodiversity, including the development of the International Pollinators Initiative (UNEP/CBD/SBSTTA/7/9). As noted in paragraph 21 of that progress report, syntheses of case-studies and analysis of lessons learned are under preparation for various dimensions of agricultural biodiversity. As recommended by the liaison group on agricultural biodiversity, which met in January 2001, the present information note has been prepared by FAO to provide a synthesis of case-studies and lessons learned on soil biodiversity.*

the fair and equitable sharing of benefits arising out of the use of genetic resources. The programme of work was subsequently developed, with the support of the Food and Agriculture Organisation of the United Nations (FAO), in collaboration with partners, and on the basis of advice and recommendations of the Subsidiary Body for Scientific, Technical and Technological Advice (SBSTTA), was launched at COP-5 (decision V/5, Nairobi, 2000). It has four main objectives: assessment; management practices and policies; capacity building; and national plans and strategies and mainstreaming. FAO was invited to support the development and implementation of the programme. Moreover, governments, funding agencies, the private sector and NGOs were invited to join efforts.

2. Parties recognised, *inter alia*, the need to improve understanding: of the multiple goods and services provided by the different levels and functions of agricultural biodiversity; of the relationship between diversity, resilience and production in agro-ecosystems; and of the impacts of traditional and newer practices and technologies on agricultural biodiversity and on the sustainability and productivity of agricultural systems. Special attention was paid to the role of soil and other below-ground biodiversity in supporting agricultural production systems, especially in nutrient cycling. It was agreed, under programme element 2.1, to carry out a series of case-studies, in a range of environments and production systems, and in each region. Recognising a critical gap in knowledge, Parties had previously been encouraged to conduct case studies on the issue of symbiotic soil micro-organisms in agriculture (Annex 3, COP decision III/11) and subsequently on soil biota in general (decision IV/6, Bratislava, 1998).

This paper has been prepared as a contribution to the item on agricultural biodiversity of the 7th meeting of SBSTTA to present work in progress and especially to highlight the important roles and functions of soil biodiversity - a critical, yet much neglected component of biological diversity and agricultural ecosystems. It emphasises the importance and value of the sustainable management of soil biodiversity and illustrates a range of opportunities and ongoing work. It contributes simultaneously to the above CBD decisions on agricultural biodiversity and to FAOs mandate for improving agricultural (including forestry) production and food security, particularly in regard to integrated land resources management. The material has been derived through networking with partners and resource persons, literature review and Internet search, and a global survey of soil biodiversity expertise and activities. In accordance with COP decisions III/11, IV/6 and V/5, more concrete case studies from countries are strongly encouraged to enable FAO to supplement this initial overview with a useful synthesis of relevant case studies and practical experiences. This would further assist SBSTTA in identifying and prioritising further work in this important area of below-ground biodiversity.

Soil Biodiversity - the Root of Sustainable Agriculture

4. Soil is a dynamic, living matrix that is an essential part of the terrestrial ecosystem. It is a critical resource not only to agricultural production and food security but also to the maintenance of most life processes.

5. Soils contain enormous numbers of diverse living organisms assembled in complex and varied communities. Soil biodiversity reflects the variability among living organisms in the soil – ranging from the myriad of invisible microbes, bacteria and fungi to the more familiar macro-fauna such as earthworms and termites. Plant roots can also be considered as soil organisms in view of their symbiotic relationships and interactions with other soil components. These diverse organisms interact with one another and with the various plants and animals in the ecosystem forming a complex web of biological activity. Environmental factors, such as temperature, moisture and acidity, as well as anthropogenic actions, in particular, agricultural and forestry management practices, affect to different extents soil biological communities and their functions.

6. Soil organisms are an integral part of agricultural and forestry ecosystems; and they play a critical role in maintaining soil health,

ecosystem functions and production. Each organism has a specific role in the complex web of life in the soil:

- The activities of certain organisms affect soil structure - especially the so-called “soil engineers” such as worms and termites - through mixing soil horizons and organic matter and increasing porosity. This directly determines vulnerability to soil erosion and availability of the soil profile to plants;
- The functions of soil biota are central to decomposition processes and nutrient cycling. They therefore affect plant growth and productivity as well as the release of pollutants in the environment, for example the leaching of nitrates into water resources;
- Certain soil organisms can be detrimental to plant growth, for example, the build up of nematodes under certain cropping practices. However, they can also protect crops from pest and disease outbreaks through biological control and reduced susceptibility;
- The activities of certain organisms determine the carbon cycle - the rates of carbon sequestration and gaseous emissions and soil organic matter transformation;
- Plant roots, through their interactions with other soil components and symbiotic relationships, especially Rhizobium bacteria and Mycorrhiza, play a key role in the uptake of nutrients and water, and contribute to the maintenance of soil porosity and organic matter content, through their growth and biomass;
- Soil organisms can also be used to reduce or eliminate environmental hazards resulting from accumulations of toxic chemicals or other hazardous wastes. This action is known as bioremediation.

7. The interacting functions of soil organisms and the effects of human activities in managing land for agriculture and forestry affect soil health and quality. **Soil quality** is the capacity of a specific kind of soil to function, within natural or managed ecosystems boundaries, to sustain plant and animal production, maintain or enhance water and air quality, and support human health and habitation. The

concept of **soil health** includes the ecological attributes of the soil, which have implications beyond its quality or capacity to produce a particular crop. These attributes are chiefly those associated with the soil biota: its diversity, its food web structure, its activity and the range of functions it performs. Soil biodiversity *per se* may not be a soil property that is critical for the production of a given crop, but it is a property that may be vital for the continued capacity of the soil to support that crop.

8. The sustained use of the earth’s land and water resources - and thereby plant, animal and human health - is dependent upon maintaining the health of the living biota that provide critical processes and ecosystem services. However, current technologies and development support for increased agricultural production have largely ignored this vital management component. The improved management of soil biota could play a vital role in maintaining soil quality and health and in achieving the goals of agricultural production and food security and sustainable land use and land resources management.

Why should soil biodiversity be managed?

9. Given escalating population growth, land degradation and increasing demands for food, achieving sustainable agriculture and viable agricultural systems is critical to the issue of food security and poverty alleviation in most, if not all, developing countries. It is fundamental to the sustained productivity and viability of agricultural systems worldwide.
10. Sustainable agriculture (including forestry) involves the successful management of agricultural resources to satisfy human needs while maintaining or enhancing environmental quality and conserving natural resources for future generations. Improvement in agricultural sustainability requires, alongside effective water and crop management, the optimal use and management of soil fertility and soil physical properties. Both rely on soil biological processes and soil biodiversity. This calls for the widespread adoption of

management practices that enhance soil biological activity and thereby build up long-term soil productivity and health.

11. It is well known that land management practices alter soil conditions and the soil community of micro-, meso- and macro-organisms. However, the relationship between specific practices and soil functions is less clear. In general, the **structure of soil communities** is largely determined by ecosystem characteristics and land use systems. For example, arid systems have few earthworms, but have termites, ants and other invertebrates that serve similar functions. On the other hand, the **level of activity** of different species depends on specific management practices as these affect the micro-environment conditions, including temperature, moisture, aeration, pH, pore size, and type of food sources.
12. Management strategies, including tillage, crop rotations and use of plant residues and manure, change soil habitats and the food web and alter soil quality, or the capacity of the soil to perform its functions. For example, soil compaction, poor vegetation cover and/or lack of plant litter covering the soil surface tend to reduce the number of soil arthropods. Farming practices that minimise soil disturbance (ploughing) and return plant residues to the soil, such as no-tillage farming and crop rotation, allow to slowly rebuild and restore soil organic matter. Reducing tillage tends to also result in increased growth of fungi, including mycorrhizal fungi
13. The goal of efficient agriculture is to develop agro-ecosystems with minimal dependence on agrochemical and energy inputs, in which ecological interactions and synergy among biological components provide the mechanisms for the systems to sponsor their own soil fertility and crop production functions. The mix of soil organisms in the soil also partially determines soil resilience, the desirable ability of a given soil to recover its functions after a disturbance such as fire, compaction and tillage.
14. There is a recognised need to bring together experience and ideas on the management of agricultural biodiversity in agricultural ecosystems, and, through international and national biodiversity

strategies and action plans and harmonised policies, to bring about a transformation of unsustainable agricultural practices to sustainable practices and systems. Nonetheless, the fundamental role of soil biodiversity in maintaining sustainable and efficient agricultural systems is still largely neglected in this process and in the majority of related agricultural and environmental initiatives.

II. The challenge of managing soil biota

Soil biodiversity management and farmer practices

15. Farming communities are concerned with land management issues such as water availability to plants, access to sources of fuel and fodder, control of soil erosion and land degradation, especially avoiding soil nutrient depletion and pollution of air, soil and water resources. At the global scale, the aggregated effects of these issues are embedded in the concerns of the international conventions on desertification, climate change and biodiversity.

16. Nonetheless, farmers are essentially driven not by environmental concerns, but by economics, by issues of costs and returns and efficiency in terms of labour and energy and use of external inputs. A central paradigm for the farmer for the maintenance and management of soil fertility, without undue reliance on costly and often risky external inputs, is to utilise his or her management practices to influence soil biological populations and processes in such a way as to improve and sustain land productivity. The means to create a more favourable environment within the soil and soil biological community for crop production involves site-specific decisions concerning crop selection and rotations, tillage, fertiliser and planting practices, crop residues and livestock grazing. These and many other factors influence ecological interactions and ecosystem function.

17. Soil biota can increase or reduce agricultural productivity depending on its composition and the effects of its different activities. *Vice versa*, farming practices modify soil life including the total number

of organisms, the diversity of species and the activity of the individual organisms and the aggregate functions of soil biota. These changes can be beneficial or detrimental to the soil biota and its functions and its regenerative capacity.

18. Through a review of literature and ongoing work, much has been reported on the loss of managed soil biodiversity and its functions in different agricultural systems under controlled-research conditions. This work has been largely driven by pure research and commercial or private sector interests rather than by poorer, smallholder farmers' needs and by national goals. There has been relatively limited practical work on how farmers' manage their resources to sustain and enhance their value and, in particular, to develop farming practices and systems that optimise the beneficial activities of this managed soil biota.
19. Over the last few years, the concepts of **Integrated Plant Nutrient Management** (IPNM) and **Integrated Soil Management** (ISM) have been gaining acceptance, moving away from a more sectoral and inputs-driven approach. IPNM advocates the careful management of nutrient stocks and flows in a way that leads to profitable and sustained production. ISM emphasises the management of nutrient flows, but also highlights other important aspects of the soil complex, such as maintaining organic matter content, soil structure, moisture and biodiversity.
20. Capturing the benefits of soil biological activity for sustainable and productive agriculture requires a better understanding of the linkages among soil life and ecosystem function and the impacts of human interventions. The complex interaction among soil, plant and animal life, environmental factors and human actions must be effectively managed as an integrated system. Greater attention to the management of soil biological resources - a hitherto neglected area in mainstream agriculture - will require a collaborative effort among scientists and farmers' and across ecological zones and countries building on successful experiences.

21. The inter-regional **Tropical soil biology and fertility programme** (TSBF), is a research programme that addresses such issues. It focuses on the management of the biological and organic resources of soil, including understanding of the interactions between the soil biological system and inorganic fertilisers and other industrial inputs. It has played a pioneer role in networking with a wide range of partners, including the African Network for Soil Biology and Fertility (AfNet), South Asian Regional Network (SARNet), and various regional and global alliances, as well as the establishment of a Soil Biodiversity Network, the result of a workshop in 1995, in Hyderabad, India. The TSBF process has led to a Soil Biology Initiative among members in some 10 African countries to improve soil biological management practices and raise productivity in African farming systems, particularly of smallholders. Moreover, a 5-year, multi-country project "Conservation and sustainable management of below-ground biodiversity", has, during 2001, been accepted for funding by the Global Environment Facility (GEF).

The benefits from better management of soil biota

22. As noted above, soil organisms contribute a wide range of essential services to the sustainable functioning of all ecosystems. They act as the primary driving agents of nutrient cycling, regulating the dynamics of soil organic matter, soil carbon sequestration and greenhouse gas emissions; modifying soil physical structure and water regimes, enhancing the amount and efficiency of nutrient acquisition by the vegetation and enhancing plant health. These services are not only essential to the functioning of natural ecosystems but constitute an important resource for sustainable agricultural systems.

23. Direct and indirect benefits of improving soil biological management in agricultural systems include economic, environmental and food security benefits:

    - **Economic benefits:** Soil biological management reduces input costs by enhancing resource use efficiency (especially decomposition and nutrient cycling, nitrogen fixation and water storage and movement). Less fertiliser may be needed if nutrient cycling becomes more efficient and less fertiliser is leached from the rooting zone. Fewer pesticides are needed where a diverse set of pest-control organisms is active. As soil structure improves, the availability of water and nutrients to plants also improves. It is estimated that the value of “ecosystem services” (e.g. organic waste disposal, soil formation, bioremediation, N_2 fixation and biocontrol) provided each year by soil biota in agricultural systems worldwide may exceed US$ 1,542 billion.[2]

- **Environmental protection:** Soil organisms filter and detoxify chemicals and absorb the excess nutrients that would otherwise become pollutants when they reach groundwater or surface water. The conservation and management of soil biota help to prevent pollution and land degradation, especially through minimising the use of agro-chemicals and maintaining/enhancing soil structure and cation exchange capacity (CEC). Excessive reduction in soil biodiversity, especially the loss of keystone species or species with unique functions, for example, as a result of excess chemicals, compaction or disturbance, may have catastrophic ecological effects leading to loss of agricultural productive capacity.
- **Food security:** Soil biological management can improve crop yield and quality, especially through controlling pests and diseases and enhancing plant growth. Below-ground biodiversity determines resource use efficiency, as well as the sustainability and resilience of low-input agro-ecological systems, which ensure the food security of much of the world’s population, especially the poor. In addition, some soil organisms are consumed as an important source of protein by different cultures and others are used for medicinal purposes. At least 32 Amerindian groups in the Amazon basin use terrestrial invertebrates as food, and especially, as sources of animal protein - a strategy that takes advantage of the

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[2] *Pimentel, D. et. al., 1997. BioScience, 47(11), 747-757.*

abundance of these highly renewable elements of the rainforest ecosystem.[3]

24. The improved management of soil biota and its diversity contributes both to the needs of farmers', especially in maintaining productivity and increasing returns from labour and other inputs, and to national interests through maintaining a healthy and well functioning ecosystem in terms of water quality (hydrological cycle) and preventing soil erosion and land degradation (nutrient and carbon cycles). There is a need to improve recognition of these multiple benefits and to promote actions that maintain/enhance soil biodiversity and its vital and valuable functions.

Understanding and assessment of soil biota

25. As mentioned in paragraph 2 above, Parties to the CBD were encouraged to conduct case studies on soil biota in agriculture (COP decisions III/11 and IV/6), including:
    - the measurement and monitoring of the worldwide loss of (symbiotic) soil (micro-)organisms;
    - the identification and promotion of the transfer of technologies for the detection of (symbiotic) soil (micro-)organisms and their uses in plant nutrition;
    - the estimation of potential and actual economic gains associated with reduced use of nitrogen and phosphorus chemical fertilisation of crops with the enhanced use and conservation of (symbiotic) soil (micro-) organisms; the identification and promotion of best practices for more sustainable agriculture and of conservation measures to conserve (symbiotic) soil (micro-) organisms or to promote their reestablishment.
26. Under COP decision IV/6, Parties requested various organisations, particularly FAO, to, *inter alia,* provide inputs on methodologies for assessments of agricultural biodiversity and tools for identification and monitoring (including criteria and indicators; rapid assessment

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[3] *Paoletti, M G. et. al., 2000. Proc. R. Soc. Lond. B. 267, 2247-2252.*

techniques; underlying causes behind the loss of biological diversity; and incentives to overcome constraints and enhance the conservation and sustainable use of agricultural biodiversity and the fair and equitable sharing of benefits). Assessment activities to be undertaken by Parties, with the support of bilateral and international agencies, as agreed under Programme Element 1 of the Programme of Work (decision V/5), also specified promoting assessments: of different components of agro-biodiversity that provide ecological services, for instance nutrient cycling; of knowledge, innovations and practices of farmers and indigenous and local communities in sustaining agro-biodiversity and ecosystem services for, and in support of, food production and food security; and of interactions between agricultural practices and the conservation and sustainable use of biodiversity.

27. Soils generally support one of the most extensive networks of living organisms on earth, but because of the interactions between physical, chemical and biological properties of soil, their investigation is complex, and understanding of the individuals, soil communities and their interactions is limited and fragmentary. This situation reflects the general lack of information on microbial genetic diversity in agriculture, though the lack of knowledge is particularly acute for soil biota, maybe in view of their complexity and the difficulty of observation, being underground as well as largely invisible.

28. Soil micro-organism taxonomy and ecology is a vast area of study for which comprehensive data and information is limited. Existing data and information on species characteristics and taxonomic data is largely derived from collections. Large collection of fungi and plant bacteria are held by CABI and by UNESCO's global network of Microbial Resources Centres (MIRCENS), that are hosted by various academic and/or research institutes and supported by UNEP, FAO, UNIDO and bilateral donors. International cooperation in the management of this global resource ensures an effective triangle of research, education and development. Efforts on taxonomy research linked to better understanding of soil biota functions are also being conducted by DIVERSITAS, which is coordinating

information, and identifying priorities, on how soil and sediment species composition and community structure (species distribution and their interactions) influence ecosystem functioning.

29. There tends to be more widespread knowledge about detrimental soil organisms and their effects on plant growth in different farming systems, than their effects on soil processes and their interactions with other soil organisms and activities. Likewise more is known about the effects of certain beneficial organisms, than the management practices required to maintain, or enhance, populations and the activities of such organisms. The role of different soil populations is often not well understood, even though their overall importance is generally accepted. Rapid and accurate field methods to identify single, or even groups of, organisms according to function in the soil are also lacking and need more attention.

30. To improve agro-ecosystem management, a greater appreciation is needed of the effects of this living component of the soil on soil physical, chemical and biological properties and processes and on the air and water resources with which the soil interacts. Likewise, regarding the effects of agricultural practices on soil biota and their functions. Recognition is also needed of the effect of those interactions on soil degradation, food production and mitigation of environmental problems, including the greenhouse gas effect and water pollution. Improved understanding of the organisms and related processes and of effects of farm practices, can benefit agricultural systems through increasing crop productivity and quality, reducing impacts of pathogens and input costs and reducing negative environmental impacts.

The Ecological Principles behind Soil Biological Management

31. As noted above, soil biota may be beneficial, neutral or detrimental to plant growth. Thus soil biota and their ecological interactions must be effectively managed for maximum productivity. Land managers need unbiased information that will enable them to develop biologically-based management strategies to control or manipulate soil stabilisation, nutrient cycling, crop diseases, pest infestations

and detoxification of natural and manmade contaminants. These strategies will require improved understanding of the effects on soil biota of habitats, food sources, host interactions, and the soil physical and chemical environment. Understanding the ecology regulating both beneficial and detrimental organisms is essential to harnessing and controlling their activity in agro-ecosystems with a view to promoting viable, productive and sustainable systems.

32. Soil biota eat, grow and reproduce within the soil environment. They need food, a conducive soil habitat and, in the cases of symbionts, a host organism, to survive. The ecological principles behind soil biological management, that need to be understood and respected, include:
    - **The supply of organic matter for food:** Each type of soil organism occupies a different niche in the web of life and favours a different substrate and nutrient source. Thus a rich supply and varied source of organic matter will generally support a wider variety of organisms. Organic matter may come from crop residues at the soil surface, root and cover crops, animal manure, green manure, compost and other sources.
    - **Increased plant diversity:** Crops should be mixed and their spatial-temporal distribution varied to create a greater diversity of niches and resources that stimulate soil biodiversity. Each crop contributes a unique root structure and type of residue to the soil. A diversity of soil organisms can help control pest populations, and a diversity of cultural practices can reduce weed and disease pressures. Several strategies could indirectly or directly contribute to creating different habitats to support complex mixes of soil organisms, for example: i) landscape diversity, over space and time, can be increased by using buffer strips, small fields, contour strip cropping, crop rotation, and by varying tillage practices; ii) a changing vegetation cover and sequence increases plant diversity and the types of insects, micro-organisms and wildlife that live on the farm; and iii) crop rotations encourage the presence of a wider variety of organisms, improve nutrient cycling and natural processes of pest and disease control.

- **Protecting the habitat of soil organisms:** Soil biodiversity can be stimulated by improving soil living conditions such as aeration, temperature, moisture and nutrient quantity and quality, for example through: reducing tillage and maximising soil cover, minimising compaction, minimising the use of pesticides, herbicides and fertilisers and improving drainage.

33. If farmers understand the effects of their different management practices on key categories of soil biota and their functions, and if they know how to observe and assess what is happening in the soil, then they can more successfully develop and adopt beneficial practices. However, it is not only the biophysical factors that affect farmer's decisions but also socio-economic considerations. Common constraints to the use of different soil biological management practices include the labour and time costs, monetary cost, availability of inputs (for example, planting material, inoculants and capacities) as well as social acceptability.

International Expertise in Soil Biodiversity: Findings of a Global Survey

34. An informal global survey of soil biodiversity expertise[4] with special relevance to agro-ecosystems was conducted by FAO, in mid 2001, to ascertain expertise in respect to soil fertility and sustainable agriculture and to identify how soil biology experts might assist in delineating complex issues related to the biological management of soil fertility and contributing to the identification of better farming practices and agricultural systems. The resulting survey and database is expected to assist State Members of FAO and the CBD, and various partners, in catalysing work of experts on priority issues, extending expertise into non-traditional areas, and facilitating new modes of action to effectively conserve and manage soil biological diversity.

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[4] *Conducted in September 2000 by FAO-consultants and soil biodiversity conservation researchers Dan E. Bennack (Instituto de Ecologia, Xalapa, Mexico) and George G. Brown (now at Embrapa Soybean, Londrina, Brazil).*

35. Some 123 of the 600 invited investigators, project members, extension professionals and post-graduate students from around the world responded to the survey. Four main themes were addressed: the professional backgrounds that characterise soil biodiversity experts; the location and conditions of field investigations that are being conducted; the soil organisms and soil properties and processes under investigation; and the agricultural management practices and their effects that are under study. Information was also gathered to ascertain the state of knowledge of the relationships between soil biodiversity, plant diversity and agricultural productivity and to identify case studies, projects, literature and contact points.

36. Awareness of the work programme on agricultural biodiversity adopted by the Conference of the Parties to the CBD, and of FAOs support to assist countries to implement this programme, was relatively low. However, the vast majority of soil biodiversity experts expressed their interest to assist in initiatives in the area of soil biodiversity and sustainable agriculture. The main findings emanating from the preliminary survey, based on responses, are presented below:

    ♦ Soil biodiversity experts often have multidisciplinary expertise however there was notable lack of sol biota specialists with expertise in natural resource management, rural/community development and plant pathology. A broad ecological approach is reflected by intersecting expertise in ecology, soil science and zoology, compared to the often narrower scope of microbiology, entomology, agronomy and botany specialists. Ecologists tended to have either a bias towards a systems-science approach or a population-community approach.

    ♦ Soil biodiversity experts are working in a variety of field sites, in both agricultural lands and natural undisturbed areas, and under a range of climatic and land use conditions. However, subtropical climate zones and arid regions are strongly under-represented. Forests (other than rainforests) and grasslands were the most common native vegetation types reported among field sites, followed by rainforest and savannah sites.

- Experts are studying a wide variety of soil organisms and soil processes, though specialists on earthworms, soil and litter arthropods, roots, nematodes and mycorrhizal fungi are more common. Many experts are working mainly in the area of organic matter inputs including decomposition rates, enhanced bio-availability, nutrient pools and transformations, soil physical properties. However, relatively less work was reported on soil and litter fungi, rhizobial bacteria (i.e. nitrogen-fixers) and fungal root pathogens. Work on soil processes such as nitrogen fixation, biogenic structures, soil physical processes and bio-accumulation/ degradation was rarely reported.

37. From the findings there is a clear need to identify and facilitate the transfer of such research and its application in the agricultural development context. In addition the following suggestions are made:

- The notable lack of soil biodiversity specialists with expertise in natural resource management, rural/community development and plant pathology suggests a need for soil biodiversity experts to receive some formal training in these areas and social sciences in general. This would facilitate their interactions with farmer groups managing local land, water and biological resources.
- South-south co-operation and work could be encouraged in subtropical climates and arid regions, including desert and steppes, in order to strengthen the knowledge base and facilitate delivery of soil biodiversity expertise to these important, but often marginalised, agricultural production zones. This could for example address agricultural practices related to open range and pastoral systems in regions less suitable for cropping, as well as for dryland and irrigated cropping along major watercourses, deltas and floodplains in these regions.
- There may be some bias in the survey that led to relatively little work reported on rhizobial bacteria and fungi, including fungal

root pathogens, and on soil processes such as nitrogen fixation, soil physical processes and bio-accumulation/degradation as well as soil biota interactions in regard to inoculants, tillage, inorganic fertilisers, pesticides and pH adjustments. However, these perceived gaps do raise important concerns that deserve follow-up. Firstly, it concerns the crucial and unique symbiotic relationships (plant-soil organisms) that either facilitate nutrient uptake (mycorrhizal fungi) or convert atmospheric nitrogen to readily utilisable forms - a vital area for agricultural productivity. Secondly, it may reflect a real gap in understanding of effects of certain agricultural practices, especially the use of certain agrochemical and biological inputs, on soil biological functioning and health.

III. Building on today's soil biodiversity knowledge for a sustainable future

Ongoing Work and Case Studies for the Development and Transfer of Know-how and Promotion of Best Practices:

38. The survey commissioned by FAO also inventoried projects and initiatives concerning soil biodiversity, its assessment, identification, as well as its status and role in agricultural and other ecosystems (managed and natural). Over 100 projects were reported worldwide, either ongoing or being developed by private and public agencies, universities, research organisations and consortia. These address various soil biodiversity themes, including: (i) the significance of ecosystem complexity in maintaining soil organism diversity, (ii) the effects of agricultural management on soil organisms, and (iii) the role of soil biodiversity and specific soil taxa on various ecosystem functions.

39. Out of 140 cited case studies and literature references, some 20 case studies were considered of particular interest for promotion through FAO and CBD processes. These equally reflect soil-dwelling invertebrates (such as earthworms, mites, spiders, and termites) and cases dealing with micro-organisms (including nematodes,

bacteria, fungi, and especially rhizobial bacteria and mycorrhizal fungi). Few case studies and reports considered soil biodiversity from multi-taxa, multi-functional or multi-disciplinary perspectives. Moreover, the state of knowledge of the relationship between soil biodiversity, plant diversity, and agro-ecosystem productivity is not clear from the review of case studies and citations, which are mostly narrow in scope and highly taxon-specific.

40. Surprisingly there is no unifying theme considering that soil "biodiversity" might affect agricultural productivity in ways that differ from the effects of individual species. Some studies, for example, refer to the effects of individual soil taxa on agricultural productivity, but do not consider the effects of overall taxonomic diversity (including inter-specific or higher level comparisons). Other studies refer to the effects of landscape or crop (patch) heterogeneity on the presence, abundance or biomass of soil organisms, yet these studies often fail to consider simple measures of organismal diversity (such as species and/or higher taxon richness, or other diversity measures based upon relative abundance, population size, biomass, recapture, etc.). Some investigations consider the influence of agricultural practices on certain types of soil organisms, yet ignore the impact of these practices on taxonomic and/or functional diversity *per se*.

41. The importance of soil biodiversity to plant diversity and agricultural productivity has been the subject of anecdotal and empirical investigation for some time[5], but only recently has research in this area really blossomed. Pioneering investigations have been established through detailed experimental designs[6] and some integrative research programs are ongoing. Given the complex nature of relationships between soil biodiversity, plant diversity and

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[5] *Kevan, D.K. McE. 1985. Soil zoology, then and now - mostly then. Quaest. Entomol. 21, 371.7-472.*

[6] *Naem, S., J.H. Lawton, L.J. Thompson, S.P. Lawler and R.M. Woodfin. 1995. Biotic diversity and ecosystem processes: Using the Ecotron to study a complex relationship. Endeavour 19, 58-63.*

agricultural productivity, it is expected that the number of projects, results and publications will continue to grow. There may be a need to encourage strategic alliances among individual investigators and basic and applied research institutions. There is a clear need for FAO and partners in the food and agricultural sectors to pay special attention to research and development in the area of soil biological diversity. In this way, the theoretical advances as well as practical applications of basic research might be more effectively incorporated into field activities and programmes. Partnerships among academic and other institutions undertaking soil biodiversity research and development programmes would accelerate the transfer of newly developed soil biodiversity management technologies into the field at appropriate scales of implementation.

42. In furthering SBSTTA's consideration of soil biodiversity under the programme of work on agricultural biodiversity, it is intended by FAO to assist, in collaboration with partners and upon the basis of submissions by countries, in the preparation of a further paper to present a review and synthesis of available case studies.

Reporting on Soil Biodiversity: National Reports on CBD Implementation

43. As mentioned in paragraphs 2 and 3 above, Parties to the CBD have agreed to the implementation of the programme of work on agricultural biodiversity, including, *inter alia,* specific attention to soil biodiversity, (decision V/5). National reports to the COP and reports by international agencies supporting the convention provide a means to assess progress made. In this regard, from an overview of national reports it is observed that, in general, countries report more on natural ecosystems than on agricultural ecosystems. Moreover, within agricultural systems the emphasis is on plant and animal genetic resources and often little or no information is given on soil biological diversity. Some reports stress research and monitoring, while others place more emphasis on conservation actions, but the overriding message is that almost everywhere there are initiatives upon which to build.

44. Some countries are preparing specific reports on soil biological diversity, for example the CBD focal point in Uganda, provided an example of its draft report on the conservation and sustainable use of soil biodiversity. However, such cases are few and far between. It is important for countries to review and report on the state of knowledge regarding soil biodiversity and also to link this information with other components of a given agricultural system through an ecosystem approach (looking at the status and trends of the overall ecosystem, its components and interactions, and the actual/potential impacts of past and current management practices). Without such a country-wide analysis, it will not be possible to identify priority areas requiring attention.

Opportunities for Integrating Soil Biological Management into Farmers' Practices

45. At ground level, options whereby farmers can actually manage soil biodiversity to enhance crop production include indirect processes, such as composting or the control of pathogens, and direct interventions, such as microbial inoculation.

- **Direct methods** of intervening in the production system aim to alter the abundance or activity of specific groups of organisms through inoculation and/or direct manipulation of soil biota. Inoculation with soil beneficial organisms, such as nitrogen-fixing bacteria, Mycorrhiza and earthworms, have been shown to enhance plant nutrient uptake, increase heavy metal tolerance, improve soil structure and porosity and reduce pest damage.

- **Indirect interventions** are means of managing soil biotic processes by manipulating the factors that control biotic activity (habitat structure, microclimate, nutrients and energy resources) rather than the organisms themselves. Examples of indirect interventions include most agricultural practices such as the application of organic material to soil, tillage, irrigation, green manuring and liming, as well as cropping system design and management. These must not be conducted independently, but in a holistic fashion, because of the recurrent interactions between different management strategies, hierarchical levels of management and different soil organisms.[7]

46. A few key areas of attention and a number of opportunities that are available and being utilised for managing soil biota are outlined below.

a) Soil biota assessment and sustainable land management

47. **What is known.** Soil biota can have both positive and negative effects on agricultural production. Negative impacts often occur when soil management systems are not well balanced with their environment. For example, inherent soil processes such as mineralization can no longer supply adequate amounts of nutrients for crop production because of long-term (continuous) removal, leaching, erosion or volatilisation. Consequently, such biological processes have in many systems been supplemented by the use of commercially available inorganic nutrient sources. However with decreasing organic matter content, and associated properties such as water retention and cation exchange capacity (CEC), the capacity of the soil to retain and make available the nutrients, as and when required, is significantly reduced. Thus soil quality or soil health evaluations need to focus not only on chemical (fertility) considerations, but on the dynamic soil condition - a combination of physical, biological and chemical characteristics - which is directly affected by recent and current land use decisions and practices. Land managers can only balance potential positive and negative impacts of their decisions on soil biota through understanding the effects of individual components and their interactions within the agricultural system. This includes understanding the numerous and intricate interactions among climate, soil type, plant species and diversity, soil biological community and soil management practices.

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[7] *Swift, MJ. 1999. Towards the second paradigm: Integrated biological management of soil. In: JO. Siqueira, FMS. Moreira, AS. Lopes, LRG. Guiherme, V. Faquin, AE. Furtani Neto and JG. Cavalho (eds.) Inter-relacao fertilidade, biologia do solo e nutricao de plantas. UFLA, Brasil. pp. 11.24.*

48. **The case of soil bioindicators:** The potential of using different components of soil biota and its activity as biological indicators has been cited by different authors. Such indicators include soil microbial biomass, soil enzyme activity, soil micro-biota, including bacteria (eubacteria and archacbacteria), fungi, algae and plant root pathogens, soil micro-fauna (protozoa, nematodes), macro-fauna, total soil biodiversity, etc. Soil organisms have been shown to be potentially useful indicators of soil health because they respond to soil management in time scales (months/years) that are relevant to land management[8]. For example, changes in microbial biomass, or abundance of selected functional groups of micro-organisms (e.g. Mychorrizal fungi), may be detected well in advance of changes in soil organic matter content or other soil physical or chemical properties[9]. One of the major difficulties in the use of soil organisms *per se*, or of soil processes mediated by soil organisms, as indicators of soil health has been methodological - what to measure and how and when to measure it and how to interpret changes in term of soil function[8]. Despite those difficulties there have been major advances in our understanding of the soil biota and its functioning at the community level in recent years[10].

49. **Gaps and needs.** More process-level information is needed to understand the role of soil biota in critical soil processes such as nutrient cycling and nutrient movement throughout the soil profile and in the soil surrounding plant roots. For example, soil nutrient use efficiency can only be maximised when the interaction of soil biota with environmental factors, including temperature, water content, and energy source is understood. There is currently a fundamental knowledge gap in the interpretation and linking of

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[8] *Pankhurst, C.E., 1994. Biological indicators of soil health and sustainable productivity. In: Greenland, D.J. and Szabolcs, I. (eds.) Soil Resilience and Sustainable Land Use. CAB International, Wallingford, UK, pp. 331-351*

[9] *Sparling, G.P., 1997. Soil microbial biomass, activity and nutrient cycling as indicators of soil health. In: Pankhurst, C.E; Doube, B.M. & Gupta, V.V.S.R. (eds) Biological indicators of soil health. CAB International, Wallingford, UK, pp. 97-119.*

[10] *Synthesis from Pankhurst, C.E., Doube, B.M. and Gupta VVSR, 1997. Biological indicators of soil health, CAB International, Wallingford, UK, pp. 419-435.*

various proposed biological, chemical and physical indicators. Measurement protocols and indexing techniques are needed for easy identification of the soil properties, processes and the effects of human management practices over time. Soil quality assessment and interpretation tools must be sensitive and responsive to the various soil properties and processes that respond to changes in soil and crop management practices and land use decisions. They also need to account for differences in inherent soil conditions among various physiographic regions and their response, both positive and negative, to management practices. They should help determine appropriate land uses and input needs and help land owners and operators to select or develop more environmentally-sound management practices, while providing the food, feed and fibre needed to satisfy increasing human needs.

50. **Opportunities/Areas for action.** The assessment of the health of soils, through the identification of key soil properties, which can serve as indicators of soil health, has become a major issue for land managers and the food and agricultural sector through the world. For example, FAO has recently been identified as the executing agency for conducting, in close cooperation with multiple partners, the GEF/UNEP Land Degradation Assessment in Drylands (LADA). Soil biota and its functions should be a key component of such assessments. In particular, there is a need to determine short- and long-term effects of agricultural management practices on soil biological community populations, biodiversity, functioning and resilience. Relating soil quality/ health to productivity, in terms of crop yield and profitability, and environmental effects from drainage, leaching, runoff and erosion is essential in order to evaluate the sustainability of various land management strategies.

51. There is recent progress in realising that soil health, by its broadest definition, is inseparable from issues of sustainability. The challenge ahead is to develop holistic approaches for assessing soil quality and health that are useful to producers, specialists and policy makers in identifying agricultural and land use management systems that

are profitable and will sustain finite soil resources for future generations. Benefits of paying more attention to soil health and its assessment include its potential use in: the evaluation of land-use policy and of practices that degrade or improve the soil resource; and in the identification of critical landscapes or management systems and of gaps in our knowledge base and understanding of sustainable management.

b) Managing Interactions among Land Management, Soil Biodiversity and Agricultural Production

52. **What is known.** Land use and the type of farming system impacts upon soil life, while soil management controls and manipulates the organisms responsible for nutrient cycling, crop diseases and pest damage through its effects on soil physical and chemical conditions, biological habitat, food sources and plant-host interactions. Biotic processes impact on long-term productivity, soil fertility, soil aggregation, erosion and other indicators of soil quality. In turn, the soil biota and their interactions play a part in the success of any management decision. For example, intensive cultivation coupled with mono-cropping practices may detrimentally affect the functioning of the soil biota leading to loss of plant nutrients and soil aggregate structure and resulting in soil degradation, environmental pollution and declining crop yields. On the other hand, minimum tillage practices and better crop cover, coupled with a more diverse cropping regime, may promote the more effective functioning of soil biota, resulting in improved soil structure and nutrient and water management and hence crop productivity.

53. **Case study of Biological nitrogen fixation:** The natural process of biological nitrogen fixation (BNF) constitutes an important source of nitrogen for crop growth and protein production in many soils and ecosystems. It therefore provides a major alternative to the use of commercial nitrogen fertiliser in agriculture. It has recently been estimated that global terrestrial BNF ranges between 100 and 290 million tons of nitrogen per year of which 40-48 million tons N

per year is estimated to be biologically fixed in agricultural crops and fields[11]. In comparison, 83 million tons per year are currently fixed industrially for the production of fertiliser[12].

54. Biologically fixed N_2, either asymbiotic, associative or symbiotic, is considered a renewable resource, which should constitute an integral part of sustainable agro-ecosystems globally. The contribution of legume N fixation to the N-economy of any ecosystem is mediated by: the efficiency of the N_2 fixing system; the contribution of BNF to the soil N pool; and the total amount of N_2 fixed that actually is recycled by human practices and animal manure into the system. Several opportunities to enhance BNF inputs are available across different agro-ecosystems and socio-economic conditions, *inter alia*: through altering the number of effective symbiotic or associated organisms in the system (inoculation); screening and selection of the appropriate legume crop (selecting high BNF species well adapted to environmental conditions); and management practices that enhance N_2 fixation and recycling of net N_2 inputs into the cropping system (rotation, green manure application, no-tillage, strategic use of legumes, etc.)[13].

55. **Gaps and needs.** The complex relationships between soil biota, ecosystem functioning and land management practices must be well understood in order to develop guidelines for agriculture that will optimise resilience and sustainability of the ecosystem. A better understanding of the ecology of beneficial and harmful organisms is needed to utilise and control their expression in agricultural systems. An understanding of soil biota and their ecology must be developed, so that the ecological and biological effects of resident

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[11] *Cleveland, C.C.; Towsend, A.R; Schimel, D.S.; Fisher, H.; Howarth, R.W.; Hedein, L.O.; Perakis, S.S.; Latty, E.F.; Von Fischer, J.C.; Elseroad, A. and Watson, M.F.; 1999. Global patterns of terrestrial biological nitrogen fixation in natural ecosystems. Global Biogeochem. Cycles 13, 623-645*

[12] *Jenkinson, D.A., 2001. The impact of humans on the nitrogen cycle, with focus on temperate arable agriculture. Plant and Soil 228, 3-15.*

[13] *FAO/AGLL Soil Biodiversity Portal (http://www.fao.org/ag/AGL/agll/soilbiod/default.htm). Montanez, A. 2000. Overview and case studies on BNF: perspectives and limitations.*

soil populations can be used to reduce inputs of non-renewable resources while still increasing productivity needed to meet food, feed and fibre demand.

56. **Opportunities/Areas for action.** There is a need to enhance scientific and farm knowledge of soil biota-manipulation and ecosystem interactions to obtain better understanding of the processes they control and, thereby, to influence plant growth, soil biotic functions and soil productivity. This includes:
    - development of fundamental understanding of the ecological characteristics and processes of the soil and root biology to predict accurately root, seed, soil and soil biota interactions;
    - identification of fertility, cultural, spatial and temporal factors affecting these interactions;
    - development of effective strategies to manage soil biota as an integrated aspect of soil and land resources management;
    - development of improved methods to identify and characterise soil biota populations and their activities for farmer level in order to help in the interpretation of interactions between farmers' practices, soil function and agricultural production.

c) Soil biodiversity and biological management of pests

57. **What is known:** The rate and extent of build-up or maintenance of indigenous or introduced pathogens or pests depend on many environmental and cultural factors, including residues, organic matter and cover crop issues, plant stress, soil tillage, poor irrigation management and fertilisation practices and crop genetics. Intensive cropping, monocropping and the over-use of agro-chemicals often increases the build up of soil-borne pathogens (disease-carrying organisms), pests and weeds. This is also reflected following conversion to reduced or no-tillage practices, when carefully controlled herbicide use and prudent pest management practices may be required in the initial years until an ecological balance is restored and the natural biocontrol mechanisms become reestablished. Under no-tillage it has been reported that pathogens,

pests and weeds are not necessarily greater but may differ from those prevalent under tilled systems; with appropriate management under no-tillage the equilibrium tends to favour beneficial organisms.

58. Soil biota can influence the growth of some organisms including larger life forms such as certain insects, crop plants and weeds, both positively and negatively. In some cases, deterioration of soil productivity stems from changes in soil biotic communities, reducing their capacity to suppress root pathogens and pests by biological means. Pathogens and pests unchecked by ecological competition can achieve populations that are devastating to agriculture and pose serious threats to economic sustainability. The nature of the pest outbreak, whether bacterial, fungal, viral, nematode, insect or weed, indicates the kind of management strategies needed to restrict or eliminate its activities. The strategies available to farmers are cultural (cropping practice), chemical and biological; however, not all strategies are feasible for every cropping system. Ecologically-oriented pest management within a viable, integrated systems' approach is gaining popularity. Management of the edaphic (soil-based) phase of the life cycle needs to be explored to develop additional biological pest management options.

59. **Case study of alternatives to methyl bromide in managing pests:** Under the Montreal Protocol of 1991, methyl bromide was defined as a chemical that contributes to depletion of the Earth's ozone layer; and it was internationally agreed that consumption of this product will be frozen in developing countries in 2002. Farmers who are dependent on methyl bromide for suppressing soil-borne pests and diseases are having to shift towards more environmentally sustainable agricultural practices. Alternatives to the use of methyl bromide have been investigated and biofumigation is one such example, that uses the Brassica family (i.e. broccoli, cabbage, cauliflower and rape) for producing toxic compounds. Preliminary results have shown that biofumigation, also combined with solarization, could be a successful biological alternative for producing

fumigant-like chemicals in the soil for suppressing soil-borne pests and diseases and helping promote soil health[14].

60. **Gaps and needs.** Use of soil biota in pest management could increase crop efficiency, decrease the need for tillage and decrease the use of synthetic chemical pesticides. Often individual pathogens have been studied in isolation, which limits knowledge of activities *in situ* with the whole biotic community. A greater awareness of the full range of the soil biota community and its impact on its own soil community dynamics, plant growth and chemical-plant interactions are critical. Integrative approaches have the potential to be used to manage the production system and natural soil organism-plant interactions for pest suppression, either from adding beneficial organisms that can suppress the pests or managing or increasing such organisms that are resident in the soil. Further study is required, so that the ecological and biological effects of the resident soil organism population on pest growth can be used effectively in pest management strategies. Moreover, the use of soil biotic dynamics and integrated approaches to managing soil-borne pathogens or pests may also require additional soil management practices.

61. **Opportunities/Areas for action.** Soil micro-fauna play an important role in suppression of plant pathogens and represent a significant biological control potential. There are opportunities to develop effective and economically feasible disease and pest control strategies that reduce pathogens and pests through the introduction of antagonists or by managing resident soil biota to increase their activity. Efforts to manipulate and exploit the friendly fauna populations for crop benefit must be compatible with microbial symbionts, and other plant-growth promoting rhizosphere organisms, and with fungi and bacteria that are being promoted for biological control of diseases. This is clearly an area with great opportunities for further research.

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[14] *http://www.fao.org/WAICENT/FAOINFO/AGRICULT/AGP/AGPP/IPM/Web_Brom/Default.htm*

d) Bioremediation: The Use of Soil Biota in Environmentally-friendly Treatments for the Decontamination of Soils

62. **What is known.** The goal of bioremediation efforts is to reduce the potential toxicity of chemical contaminants in the field by using micro-organisms, plants and animals to transform, metabolise, remove or immobilise toxicants. There is already a significant knowledge-base about many pathways for organic degradation, and several important contaminant degradation mechanisms are under detailed investigation[15]. Different types of organisms can be bioremediation agents, for example, micro-organisms (primarily bacteria and fungi) are nature's original recyclers. Their capability to transform natural and synthetic chemicals into sources of energy and raw materials for their own growth highlights their value as cheaper and more environmentally-benign alternatives to chemical or physical remediation processes. Plant roots can also indirectly stimulate microbial degradation of contaminants in the rhizosphere. The intrinsic ability of certain plants for uptake, translocation, transformation and detoxification of contaminants also offers a newly recognised resource that can be exploited. Research continues to discover and verify the bioremediation potential and unique properties of many organisms.

63. **Case study of Bioremediation:** These techniques are used to remove environmental pollutants from sites where they have been released or more often to reduce their concentrations to levels considered acceptable to site owners and/or regulatory agencies. Many bioremediation techniques exist to treat *in situ* soil contaminants and a number of organisms have been involved, particularly bacteria – such as *Achromobacter, Acinetobacter, Alcaligenes, Bacillus, Nocardia, Pseudomonas* – and fungi such as *Trichoderma, Rhodotorula, Mirtirella, Aspergillus*[15]. The rate at which microbial communities adapt their metabolism to toxic compounds is crucial in bioremediation. A recent addition to the growing list of bacteria

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[15] *Microbial transformation and degradation of toxic organic chemicals. 1995. Young LY, and Cerniglia CE eds., Wiley-Liss, New York.*

that can sequester or reduce metals is *Geobacter metallireducens*, which removes uranium, a radioactive waste, from drainage waters in mining operations and from contaminated groundwater[16]. The concept of phytoremediation - the use of plants for abatement and containment of pollution - is developing as an acceptable management technique. This concept is also being applied in other environments, such as riparian zones and filter strips.

64. **Gaps and needs.** A tiny fraction of the soil microbial diversity of the Earth has been identified, and an even smaller fraction has been examined for its biodegradation potential. Understanding of biochemical transformations of contaminants in soil has advanced in recent years. However, knowledge of the specific pathways for degradation/ detoxification and of the role of specific organisms and communities is limited. Biological approaches on the molecular level can clarify the expression and regulation of xenobiotic (contaminant) degradation and help provide methods to develop plants and micro-organisms with enhanced detoxification ability. This knowledge is essential for understanding the ability of soil to maintain a biological buffering barrier for pollution and in the design of systems to decontaminate soil and water.

65. **Opportunities/Areas for action.** Despite the successful contributions of existing knowledge, the understanding of biotransformation and biodegradation pathways and mechanisms in the field is incomplete. Opportunities are wide for further research (for example of microbial physiology and ecology, enzymology, biochemistry and plant-micro-organism interactions) and technology applications. Opportunities exist for the development of knowledge and techniques that will minimise the impact of agrochemicals and other xenobiotics in the environment and of approaches to promote the degradation of xenobiotics in soils. Improved methods and decision-making tools are needed for soils that require remediation with a view to improving

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[16] *US-EC Task Force on Biotechnology Research. Biotechnology and Genetic Resources. Proceedings of a workshop; 1992 October 21-22; Airlie, Va. Available from the NSF Biological Sciences Directorate, Arlington, Va.*

soil productivity, protecting human health and preventing environmental degradation.

e) The ecological impact of agricultural biotechnology

66. **What is known:** Agricultural biotechnology, if appropriately integrated with other technologies, offers opportunities for developing more productive and sustainable systems, for example the development of plant varieties and animal races for overcoming specific constraints such as soil and climatic limitations and specific pests and diseases. Biotechnology includes a wide array of techniques and applications, from natural fermentation processes and cell culture to genetic engineering, protein engineering and DNA amplification. Transgenic materials provide greatly increased opportunities but also potentially significant risks of affecting soil biodiversity and the ecosystem at all levels, for example, through upsetting the delicately balanced and complex food web.
67. There is a need to assist national and local governments in the formulation and application of policies that ensure the proper ownership and receiving of benefits deriving from the use of soil biodiversity, in particular the technologies and products that derive from the manipulation and extraction of particular components of the soil biota (especially micro-organisms and their products). Taking into account issues of bioprospecting, traditional knowledge and farmers’ rights, this raises the important consideration of finding ways in which soil biodiversity and associated knowledge systems, can be managed for the benefit of farmers and rural communities and to ensure that legal and international property rights regimes support this aim.
68. An example of the beneficial use of biotechnology in the management of soil biodiversity is in the development of **improved microbial inoculants**. Effective wild-type strains are isolated from the environment for use as microbial inoculants in agriculture and recombinant DNA technology (i.e. genetic engineering) may be used to further improve microbial strains. Microbial characteristics that are being targeted for improved inoculant performance include: the

survival ability of the inoculated strain, as in the case of strains that are better adjusted to soil constraints such as salinity, acidity or aridity; competitive nodulation of legume roots, as in the case of symbiotic nitrogen-fixing Rhizobium bacteria; and interactions with beneficial micro-organisms, for example compatibility with mycorrhizal fungi, and interactions with detrimental micro-organisms, for example for the inhibition of plant pathogens in the rhizosphere.

69. On the other hand, the area under **transgenic crops** is rapidly expanding and yet it is not well known what might be the long term effects on the ecosystem of potentially higher herbicide applications or the indirect effects of transgenic plant root exudates (secretions). The decomposition of modified genetic material from plant remains in the soil could seriously affect the balance of soil micro-organisms and be an ideal medium for horizontal gene transfer. Incorporation into plants of genes from *Bacillus thuringiensis* (Bt) toxins that code for the production of insecticidal toxins can be incorporated into the soil through leaf materials, when farmers incorporate crop residues after harvest. Toxins may persist for 2-3 months, resisting degradation by binding to clay and humic acid soil particles while maintaining toxin activity[17]. Such active Bt toxins that end up and accumulate in the soil and water from transgenic leaf litter may have negative impacts on soil and aquatic invertebrates and nutrient cycling processes[18]. Increased and frequent use of glyphosphate applications has produced changes in the microbial composition of soil in the field associated with "Roundup Ready" soybean production[19]. The use of glyphosphate-resistant soybean changes the dominance of fungi versus bacteria

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[17] *Palm et al. 1996. Persistance in soil of transgenic plant produced Bacillus thuringiensis var. Kurstaki endotoxin. Canadian J. Microbiology*

[18] *Donegan, KK et al. 1995. Changes in levels, species, and DNA fingerprints of soil microorganisms associated with cotton expressing the Bacillus thuringiensis var. Kurstaki endotoxin. Applied Soil Ecology 2, 111-124.*

[19] *Kremer RJ et al. Herbicide impact on Fusarium spp and soybean cyst nematodes in glyphosphate tolerant soybean. American Society of Agronomy.*

in the soil, altering nutrient cycling processes, nutrient retention ability and the ability of the soil to suppress disease. There has been little attention to monitor and improve understanding of the effects of transgenic crop plants, such as herbicide resistant soya beans or cereals, on soil biodiversity and their functions.

70. Perturbations have been recorded by several authors with **the introduction in the soil of genetically modified micro-organisms** (such as *Pseudomonas fluorescens*), including displacement of indigenous populations, suppression of fungal populations, reduced protozoa populations, altered soil enzymatic activity, and increased carbon turnover[20]. Circumstantial evidence that genetic exchanges between strains of Rhizobia occur in a field environment has been provided by population studies. However, information on the time scale and on the conditions in which these exchanges take place, is still missing. More research on the consequences of the release of novel organisms in the rhizosphere before they can be safely utilised is necessary.

71. **Opportunities/Areas for action:** Genetically modified organisms (GMOs) need to be adequately assessed for their environmental or human health effects before they are released into the environment. However, it is very difficult to predict how GMOs will behave once in the agricultural ecosystem. Today, results show that soil organisms are extremely sensitive to the use of engineered plants, and the effects are unpredictable. The impact of modern biotechnology on the environment and on human and animal health needs careful assessment on a case by case basis and through applying, in each situation, the precautionary approach, as adopted by the CBD. Attention is drawn to the need to consider how to implement the precautionary approach effectively and thereby address the concerns over risks and potential benefits of GMOs. International bodies such as FAO, UNEP, UNESCO and the CBD

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[20] *Naseby DC, Lynch JM (1998). Soil enzymes and microbial population structure to determine the impact of wild type and genetically modified Pseudomonas fluorescens in the rhizosphere of pea. Mol. Ecol., 7, 367-376.*

process, in particular the Biosafety Protocol, may provide guidance and assistance to countries on this matter. However, final decisions on the use of biotechnology remain a national responsibility.

72. This section has attempted to provide an overview of a range of opportunities that are available whereby farmers can actually manage soil biodiversity to enhance agricultural productivity. Nonetheless, as already noted, the adaptation and adoption of such technologies and sustainable systems requires an integrated natural resources management and agro-ecosystems approach in view of the complexity of soil biodiversity and the multiple biophysical–human interactions. In particular, it is important to stress that each opportunity has socio-economic as well as technical and environmental implications, and only those options that are economically viable and socially and culturally acceptable will be of interest to farming communities.

IV. The international framework regarding soil biodiversity conservation and management

International conventions and initiatives

73. In the dialogue between research institutes, international organisations, private and public sectors and recipient governments with the aim of effectively integrating soil biological management into environmental and sustainable development policies and initiatives, a number of international agreements and conventions serve as important signposts. In addition to the **Convention on Biological Diversity** (CBD), whose consideration of soil biodiversity is presented in paragraphs 1 and 2 of this paper, the following agreements and processes are of relevance. These also highlight the importance of fostering participation and partnership with the broad range of stakeholders concerned as a means to address more effectively the problems encountered.

74. **UNCED-Agenda 21:** The current set of international environmental conventions have been developed on the basis of the global policy

statement - Agenda 21 Plan of Action – that was adopted at the UN Conference on Environment and Development in Rio l992. This "Earth Summit" called for countries to incorporate environmental considerations into their development plans and build national strategies for sustainable development. At the United Nations General Assembly's special session in 1997 – "Rio plus five" - countries agreed to have such national strategies in place by 2002, which should be the product of extensive consultation with the stakeholders concerned. Countries are being assisted by donors to develop and implement these national strategies. A "Rio plus ten" summit will take place in Johannesburg in 2002 to assess progress achieved since 1992. The national strategies for sustainable development provide a useful framework for addressing issues of soil biodiversity management and conservation as part of an integrated approach.

75. **The UN Convention to Combat Desertification (CCD)** aims to address land degradation and drought in dryland areas, with the aim of improving living conditions. The text of this Convention binds signatory governments to promote long-term integrated strategies to improve the productivity of land, rehabilitate degraded areas, and conserve and manage land and water resources in a sustainable fashion, in particular at community level. National Action Programmes to address land degradation are being drawn up by a large number of countries through a consultative process, for which donor support is being sought. Soil biological management, including the conservation and sustainable use of soil biodiversity and its functions, should be an integral part of such plans.

76. **The UN Framework Convention on Climate Change (FCCC)** aims to achieve stabilisation of greenhouse gas concentrations in the atmosphere at a level that will prevent dangerous interference with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner. The Kyoto protocol, which aims at a reduction of carbon dioxide

emissions, was drafted in 1997, and awaits ratification. There are various links between climate change and soil management especially in regard to carbon sequestration (the storage or fixation of Carbon in soil organic matter and in plant biomass) and greenhouse gas emissions (GHG). The most important greenhouse gases are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Photosynthesis in plants leads to carbon fixation and CO_2. Decomposition and burning of biomass, however, releases CO_2 back to the atmosphere. Methane is produced in wetlands and rice fields, and by ruminant animals. Soils also emit N_2O as a result of microbial processes. At a global level, the mining, manufacture and transport of mineral fertilisers contribute to CO_2 and N_2O emissions". Thus, changes to soil fertility management by incorporating or enhancing biological management of soil fertility could have significant implications for climate change.

77. Agriculture provides a major share of national income and export earnings in many developing countries, while ensuring food security, income and employment to a large proportion of the population. Farmers, governments and scientists are increasingly aware that declining soil fertility is becoming a major concern worldwide with social, food security and environmental implications. As a result, controlling erosion and improving the management of soil fertility have become a major issue on the development policy agenda. In this regard, the **Soil Fertility Initiative (SFI)** for Sub-Saharan Africa was launched as part of the Rome Declaration on World Food Security in 1996, among key collaborating organisations, including the World Bank, FAO, ICRAF, IFDC, IFA, IFPRI and USAID. This interactive process aimed at increasing synergies and catalysing comprehensive strategies and actions at country level to enhance soil fertility restoration and management and prevent further nutrient mining. The focus was placed on practical solutions, including better use of organic and mineral fertilisers, integrated land husbandry approaches as well as overcoming institutional and policy constraints, such as land tenure and marketing. The development of Soil Management Action Plans has been promoted in over 20

countries through participatory review and prioritisation processes. In Burkina Faso and Ghana, for example, such plans have been developed and approved by the government. In other countries, certain priority actions are being addressed through investment and technical assistance programmes and with donor support.

78. A multitude of programmes in the agricultural and land sectors are supporting improved soil and land resources management and provide great scope for expanding attention to the conservation and sustainable use of soil biodiversity and the important functions of soil organisms. FAOs support to Member countries could be further mobilised to integrate soil biodiversity management through, *inter alia*: projects to improve capacities and tools and farmer-led learning approaches for soil productivity improvement and conservation agriculture, initiated through its Technical Cooperation Programme, the Special Program on Food Security and work on sustainable livelihoods; projects to mitigate land degradation and promote integrated watershed management and production systems; and, the CBD/FAO joint Programme of Work on Biodiversity for Food and Agriculture.

79. More specifically, the **FAO-Netherlands Partnership Programme** (FNPP) is a two-year programme that is supporting work by FAO towards the conservation and use of agricultural biodiversity within sustainable ecosystems and its contribution to global food security. One of the four main areas of attention is on improving understanding and implementation of the ecosystem approach, including adaptive management and best practices. In this regard, the **sub-component on soil biodiversity** aims to help catalyse more applied work in the agricultural and land sectors with the support of scientific institutes that are currently focusing their research on certain categories and functions of soil biodiversity and on specific technologies. There are three main aims and axes of cooperation:

    - Sharing of knowledge and information on the roles of diverse soil organisms in providing key goods and services and the impacts of existing and new agricultural technologies and management practices, with a view to developing guidance for agricultural and environmental-CBD fora;

- Collaboration among relevant programmes, networks and national and inter-national bodies to identify and promote improved soil biological management practices for different conditions and their integration into ongoing land management and soil productivity efforts; and,
- Establishing partnerships among farmers/land resource users and researchers/ development programmes to monitor and assess different practices and prepare case studies and to integrate soil biodiversity issues into documentation and training materials.

80. This FNPP soil biodiversity project is identifying and establishing linkages as appropriate with ongoing programmes and networks, for example:

- the GEF/UNEP project and network on the Conservation and Sustainable Management of Below-Ground Biodiversity hosted by the Tropical Soil Biodiversity and Fertility program (TSBF) of UNESCO-Diversitas;
- Networks including the IBOY and CYTED Macro-fauna networks, and various mycorrhiza and rhizobia networks such as the “Asociación Latino Americana de Rhizobiología” (ALAR), the “Caribbean Mycorrhizal Network” (CARIVAM) in Latin America, as well as gender/indigenous knowledge networks, such as the FAO-LINKS gender, biodiversity and indigenous knowledge network and the soil and gender network of University of Berne;
- Research bodies such as Institut de Recherche et Developpement (IRD-UR), in France, on Biodiversity and Soil Functioning which is holding a macro-fauna meeting (Paris, December 2001)**;** the NERC Soil biodiversity Program and CABI in UK; the CLUE project and the Wageningen simulation project on biodiversity, which is assessing the impact of soil biodiversity on ecosystem functioning, in Holland;

- Agro-biology/ecology bodies such as Centro de Pesquisa em Agrobiologia of Embrapa, Brazil and University of Padova Agroecology Laboratory;
- Soil biodiversity projects such as CYTED Project (Latin America) and SHIFT Project (GTZ-Embrapa), Manaus, Amazonas, Brazil; EU Soil biodiversity and ecosystem functioning program; and the UNU People Land Management and Environmental Change Project (PLEC), which is concerned with indigenous approaches to above-ground agrobiodiversity.

81. An international technical workshop on “Integrated Soil Biological Management and Sustainable Agriculture” is scheduled for mid 2002, with support of the FNPP programme, and in collaboration with technical partners, to further review the state of the art, with a focus on practical experiences, and to help identify priorities for action. Consultation has been initiated with Embrapa, Brazil, as a possible host institution. This review process should take into account the crucial role of soil biodiversity in agricultural production and in providing wider ecosystem services, and the need for appropriate management technologies, building on local knowledge systems and ensuring integrated approaches.

V. Conclusions and areas for consideration

Conclusions

82. Soil biologists and agriculturalists are challenged to address a major global concern: *“How to provide greater food security for all nations on earth in a sustainable way?”.* In addressing soil biodiversity and relevant societal concerns it is necessary to take an **ecosystem approach** and **a multi-disciplinary approach** in order to better understand biophysical and human interactions and the complexity of the living systems. However, as underground biodiversity is incredibly complex, it may require to initially focus, for example to assess specific functions of soil biota in productive agro-ecosystems and impacts of specific farming systems, technologies and

practices. Nonetheless, this should subsequently lead to the development of integrated soil biological management as a means to maintain renewable soil fertility and ecosystem services.[20]

83. Soil biota provide key ecosystem services that are responsible for naturally renewable soil fertility, for mediating carbon sinks in the soil and many other functions. The conservation of healthy communities of soil biota and prudent use of specific soil organisms through biological soil management can be used to maintain and enhance soil fertility and ensure productive and sustainable agricultural systems[21]. Moreover, the consequences of neglecting or abusing soil life will weaken soil functions, and contribute to greater loss of fertile lands and an over-reliance on chemical means for maintaining agricultural production. This emphasises the need to enhance collaboration among soil biology specialists and agricultural practitioners, those concerned with land degradation and other stakeholders in promoting improved soil biological management.

84. In view of the complex nature and limited knowledge of soil biodiversity there is a need to identify and assess the **feasibility of potential soil biodiversity activities and applications** in order identify priorities and to evaluate costs and benefits to different user groups. In particular, in view of the following notable gaps in knowledge:

- Soil biota are highly diverse and numerically staggering, yet only major taxonomic and functional groups are well known;
- Critical ecosystem services provided by soil biota (e.g., organic matter decomposition, nutrient cycling and pest control) are still under intense investigation;
- Little is known of the colonisation-extinction dynamics of soil biota or how the additions and deletions of keystone taxa or

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[20] *Wake, M.H. 2001. Integrative biology: its promise and its perils. In: Biological Science: Challenges for the 21st Century. G. Bernardi, J.C. Mounolou and T. Younés, eds. Biology International 41, 71-74.*

[21] *Matson, P.A., W.J. Parton, A.G. Power, and M.J. Swift. 1997. Agricultural intensification and ecosystem properties. Science, 277, 504-509.*

functional groups will influence sustainable agricultural productivity;

- Not all strategic objectives and programmatic activities will benefit equally (i.e. immediate gains will be realised in some areas, mid- to long-term gains in others, and little or no benefits may be seen in other areas).

Areas for Consideration

85. In accordance with the programme of work on agricultural biodiversity and taking into account the above findings, there is a need for promoting coordinated actions and concerted attention on soil biodiversity with a view to enhancing its contributions to agricultural productivity and sustainability and to combating land degradation, including, as appropriate, the biological restoration of soil fertility (i.e. in fragile areas such as dryland, coastal and mountain environments and following natural disasters such as droughts, floods or excessive rains). In this regard, an **International Soil Biodiversity Initiative** is proposed to encourage country Parties to the CBD and FAO Member Nations to make progress, especially in the areas of: Technical assessments; Adaptive management of soil biota; Capacity-building; and Mainstreaming of relevant soil biology issues into various institutions and processes.

86. The main objectives of such an initiative could, *inter alia:*

    1) Promoting the assessment, sharing of knowledge, information and case studies and awareness raising (i.e. on the roles and importance of diverse soil organisms in providing key goods and services and on the positive and negative impacts of existing and new agricultural technologies and management practices), with a view to developing guidance for field workers/technicians and for national and international priority setting and policies.

    2) Enhancing collaboration among relevant programmes, networks, research institutes and national and international bodies to, firstly, develop indicators and field methodologies for monitoring and assessing soil biodiversity and its functions and the effects of

land use/management practices on soil quality and health, and thereby, to identify and promote improved soil biological management practices for different conditions and their integration into ongoing agriculture/land management efforts.

3) Strengthening capacities and partnerships among farmers/land resource users, researchers and development programmes: to monitor and assess different practices and prepare case studies; to integrate soil biodiversity issues into documentation, training materials and policies (guidelines, compendia of "best practices", etc.); and to facilitate participatory research and technology transfer on soil biodiversity/biological management, with a view to promoting sustainable agriculture and improved land management.

87. The suggested approach should be a participatory and Integrated Soil Biological Management (ISBM) process that involves the range of stakeholders in a flexible and iterative process of creating, sharing, and improving experiences of integrated soil biological management. A focus is suggested on the following user groups: i) Resource-poor farmers, small-scale producers (men and women) and rural communities (especially those living on marginal and/or degraded lands as these are particularly amenable to soil biological management practices); and ii) Policy makers and promoters of sustainable agriculture in Low Income Food-Deficit Countries (LIFDCs), including research institutes, extension programmes, NGOs and international funding partners.

88. A focus should be placed on developing and refining existing opportunities (direct and indirect management interventions) for different biophysical and socio-economic conditions, and their integration with other management strategies (soil and water, crop and livestock, integrated pest management, etc.) The challenge will be to identify and promote integrated systems that are economically viable, environmentally sustainable and appropriate both socially and culturally. This could be initiated through pilot-level demonstration projects, with subsequent scaling-up processes

through global and regional programmes and in collaboration with partners (CGIAR, TSBF, NGOs and others). Case studies of intervention practices could be developed into training materials and management guidelines, and then applied research could be sponsored to generalise these guidelines into management practices relevant to particular agro-ecological zones and for farmers, extension agents and technicians at various levels and of various economic means (i.e. low and high-input farmers).

89. In accordance with the call for case studies under the CBD programme of work on agricultural biodiversity, contributions illustrating experiences in the conservation and sustainable use of soil biodiversity are solicited from all concerned actors in the agriculture and environment sectors, in order to facilitate the review and prioritisation process for further work.

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