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BIOLOGICAL MANAGEMENT OF SOIL ECOSYSTEMS FOR SUSTAINABLE AGRICULTURE

BIOLOGICAL MANAGEMENT OF SOIL ECOSYSTEMS FOR SUSTAINABLE AGRICULTURE

Report of the International Technical Workshop

Organized by
EMBRAPA-Soybean and FAO

Londrina, Brazil, 24 to 27 June 2002

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
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Summary

The International Technical Workshop on Biological Management of Soil Ecosystems for Sustainable Agriculture was organized as a contribution to the joint programme of the Convention on Biological Diversity (CBD) and FAO in accordance with FAO's mandate on sustainable agriculture and food security and with Decision V/5 of the Conference of the Parties (COP) to the CBD.

More than 45 participants from more than 18 countries, representing a heterogeneous range of scientists and practitioners from each region, joined efforts to review and discuss the concept and practices of integrated soil management, share successful experiences and identify priorities for action.

Purpose of the workshop

The specific objectives of the workshop were:

- Share knowledge among a range of experts from all regions.
- Develop and promote guiding principles and good practices for enhancing soil biodiversity and its functions as part of an integrated approach for the management of land resources and agricultural ecosystems.
- Provide technical guidance to realize the benefits of biological management of soil ecosystems in terms of enhanced productivity and sustainability.
- Agree on the strategy and priority actions for implementing the International Initiative on Conservation and Sustainable Use of Soil Biodiversity, as part of an integrated agricultural development process including capacity building, assessment and monitoring, adaptive management, and mainstreaming.

Discussion and findings

The participants reviewed and discussed the case studies presented. These case studies reflected a range of production systems and socio-economic conditions. The participants focused their attention on the areas of indicators and assessment of soil health, adaptive management and innovative technologies with a view to identifying lessons learned and knowledge gaps. Based on working-group discussions, plenary sessions and existing knowledge, experiences and materials, the participants laid the foundations for the development of practical guidelines to promote on-farm research and technology development in integrated soil biological management (i.e. strategies, approaches and technologies) with a view to enhancing the productivity and sustainability of diverse land use systems and conserving soil and associated agricultural biodiversity.

Follow-up

The participants suggested that progress could be made through focusing on the following strategic areas of action:

- Increasing recognition of the essential services provided by soil biodiversity across all production systems and its relation to land management, through information sharing and networking, raising public awareness, education and capacity building.
- Capacity building to promote the adoption of integrated approaches and coordinated activities and processes for the sustainable use of soil biodiversity and enhancement of agro-ecosystem functions; in particular, in the areas of assessment and monitoring, adaptive management; and research and development (R&D).
- Developing partnerships and cooperative actions through mainstreaming and cooperation.

It is intended that the suggested principles, development process, strategy and priority actions presented in this workshop report provide a preliminary basis to further stimulate exchange of information and experiences among countries and relevant institutions. This should lead to a coordinated process for the establishment and conduct of the Soil Biodiversity Initiative (SBI), as established under COP Decision V/5 (Nairobi, April 2002), as a cross-cutting initiative within the CBD programme of work on agricultural biodiversity, and through the coordination and with the technical and policy support of FAO.

The findings and recommendations in regard to the three main thematic areas considered at the Londrina workshop are presented in the form of a framework for action that outlines proposed

Framework for action as a basis for further development of the Soil Biodiversity Initiative

Objective 1 – Sharing of knowledge and information, and awareness raising.

Activity 1.1 – Compilation and dissemination of case studies for use in awareness raising and capacity building.

Activity 1.2 – Creation and strengthening of networking arrangements for sharing of information, experiences and expertise with a focus on supporting local initiatives on the ground rather than institution building.

Activity 1.3 – Enhancing public awareness, education and knowledge on integrated soil management and agro-ecological approaches.

Activity 1.4 – Development of information systems and databases.

Objective 2 – Capacity building for the development and transfer of knowledge of soil biodiversity and ecosystem management into farmers' practices.

Activity 2.1 – Evaluating capacity building needs of farmers and other land managers, researchers and development programmes for integrated soil biological and ecosystems management.

Activity 2.2 – Development of soil bioindicators and tools for assessment and monitoring of soil health and ecosystem functioning.

Activity 2.3 – Promotion of adaptive management approaches for the development and uptake of improved soil biological management practices, technologies and policies that enhance soil health and ecosystem function and contribute to sustained agricultural productivity and livelihoods.

Activity 2.4 – Mobilization of targeted participatory R&D in order to enhance understanding of soil biodiversity functions and ecosystem resilience in relation to land use and sustainable agriculture.

Objective 3 – Strengthening collaboration among actors and institutions and mainstreaming soil biodiversity and biological management into agricultural and land management and rehabilitation programmes.

Activity 3.1 – Mainstreaming soil biodiversity and ecosystem management in agricultural and land management programmes and policies.

Activity 3.2 – Develop partnerships and collaborative activities for development and implementation of the Soil Biodiversity Initiative as an FAO-CBD partnership.

objectives and activities. It is envisaged that this framework will provide the basis for the further development of the strategy and action plan for implementation of the International Initiative on the Conservation and Sustainable use of Soil Biodiversity, further referred to as the SBI, as an integral part of the programme of work on agricultural biodiversity. It will be a partnership effort by FAO, the CBD Secretariat and Parties, and other interested partner organizations and bodies.

> *"The condition of our soils ultimately determines human health by serving as a major medium for food and fibre production and a primary interface with the environment, influencing the quality of the air we breathe and water we drink. Thus, there is a clear linkage between soil quality and human and environmental health. As such, the health of our soil resources is a primary indicator of the sustainability of our land management practices."*
>
> *(Acton and Gregorich, 1995)*

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The workshop organizers in the Land and Plant Nutrient Management Service of the Food and Agriculture Organization of the United Nations (FAO) would like to thank EMBRAPA-Soybean for having kindly hosted and significantly contributed to the successful organization of the International Technical Workshop on Biological Management of Soil Ecosystems for Sustainable Agriculture. Particular thanks are due to George Brown and Mariangela Hungria for their special support. The financial support provided through the agricultural biodiversity component of the FAO-Netherlands Partnership Programme (FNPP) was greatly appreciated, as it enabled the organization of this ground-breaking workshop and the participation of technical experts from some 18 countries throughout the world. Thanks are also extended to each of the individual contributors who made the effort to participate and/or to provide case studies that stimulated such a dynamic and fruitful workshop.

This workshop report has been prepared by the workshop facilitators, Sally Bunning, FAO land conservation and management officer and Adriana Montañez, FAO consultant, with the aim to reflect and recognize the valuable and diverse contributions that each and everyone provided. It is hoped that this report does due credit to the range of expertise and experiences and the quality of the discussions on soil biodiversity assessment and monitoring, adaptive management, research and technological innovation.

Special thanks go to the support staff who provided assistance in the workshop preparation and travel and logistical arrangements. Appreciation is acknowledged for the managerial support provided by Parviz Koohafkan and Peter Kenmore of FAO's Agriculture Department. Thanks are expressed for the comments and suggestions made during the peer review and editing of this document, in particular to Juan Jiménez, Robert Brinkman and Julian Plummer as well as Lynette Chalk for formatting and final presentation.

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Acronyms

ACT	African Conservation Tillage Network
Al	Aluminium
ALAR	Asociación Latino Americana de Rhizobiología (network)
AMF	Arbuscular mycorrhizal fungi
ASB	Alternatives to slash and burn (programme/global partnership)
BGBD	Below-ground biodiversity (network project on conservation and sustainable management)
BNF	Biological nitrogen fixation
C	Carbon
C_U	Carbon uptake
C_F	Carbon fixation
C_E	Carbon emissions
C_T	Carbon transfer
Ca	Calcium
CABI	CAB International (non-profit organization/publisher in applied life sciences)
CAMAREN	Consortium for natural resources management training (Ecuador)
CBD	Convention on Biological Diversity (UN)
CCD	Convention to Combat Desertification (UN)
CEC	Cation exchange capacity
CGIAR	Consultative Group for International Agricultural Research
CGRFA	Commission on Genetic Resources for Food and Agriculture
CIAT	International Center for Tropical Agriculture
COAG	Committee on Agriculture (FAO)
COP	Conference of the Parties (to the CBD, CCD, etc.)
CSIRO	Commonwealth Scientific and Industrial Research Organisation (Australia)
CYTED	Ciencia y Tecnología para el Desarrollo (Ibero-American programme)
DGGE	Differential gradient gel electrophoresis
DGIS-NET	Directorate General for International Cooperation (Netherlands)
EBDA	Egyptian Biodynamic Association
ECOPORT	Internet-based portal to ecological database and information (www.ecoport.org)
EMBRAPA	Brazilian Agricultural Research Corporation
FAO	Food and Agriculture Organization of the United Nations
FBO	Bio-organic fertilization
FCCC	Framework Convention on Climate Change (UN)
FFS	Farmer field school (learning-by-doing experiential approach)
FNPP	FAO-Netherlands Partnership Programme
GEF	Global Environment Fund (UN)
GM	Genetically modified
GMO	Genetically modified organism
GTZ	German Technical Cooperation Organization

IAPAR	Agronomic Institute of Paraná (Brazil)
IARC	International agricultural research centre
IBOY	International Biodiversity Observation Year
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IFAD	International Fund for Agricultural Development
INCA	National Institute of Agricultural Sciences (Cuba)
INERA	Institut pour l'Environnement et la Recherche Agricole
INREF	North-South Interdisciplinary Research and Education Fund
IPM	Integrated pest management
IPPM	Integrated production and pest management
IRD	Institut de Recherche pour le Developpement (formerly ORSTOM, France)
ISNM	Integrated soil and nutrient management
IUSS	International Union of Soil Science
K	Potassium
LADA	Land degradation assessment in dryland areas (programme)
LEIA/HEIA	Low external input agriculture / high external input agriculture
Mg	Magnesium
MIRCEN	Microbial Resources Centres (and global network in environmental, applied microbiology and biotechnology research)
MOIST	Management of Organic Inputs in Soils of the Tropics
N	Nitrogen
NAR	National agricultural research
NBSAP	National biodiversity strategy and action plan
NGO	Non-governmental organization
OECD	Organization for Economic Cooperation and Development
P	Phosphorus
PAIA	Priority Area for Interdisciplinary Action (FAO)
PLEC	People, Land Management and Environmental Change (UN University)
PTD	Participatory technology development
R&D	Research and development
SBI	Soil Biodiversity Initiative
SBSTTA	Subsidiary Body on Scientific, Technical and Technological Advice (of the CBD)
SEKEM	Vitality from the Sun (farm of Egyptian Biodynamic Agriculture Association)
SPI	Soil productivity improvement
TSBF	Tropical Soil Biology and Fertility Institute of CIAT
TOT	Training of trainers
UN	United Nations
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
WSSD	World Summit on Sustainable Development (Johannesburg, 2002)

Chapter 1
Objectives and context of the Londrina workshop

BACKGROUND

In the work of the Food and Agriculture Organization of the United Nations (FAO) together with its member countries, there has been increasing recognition of the need for a holistic consideration of agricultural systems, livelihoods and food security. The Strategic Framework of FAO (2000-2015) established a set of cross-cutting programme areas for interdisciplinary action known as Priority Area for Interdisciplinary Action (PAIAs). In particular, the contribution of the Agriculture Department of FAO to the interdisciplinary programmes on biodiversity for food and agriculture (PAIA-BIOD) and on integrated production systems (PAIA-PRODS) is encouraging a more integrated approach for the sustainable management of land and water resources, biological resources and ecosystems with a view to promoting sustainable and productive agriculture.

Substantial efforts are underway to strengthen agricultural biodiversity considerations through improved understanding, capacity building, including methods and tools development, as well as partnerships and networking. In addition to strengthening the genetic resources dimension in terms of *in-situ* conservation through sustainable use, and providing an enabling environment to farmers through addressing socio-economic and policy issues, there is now a greater focus on crop- and livestock-associated biodiversity that contributes to ecosystem functioning, including pollinators, beneficial predators and integrated pest management (IPM), and soil biodiversity. Simultaneously, in terms of managing the land and water resource base, this includes a more holistic approach for addressing declining soil fertility, land degradation and drought, and other land-related constraints through an integrated land resources management approach. A recent change has been a move away from the conventional focus on overcoming soil chemical and physical constraints (such as nutrient deficiencies, salinity and compaction) to a focus on soil health through an approach centred on soil biological management, and interactions among components of the system (soil, water, plant and livestock) and human management practices. Such an ecosystem approach requires attention to the wider socio-economic considerations and the farming context.

The 1992 Convention on Biological Diversity (CBD) has fuelled increasing interest in agricultural biodiversity. Led by environmental bodies, the initial focus was on the conservation and sustainable use of biological diversity and on the fair and equitable sharing of benefits in systems other than agricultural systems. However, efforts of FAO and many other human development organizations and delegates who recognized the importance and specific nature of biodiversity important for food and agriculture led to the development and adoption, in 1996, of a programme of work for the conservation and sustainable use of agricultural biodiversity (Decision III/11). The programme elements and priorities have developed gradually through subsequent efforts by concerned stakeholders, scientific and technical reviews, and decisions of the Parties to the convention.

Of particular relevance to this workshop, and as a result of the information coordinated and provided by FAO, the Conference of the Parties (COP) of the CBD decided (COP Decision VI/5, April 2002): "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". (http://www.biodiv.org/programmes/agro/decisions.asp)

In striving for productive and sustainable agriculture, there is a need to promote a concerted effort among concerned disciplines to understand the complex soil-water-plant interactions, the role and importance of soil biological processes, and the impacts of farmers' management practices. Moreover, it is necessary to achieve worldwide recognition of the need to conserve soil health and function as the basis for human life on the planet. In this light, the Brazilian Agricultural Research Corporation (EMBRAPA) and FAO joined forces to organize the International Technical Workshop on Biological Management of Soil Ecosystems for Sustainable Agriculture, hosted by EMBRAPA-Soybean in Londrina, Brazil, 24-27 June, 2002. The FAO-Netherlands Partnership Programme (FNPP) was the primary source of funding for the workshop.

This workshop is the first step by FAO to consider the issue of soil biodiversity and sustainable agriculture comprehensively at a technical level, reflecting the renewed interest in agro-ecological approaches for sustaining productive agricultural systems. The Commission on Genetic Resources for Food and Agriculture (CGRFA) welcomed a background paper on this issue at its 17th session (2002), and the CGFRA and the Committee on Agriculture (COAG), to which it reports, could provide guidance as to the role and cooperation of the organization in response to the proposed CBD initiative, in accordance with FAO's mandate, priorities and programme of work and budget.

The overall aim of this technical workshop was to review current understanding and knowledge of the biological management of soil ecosystems and assessment of soil health, and to identify useful methods, tools and lessons learned that can provide the basis for the development and promotion of land use systems and management practices that enhance soil quality and its ecological functions. The workshop provided a diverse and dynamic forum for: (i) sharing experiences among experts from each region; (ii) discussing the principles and practices of integrated soil biological and ecosystem management; and (iii) identifying priorities for cooperative action.

Soil biodiversity, agriculture, sustainable management and farmer context

"Soil biodiversity per se may not be a soil property that is critical for the production of a given crop, but it may be vital for the continued capacity of the soil to support that cropping system." (Doran and Parkin, 1994)

Practising agriculture means selecting a few species of plants or animals that are useful or edible, and modifying their environment to provide them with nutrients (food), water and air, so that they grow in the best conditions. The resulting agricultural ecosystems or agro-ecosystems are those 'ecosystems that are used for agriculture'. These are found in most areas and their interactions with human activities, taking into consideration socio-economic and policy considerations and sociocultural diversity, are determinant. The biological diversity of these agro-ecosystems, hereafter referred to as agricultural biodiversity, reflects the whole range of biodiversity from genetic and species level to ecosystem level, although until recent years the focus was more on plant and animal diversity. The development of the ecosystem approach as the primary framework for action under the CBD is enabling due attention to be paid to the interactions among components of the system, with human activity at the centre, to the complex food webs and functions of the system and to the less tangible attributes of landscape diversity.

The agricultural biodiversity work programme of the CBD focuses on assessing the status and trends of the world's agricultural biodiversity and of their underlying causes, as well as of local knowledge of its management. It also works to identify and promote adaptive management practices, technologies, policies and incentives. The aims of the work programme as outlined in COP Decision III/1, paragraph 1, are:

- to promote the positive effects and mitigate the negative impacts of agricultural practices on biological diversity in agro-ecosystems and their interface with other ecosystems;
- to promote the conservation and sustainable use of genetic resources of actual or potential value for food and agriculture;
- to promote the fair and equitable sharing of benefits arising out of the utilization of genetic resources.

The expert meeting on agri-biodiversity held by the Organization for Economic Cooperation and Development (OECD) in Zurich (November 2001) made several recommendations concerning the measuring of the environmental performance of agriculture. These related mainly to the establishment of useful and relevant indicators within a common, flexible and transparent framework that could be integrated into policy monitoring in member countries involving a wide range of stakeholders and contributing to other international initiatives related to developing indicators. It was recognized that a major challenge facing OECD member and non-member countries is the need to reconcile expanding agricultural production with meeting national and international objectives and commitments for the conservation and enhancement of biodiversity and sustainable land resources management, given the projected need to increase global food production by over 20 percent by 2020 in order to meet the growing demands of expanding human and animal populations.

The most vital link between sustainable land management and productive agriculture is provided by the functions of diverse soil organisms in response to land use and human management practices. However, there is very limited recognition in the agriculture and environment sectors of the wide range and huge populations of soil biota that exist in most healthy soils, or of the multiple and essential functions they perform. Moreover, there has been limited and fragmented work to improve understanding of such services and to enhance their value in terms of economic, food security and environmental benefits through improved management. Although in-depth research has examined certain organisms and specific functions, this has tended to neglect a more holistic approach to managing soil life.

Farmers' management practices and land use decisions influence ecological processes and soil-water-plant interactions. Indeed, through their decisions, farmers seek to manage soil processes in such a way as to achieve desirable effects on short- and long-term soil productivity and health. The processes of land utilization and agricultural intensification are a significant cause of soil biodiversity loss and related impacts on ecosystem function and resilience. A better understanding of the linkages between soil life and ecosystem function and the impact of human interventions will enable both the reduction of their negative impacts and the more effective capture of the benefits of soil biological activity for sustainable and productive agriculture.

Achieving sustainable agriculture and viable agricultural systems is critical to food security and poverty alleviation given escalating population growth, land degradation and increasing demands for food. 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, together with 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 soil is a complex, multifaceted 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 micro-organisms live in soils, ranging in size from the almost invisible microbiota (e.g. bacteria, fungi and protozoa) to the more conspicuous macrofauna and megafauna (e.g. earthworms, termites, millipedes, moles and rats).

The activities of this wide range of soil biota contribute to many critical ecosystem services. These services include: soil formation; organic matter decomposition, and thereby nutrient availability and carbon (C) sequestration (and conversely greenhouse gas emissions); nitrogen (N) fixation and plant nutrient uptake; suppression or induction of plant diseases and pests; and bioremediation of degraded and contaminated soils (through detoxification of contaminants and restoration of soil physical, chemical and biological properties and processes). The effects of soil organisms also influence water infiltration and runoff and moisture retention through effects on soil structure and composition and indirectly on plant growth and soil cover. These services are critical to the functioning of natural ecosystems and constitute an important resource for sustainable agricultural production.

There is increasing recognition that the sustainability of agricultural systems depends on the optimal use of the available natural resources, including the soil biotic community. Thus, there is a need to acquire 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. The adaptation of management practices can minimize the negative impacts on soil biological populations and diversity and can maximize the positive (synergistic) effects on agricultural productivity for the benefit of humankind.

As agricultural intensification occurs, regulation through chemical and mechanical inputs progressively replaces the regulation of functions through soil biodiversity. There is an accelerating loss of biological diversity both above- and below-ground. Among the causes of this loss are: increasing homogenization of agricultural systems and use of monocultures; the use of agrochemicals; and excessive soil disturbance through repetitive tillage. In the long term, the erosion of genes, species and ecosystems that constitute important resources and support systems to human activities and well-being will undermine sustainable development opportunities worldwide. The challenge is to improve understanding of the benefits of biodiversity and to identify the actual and potential socio-economic causes and impacts of changes in biodiversity. This will permit the development of strategic means to use the components of biological diversity in ways that do not lead to their long-term decline while contributing to increasing the production functions that underpin human progress.

However, current knowledge in this area is fragmented and remains largely in the research domain with limited practical application by farmers. Various reasons for this situation include:

the difficulty of observation and limited local understanding of below-ground interactions and processes; a specialized research focus (on individual species or functions) and the lack of holistic or integrated solutions for specific farming systems; and insufficient institutional capacity and support services to enable a concerted resource management approach.

Workshop process and objectives

The International Technical Workshop on Biological Management of Soil Ecosystems for Sustainable Agriculture was organized as a contribution to the CBD-FAO joint programme, in accordance with Decision V/5 of the COP and FAO's mandate on sustainable agriculture and food security. Its objectives were to initiate the processes of:

- **sharing knowledge among a range of experts from all regions** with a view to increasing understanding on the importance and potential of soil biological management for sustainable and productive agriculture, and to review the state of the art (knowledge and application) in regard to the conservation and sustainable use of soil biodiversity;
- **developing and promoting guiding principles and good practices** for enhancing soil biodiversity and its functions as part of an integrated approach for the management of land resources and agricultural ecosystems. This should include sustaining life processes and key ecosystem services as well as enhancing the productivity and sustainability of the range of agricultural systems;
- **providing technical guidance to realize the benefits of biological management of soil ecosystems** in terms of enhanced productivity and sustainability. This should build on available knowledge, safe technologies and experiences of farmers and researchers, through the application of the ecosystem approach and through multidisciplinary and multistakeholder participation. It should include a set of practical techniques and tools for testing and adaptation by farmers;
- **agreeing on the strategy and priority actions for implementing the International Initiative on Conservation and Sustainable Use of Soil Biodiversity**, as part of an integrated agricultural development process including capacity building, assessment and monitoring, adaptive management, and mainstreaming.

The workshop was officially opened by Dr Caio Vidor, Director General, EMBRAPA-Soybean. He introduced the scope of the work of EMBRAPA (9 000 employees, of whom 2 000 Ph.D. and 1 000 M.Sc. holders) and the host centre, EMBRAPA-Soybean (75 scientists). He noted the focus on sustainable agriculture and the increasing attention to agro-ecological and integrated ecosystem approaches. Strategic considerations of the centre include: how to foster cooperation among scientists; how to strengthen socio-economic expertise; and how to enhance training capacity and technology transfer, in particular for tropical regions.

Ms Michelle Gauthier, CBD Secretariat, set the workshop in the context of the CBD, noting the establishment by the COP, at its 6th meeting, of the International Initiative on the Conservation and Sustainable Use of Soil Biodiversity under the programme of work on agricultural biodiversity (Decision VI/5). Opportunities for attention to this issue include:

- during consideration by the 8th meeting of the Subsidiary Body for Scientific, Technical and Technological Advice (SBSTTA-8) of mountain biodiversity and of dry and subhumid lands biodiversity (March 2003, Montreal, Canada);

- during consideration by SBSTTA-9 of protected areas, the ecosystem approach, indicators and assessment, sustainable use, and technology transfer (November 2003, Montreal, Canada);
- at COP-7 (March 2004, Kuala Lumpur);

  and in particular:
- as part of the 3rd national reports (to be provided by May 2005);
- at COP-8 (2006), during the major review of agricultural biodiversity and biodiversity in dry and subhumid regions.

The outcome is expected to guide the development of the International Initiative for the Conservation and Sustainable Use of Soil Biodiversity. The results of the workshop should be disseminated and taken up and promoted by concerned stakeholders in such a way that they are ultimately reflected in the land management practices of rural and urban communities of both developed and developing countries. The overall aim is to help improve the livelihoods of farming communities and achieve a truly sustainable agriculture that is both environmentally sound and economically viable.

More than 45 participants from more than 18 countries, representing a heterogeneous range of scientists and practitioners from each region, joined efforts to discuss the concepts and practices of integrated soil management, share successful experiences of soil biological management, and identify priorities for action.

The workshop reviewed experiences, identifying limitations and opportunities in regard to methods and tools for assessing and enhancing the functions of soil organisms through improved management practices, with a view to their wider application and further development. Throughout the workshop, emphasis was placed on ways of harnessing the services and benefits of soil biological management and promoting interactions with other agricultural sectors through an integrated ecosystem approach.

The workshop presentations and discussions during plenary and working-group sessions helped to develop a better understanding of the available knowledge of soil biological management within the overall context of sustainable agriculture and identifying gaps and needs for further work. In identifying existing and researchable tools to investigate, manage and protect soil biotic ecosystems, a focus was directed on two areas: (i) bioindicators and assessment; and (ii) adaptation of management practices and farming systems through farmer experimentation and stronger farmer-research linkages.

The participants discussed a wide range of issues in depth. They agreed on a number of recommendations for the further development and implementation of the International Initiative for the Conservation and Sustainable Use for Soil Biodiversity. Attention was placed on building on existing initiatives and on promoting the development of a coordinated programme approach, through cooperation among research and academic institutes, governments, non-governmental organizations (NGOs), civil society organizations and the private sector. The workshop constituted an important step in the process of identifying technical and financial capabilities and opportunities for implementing activities and enhancing collaboration among relevant programmes and partners.

The workshop alternated between full group discussions and meetings of smaller groups to discuss specific themes and priorities for action. In order to focus the discussions of the working groups, a prepared list of questions guided participants to address specific topics (Annex 3). The key topics identified for discussion by the working groups were: assessment and monitoring of soil health; and farmers' management of soil ecosystems. In addition, a third discussion group was included to focus on innovative technologies, research needs and risk alleviation for each of the proposed themes. Throughout the workshop, participants emphasized ways of employing the resources and strengths of local capacities to advance and to promote interactions with the other agronomic fields. The workshop closed with a discussion and compilation of specific conclusions and recommendations on how to move forward.

The following chapters of this report present an overview of the substantive discussions and a summary of the findings and recommendations reached by the International Technical Workshop on Biological Management of Soil Ecosystems for Sustainable Agriculture. For more detail, readers may refer to the contributions themselves, available on CD-ROM and on http://www.fao.org/ag/agl/agll/soilbiod/default.htm, and to the annexes of this report. A full reading of the case studies and discussions may better convey the depth of knowledge offered and the important contacts and linkages made during this event. The findings and recommendations outlined in the final section of this report build on the discussions and information from each topic.

Annex 1 details the agenda of the workshop. Annex 2 provides a list of the participants and their contact details in. Annex 3 provides the list of questions prepared to help focus the work of the working groups.

Chapter 2
Review of knowledge and issues through case studies on soil biodiversity, ecosystem management and sustainable agricutlure

Several case studies from a number of countries were presented during the workshop. They provide a range of specific lessons and results in terms of adaptive management, soil health assessment and capacity building on soil biodiversity and its ecological functions. They refer to different cropping systems, climate conditions and a range of economic situations from low- to high-input agriculture. The ecosystem approach is highlighted as an important concept for improving understanding and management of biodiversity and ecosystem services. Annex 7 presents some background about the ecosystem approach and its links to adaptive management.

Indicators for assessment and monitoring of soil health

Dr Clive Pankhurst of the Land and Water Division of the Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia, first provided a framework for consideration of the issue of assessment and monitoring. This addressed:

- practical approaches and indicators for site assessment of land degradation, land values and services, and off-site impacts;
- the capacity to interpret soil health information and develop guidelines and recommendations, using soil ecosystem parameters, simple visual bioindicators and laboratory-dependent bioindicators;
- the need for integrative measures that respond to change in soil management in time scales relevant to land users.

He noted that the challenging question is: “What measurements should be made or what can be observed that will help to evaluate the effects of management on soil function now and in the future? There is still no universally accepted list, or minimum data set, of what soil attributes could or should be measured in a given situation.”

Conventional agricultural practices for maintaining and increasing crop and fibre production in many parts of the world are placing pressure on the soil’s capacity to maintain its function. They include increasingly specialized systems and even monocultures, mechanical cultivation and harvesting, high and sometimes excessive and indiscriminate use of mineral fertilizers and pesticides. In other areas, continuous nutrient mining and unsuitable land use systems and management practices are leading to severe soil productivity decline and land degradation. This situation highlights the urgent need to develop a capacity to assess both the degree of functional degradation of the soil and the rate at which it is occurring, and to develop a holistic 'biological systems management' approach to soil health and agricultural production.

The introduction was followed by three case studies: on soil health assessment and monitoring for industrial sugar-cane production; on assessment methods using practical tools and existing expertise and materials - the potential use of soil macrofauna as bioindicators of soil quality; and on the measurement of soil respiration as an indicator of soil life.

Case 1 – Bioindicators of soil health: their use by the sugar-cane industry in Australia

Cane yields have been declining for many years despite the development of new cane varieties and pesticide controls for known pests (e.g. cane grub). The yield decline was shown to be associated with poor soil health resulting chiefly from the growth of cane as a monoculture and excessive tillage at planting required to overcome soil compaction caused by heavy harvesting machinery. Using soil health indicators (e.g. soil activity and presence of beneficial or detrimental organisms), the extent to which the soils had become degraded physically, chemically and biologically could be demonstrated to cane growers. They were also advised that the only way to reverse this trend was to change the way they manage their soils. An essential component of this process was for researchers to work in close collaboration with groups of cane growers in order to develop a new systems approach. This new approach was based on the incorporation into the farming system of green manure rotation breaks (to improve the biological health of the soil), and reduced tillage (to keep areas trafficked away from growing plants). Demonstration trials together with an economic analysis of the new system compared with the old were also important tools for facilitating this process. The approach was based on 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 designed to provide them with recipes because what might work successfully in one region might not in another.

This sugar-cane experience is a good practical example on the use of bioindicators to enhance management practices. It also provides an important message: not to develop and use soil health indicators as tools to condemn land users for their inappropriate use of the soil resource, but to use them as tools to explain what is happening and facilitate a change towards more sustainable agricultural practices.

(Clive Pankhurst, CSIRO)

Case 2 – Participatory assessment of macrofaunal functional groups for rehabilitation and improved productivity of pastures, cropland and horticulture

It is recognized that each organism in the soil drives soil processes in specific functional domains (e.g. rhizosphere, termitosphere) and that these organisms can be grouped into some 30-40 functional groups. In particular, soil macrofauna are important regulators of soil function and they are easy to measure and identify. The invertebrate communities are sensitive indicators of soil quality. Among the vast diversity of species, adaptive strategies and size range represented, the effects on the soil of the physical activities of a specific group, known as the 'soil ecosystem engineers', which also includes large invertebrates, determine activities of other, smaller soil organisms. Human management practices, such as soil tillage, affect soil macrofauna (abundance and diversity) and may create a disequilibrium that can be very difficult to correct. In addition, chemical pollution affects soil fauna adversely. Thus, the composition of faunal communities

PLATE 1
Participatory sampling of soil macrofauna (TSBF methodology) in farming systems of Tanzania
[G. Brown]

may be an accurate indicator of diffuse pollution (e.g. by heavy metals and pesticide residues) through indicator species *sensu stricto* or through bio-accumulators.

Through extensive studies, the IBOY-Macrofauna Network has confirmed that macrofauna is relatively easy to collect. It used participatory methods to involve farmers groups in the process of sampling, collection and identification of soil macrofauna functional groups (Plate 1). The standard method of the Tropical Soil Biology and Fertility Institute (TSBF) was used to collect invertebrates at more than 1 000 sites, with a focus on tropical areas. Results so far have shown that macrofauna functional groups correlated very well with different soil chemical and physical situations as well as management conditions (in particular, organic matter inputs and mineral fertilization, e.g. N). This work has produced a database that characterizes more than 42 taxonomic groups of invertebrates and associated site variables (cropping system, management practices, season, climate region, soil type, depth, etc.).

FAO considers this macrofauna database a useful and unique source of information to build on practical indicators and index on macrofauna and has committed support for the further analysis of the database. Further analyses of these results promise the identification of groups that are specific indicators for a given type of system, including development of an index, considering a set of variables. Further analysis and validation is needed in order to consider the application limits and the standardization of such indices and potential macrofauna indicators. The aim is to make findings available in a practical guideline for farmers and technicians showing linkages between specific organisms, management and beneficial or detrimental effects on soil and plant health. This guideline will then be integrated into a manual on soil productivity improvement. The need to keep this database up-to-date was also raised.

(Patrick Lavelle, International Biodiversity Observation Year (IBOY) – Macrofauna Network)

Case 3 – Methods for assessment of soil health or quality focusing on a case in Bhutan

A simple method for farmer assessment of overall biological activity of the soil and soil health has been tested in Bhutan and Kenya. This method is based on soil respiration (oxygen uptake or carbon dioxide production). It provides information on soil life activity, and can provide the basis for management decisions and for raising farmer awareness about the living nature of soils. A laboratory or field respirometer provides a measure of biological activity, nutrient mineralization, toxicity of chemicals to soil organisms and management effects. In addition to chemical and physical measures, soil respiration as a biological measure is included in the soil-quality test kit. There is a need to consider temporal and spatial changes and environmental conditions (temperature and moisture) and to measure them at comparable points in the crop cycle. Various soil test kits are available for such measurements. For example, the Solvita soil life kit indicates soil respiration by a colour indicator (http://www.solvita.co.uk/). It enables estimation of annual N release based on soil biological activity, evaluation of organic matter sufficiency of soils and overall judgements for 'soil quality' interpretation. This test procedure is as reliable as laboratory test methods and is currently the only alternative to more expensive Dräger tube procedures used in some soil investigations (US$125 excluding VAT for 12 test pack, US$97 for refill). The USDA Soil Quality Test Kit Guide (an 82-page booklet) contains procedures for 12 on-farm tests, interpretation, data recording sheets and details on how to build the kit. It can also be purchased (US$500) including initial supplies for tests of soil respiration using the Dräger tube, as well as salinity, aggregate stability, soil structure, infiltration, pH, earthworms, soil texture, bulk density, soil nitrate, compaction, water quality (http://soils.usda.gov.sqi/). However, these kits focus largely on chemical analysis.

(Martin Wood, University of Reading, The United Kingdom)

These three case studies stimulated discussion by the working group on several ideas and approaches regarding: sampling and measurement methodologies; 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 in the process of using soil health indicators. Special attention was given to methods and sampling procedures and tools. Problems in using soil organisms and their diversity as indicators of soil health include the inherent temporal and spatial heterogeneity of soil organism populations and the unpredictable interaction of soil organisms with climate factors. More comprehensive information on the impacts of different land management practices should be provided. Such information should complement information on soil organisms with other soil biological measures such as plant species and diversity, leaf litter, plant rooting system, and soil organic matter contents throughout the soil profile. Sampling scale and frequency thus affect cost and reliability. Soil bioindicators need to be robust and meaningful, and easy to measure and interpret. Work is needed to confirm which indicators, which types of organism and/or which soil biodiversity functions have these characteristics, in which environments they are reliable and how they can be monitored and the findings interpreted.

For sustainable and productive land management, soil organic matter is a critical factor in most soil types and agro-ecosystems. This is because it reflects not only soil C but also soil moisture retention, nutrient availability, resilience to erosion and the substrate for most soil biological activity. In recent years, increased attention has focused on methods of monitoring soil organic matter or soil C. This has been because of the recognition of the importance of C sequestration in soils to reducing or mitigating greenhouse gas emissions and in response to the Kyoto Protocol of the framework convention on climate change (including offsetting greenhouse gas emissions in other areas under the carbon trading mechanism).

Adaptive management for enhanced soil productivity and restoration

Dr Lijbert Brussaard introduced the issue of adaptive management of soil ecosystems, referring to the proposals of Mr Kofi Annan, UN Secretary General, at the World Summit on Sustainable Development (WSSD, Johannesburg, 2002) and his emphasis on four issues: water and sanitation, energy, agricultural productivity, and biodiversity and ecosystem management, and his recognition of the importance of making knowledge and expertise work in order to achieve the sustainable development goals. Dr Brussaard emphasized the convergence of science and of inclusive technology innovation processes for better integrated crop and soil management. He noted the need to translate science into practice through identifying indicators of system performance that are useful for farmers and land managers in assessing the economic, ecological, environmental and social impacts of their management practices and land use systems. Annex 7 provides further information on the ecosystem approach and its links to adaptive management.

The introduction was followed by a range of case studies on adaptive management. These included: technology innovation for integrated soil and crop management; biodynamic agriculture for desert reclamation; biofertilizers for mixed agriculture in the humid tropics; no-till agriculture for smallholder cropping; integrated pest and nutrition management for (i) armyworm control and (ii) nematode control; the role of soil macrofauna in soil rehabilitation in drylands; interaction between field and landscape levels in regard to conservation, sustainable use and ecosystem services; the use of vermicompost to enhance soil fertility (commercial tea production and horticulture) and the need for a communication and extension strategy for technology transfer; the importance of human dimensions of ecosystems, notably institutions and sociocultural processes and consideration of economic returns and valuing of ecosystem services. Such cases provide information that can be shared as a basis for technology transfer and improved management decisions.

Case 4 – Adaptive management and technology innovation in Mindanao, Philippines

Research on technology innovation processes for more integrated crop and soil management is being conducted through collaboration between the North-South Interdisciplinary Research and Education Fund (INREF), Wageningen, the Directorate General for International Cooperation, The Netherlands (DGIS-NET) and the FAO IPM Facility. In Mindanao, the biodiversity research programme was conducted along a landscape gradient from upland through lowland to coastal areas. It was found that agro-ecological innovations emerge from interactions among actors with potentially complementary roles, especially in marginal areas, where rural people rely on variety and variability and are active in managing the adaptation process. The process of acquiring and sharing information between the private and public sectors is very important and depends on the incentive regime, which will tend to favour certain approaches. Change is stimulated by non-satisfied needs of farmers and identification of options and experimentation to address these needs or problems.

(Lijbert Brussaard, Wageningen University, The Netherlands)

Case 5 – Biodynamic agriculture for reclamation and cotton production in Egypt

This programme has been extremely successful in reclaiming desert land for agriculture. Through regional cooperation among many actors, farmers and agricultural engineers receive training on the importance of micro-organisms for developing soil fertility. Farmers experience the importance of organic matter and compost (referred to as ‘black gold’) for organic farming and receive training in organic matter management and compost preparation (from small-scale to industrial systems) using agricultural waste and animal manure. Results include over 2 200 ha of biodynamically certified desert locations at the margins of the Nile Valley and elsewhere. The approach is strongly market oriented for the production of organic cotton, medicinal herbs and vegetables. Cotton has recently been intercropped successfully with basil and lemon grass. The project and connected smallholders are following international standards for organic agriculture (the European Community (EC), National Organic Program and Demeter). The added value fulfils standards of European Good Agricultural Practice, and Hazard Analysis and Critical Control Point. The project has recently received the Fair Trade Label award for some of its commodities.

Another network (not presented at Londrina) on organic matter management is the interdisciplinary group on the Management of Organic Inputs in Soils of the Tropics (MOIST), coordinated by Cornell University International Institute for Food, Agriculture and Development, The United States of America. The MOIST was set up to investigate and exchange information on cover crops, green manures, managed fallows and mulches in tropical farming systems. The aim is to optimize the management of organic inputs for harnessing the biological potential of legumes, manures, residues, and soil fauna in order to improve and sustain evolving agricultural systems in Asia, Africa and Latin America. It has developed searchable databases and encourages interregional exchange through seminars, electronic networking and extension materials (http://ppathw3.cals.cornell.edu/mba_project/moist/home2.html).

(Klaus Merckens, Vitality from the Sun (SEKEM): Egyptian Biodynamic Association (EBDA))

Case 6 – Biofertilizers – arbuscular mycorrhizal fungi and *Rhizobium* bacteria – for mixed agriculture in Cuba

This work illustrates the commercial production, trials and extension and adoption of arbuscular mycorrhizal fungi (AMF) inoculants by farmers in Cuba. These aim to overcome problems of soil productivity and yield declines, economic constraints and lack of fertilizers. Practical research was conducted with farmers on the application of AMF, including on-farm trials with many crops (such as coffee, rice, vegetables and soybean) and on different soil types. Capacities are strengthened through agro-ecological fairs, education and extension. Improved organic matter management is central to the functioning of the techniques.

(Eolia Treto, Instituto Nacional de Ciencias Agrícolas)

Case 7 – No-till agriculture for smallholder cropping in Brazil

The exemplary case of the farmer-driven process for the development and adoption of no-till agriculture in Brazil was outlined. A series of damaging frosts catalysed the replacement of coffee systems by annuals and especially monocultures of sorghum and soybean, which led to serious soil and water erosion and nutrient depletion. Initially, physical solutions were sought in the 1970s, until pioneer farmers, such as Herbert Bratz in Londrina, initiated experimentation with no-tillage practices. Research and extension initially criticized the spontaneous adoption of no-tillage agriculture by other farmers. However, after 30 years the no-tillage practices are being applied to millions of hectares of soybean, cotton, maize and sorghum with a range of cover crops (lupin, vetch, *Crotalaria*, pigeon pea, sorghum, pearl millet, *Mucuna*, etc.). Good practices of no-till farming provide higher yields through improved organic matter management and allelopathic effects of certain cover crops. An enabling environment is required to catalyse adoption, alleviate risk and promote stewardship and responsibility for the land. The Friends of the Land (earthworm) Club helps raise awareness of environmental concerns of urban and peri-urban consumers and community organizations. A dynamic collaborative process among farmers, extension (IAPAR) and research (EMBRAPA) combined with a supportive environment (farmer-extension-policy) has stimulated adoption by smallholders. (Care is required in interpreting these results as a smallholder farm in Brazil may be 40 ha, whereas a smallholder farm in Asia or Africa may be 0.5-1 ha).

(Ademir Calegari, Agronomic Institute of Paraná (IAPAR), Brazil)

Case 8 – A case of the transition of a renowned coffee growing area

The transition from coffee was initially to macadamia and sugar-cane production, and subsequently to degraded pasture, which was accompanied by a serious rural exodus. This case illustrated the critical issue of economic returns. Where a farming system becomes non-viable, farmers shift enterprises or even abandon farming, with resulting loss of rural economies and livelihoods. In addition to the primary agricultural goals of increased farm produce and sustained productivity, there is a growing need to better illustrate the value of ecosystem services and social and cultural benefits provided by sustainable agriculture. Thus, improved technologies, such as biological nitrogen fixation (BNF) to improve productivity, need to combine with business and environmental management, including the adequate valuation of the ecosystem services provided by farmers.

(Patrick Lavelle)

Case 9 – Selection of legumes that produce beneficial plant flavonoids for various functions

This case illustrated how plant flavonoids can suppress weeds, pathogens and pests, and promote nodulation and nutrient cycling. Flavonoids have been shown to promote microbial growth and induce *nod* genes in root nodule bacteria, to provide antibiotic molecules against insect pests and pathogens and suppress certain weeds such as the parasitic *Striga*. They also mobilize unavailable magnesium (Mg), calcium (Ca) and phosphorous (P) in alkaline soils as shown by the aluminium (Al) concentration in the cluster roots. These non-N-fixing benefits of nodulated legumes are greatest in cowpea, less in soybean and still less in common bean.

(Felix Dakora, University of Cape Town, South Africa)

Case 10 – Integrated pest management and biomass management for managing *Helicoverpa armigera* (pod borer) and enhanced productivity in Asia

Through a number of examples, this case emphasized how biomass is the engine for crop productivity and why balanced plant nutrition is crucial for enhanced productivity. The burning of rice- and wheat-straw in much of Southeast Asia (Viet Nam, Philippines, Indonesia and India) has been causing huge losses. Alternatives such as composting are available, depending on conditions. For example, a period of 35-45 days is required to compost dry straw in semi-arid conditions. There is a need to identify appropriate practices for use by cash-poor farmers and to integrate a range of low-cost practices, e.g. no-till with surface mulch, crop rotations and pest-tolerant cultivars. In addition, it is possible to be proactive, for example, seeding the soil with natural allies/beneficial micro-organisms and spraying crops with biopesticides as a prophylactic measure. There are important interactions between plant nutrition and pest management. For example, an increase in soluble N and free protein amino acids in the plant tissues, especially leaves, increases the risk of pest damage.

(O.P. Rupela, International Crops Research Institute for the Semi-Arid Topics [ICRISAT])

Case 11 – Plant parasitic nematodes associated with common bean: an integrated management approach in Kenya

his study illustrated several strategies developed to control root-knot nematode on beans (*Phaseolus vulgaris L.*). The common bean is the most important legume crop in Kenya and the major constraint on bean production is nematode infection, causing yield losses of up to 60 percent. This case demonstrated the potential of organic amendments (chicken manure, compost, neem leaves, baobab remains and farmyard manure) to suppress root-knot nematodes and to increase bean yield in field conditions. The amendments showed varying levels of nematode suppression, with chicken manure ranking as the most effective. In addition, locally isolated *Bacillus* strains showed potential for use as biocontrol agents of root-knot nematodes. 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 produces metabolites that are toxic to the nematodes.

(Nancy Karanja, University of Nairobi, in absentia)

Case 12 – Role of termites in the soil rehabilitation process in Burkina Faso

The main purpose of this work was to evaluate the capacity of termites to improve the structure of crusted soils, including their ability to reduce soil compaction, increase soil porosity, and improve the water infiltration and retention capabilities of soils in the Sahel. The stimulation of soil fauna, especially termites, using locally available organic resources (straw, wood materials and manure) is a viable option for improving soil structure in semi-arid regions. Mulch application should be timed to coincide optimally with termite foraging periods, and should anticipate seasonal rainfall events, thereby allowing nutrient release to be better synchronized with plant growth demand. The restoration of a bare sealed soil with very high runoff rates could be seen through measuring pore numbers per square metre of soil surface. This study demonstrated that termites restored crusted Sahelian soils successfully when their bioturbating and decomposing activities were managed properly by careful organic matter additions.

(Abdoulaye Mando, Institut pour l'Environnement et la Recherche Agricole, Institut de Recherche pour le Developpement (IRD), France)

Case 13 – Use of vermicompost with a focus on tea plantations in India

The purpose of this study was to restore soil fertility and improve tea production on six private tea estates in Tamil Nadu, India, using organic matter and earthworms. Trenching prunings, organic material, and earthworms between tea rows (bio-organic fertilization, or FBO) increased yields and profits dramatically and determined that FBO is an affordable tool, adaptable to situational needs and appropriate to commercial management scales from small farms to plantations. The major components of this technological package include: large-scale vermiculture production; adaptable management practices; rearing different functional types of earthworms for inoculation; selecting and placing organic matter by quality and quantity criteria. The current adoption of FBO techniques in very large-scale applications in India can already ensure positive responses of up to 50 percent enhancement in production. Based on the results obtained using FBO, a patent was deposited to protect the technique associated with this treatment. The patent, titled "Fertilization Bio-Organique dans les Plantations Arborees", was developed by Parry Agro Industries Ltd. in association with the IRD and Sambalpur University. The patent document (ref. PCT/FR97/01363) provides details of the methodology for its application.

(Bikram K. Senapati, University of Sambalpur, India)

Case 14 – Use of vermicompost to reduce soil Al toxicity in Brazil

This was a case of technology adoption failure. To reduce Al toxicity, sawdust was inoculated with earthworms. This reduced Al toxicity effectively (from 85 to 45 percent exchangeable Al) and improved the cation exchange capacity (CEC) through the extraction of Ca and Mg cations. The technique was used successfully in urban horticulture for the production of tomatoes. However, in Brazil, the promising technology of processing sawdust through earthworm inoculation and use of chicken slurry, although of proven value, did not lead to adoption by the end user. The lack of adoption was believed to be because of an inadequate extension and communication strategy.

(Patrick Lavelle, IRD, France)

Case 15 – Conservation and sustainable use of soil biodiversity

This study showed the interaction between field and watershed levels. The strategy to restore the ecosystem was based 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 soil biota. The application of different technologies that increase available moisture through diversified plant management on a soil protected by litter and rooting network demonstrated how to improve soil biodiversity, biotic activity and ecosystem services.

(Odo Primavesi, Brazil)

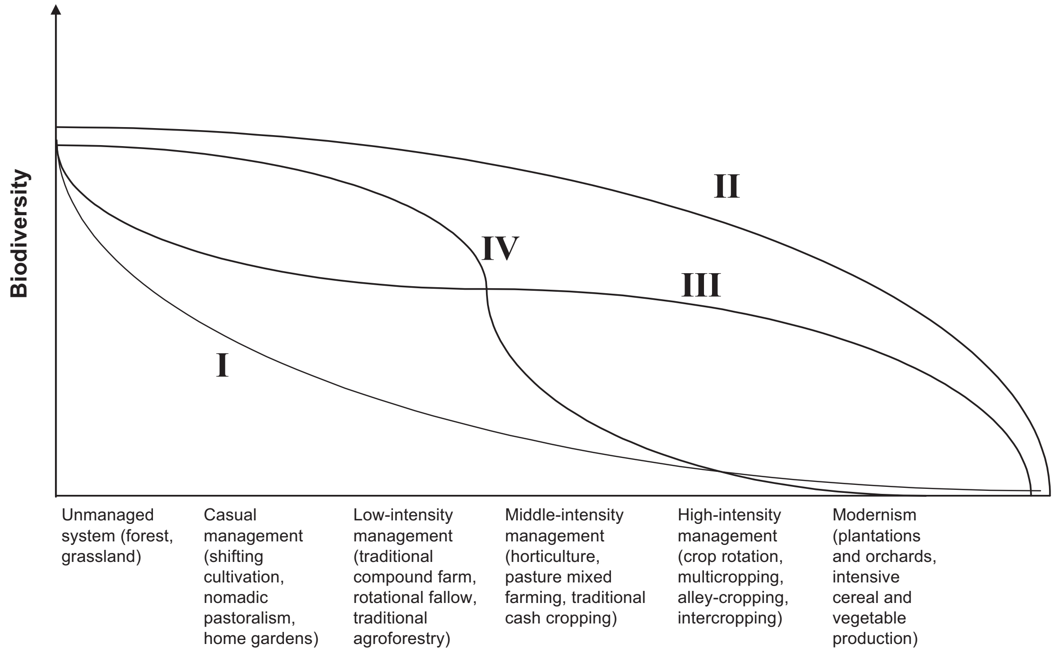
Case 16 – Adaptive management for redeveloping traditional ecosystems

This case emphasized the immeasurable variations of production systems and species diversity and managed landscapes, which comprise a range of human and natural ecosystem types. The relationship between biodiversity level and management level for a range of systems from plantations to mixed systems and unmanaged systems was considered (Figure 1). In Figure 1, Curve I and Curve II represent two extreme possibilities that seem to be unlikely. Curve III is a softer version of ecologists' expectations. Curve IV seems to be more likely and it is the most interesting from the point of view of biodiversity conservation. Efforts for the sustainable development of these traditional agro-ecosystems should be based on conserving agricultural biodiversity within the system for resilience of the system with concerns for productivity.

This case highlighted the fact that there is no direct relationship between population and land degradation. The importance of institutions and socio-economic and sociocultural processes was emphasized, as well as their interaction with the ecological process.

Workshop participants considered the ongoing work and experiences presented through the above cases on biological management of soil ecosystems. They drew attention to the need to focus on farmers' needs and on the opportunities to address soil biodiversity as a key element of an integrated soil productivity and land management strategy. It was noted that, in agricultural development, soil knowledge has been restricted largely to soil management for production (crops, pasture, trees) with a focus on the biophysical (structure, texture, soil moisture, organic matter) and chemical dimensions (soil nutrients, salinity, pH, CEC). There is a need to identify and facilitate understanding and the transfer of knowledge on the functioning of the soil ecosystem, including the management of soil biodiversity and its functions, and its adaptation and use for sustainable and productive agriculture.

Figure 1
Biodiversity changes (four patterns) as related to agro-ecosystem types and intensity of management



Source: Swift *et al*. (1996).

In developing guidance for wider use on the basis of case studies, it was also recognized that there is a need to consider, *inter alia*: the type of farming system and level of intensification, the agro-ecological zone and the scale of intervention in space (farm, community, watershed) and time (growing season to several years). There is a need to identify the range of stakeholders and to provide practical tools and approaches that link soil quality and health with agricultural productivity and socio-economic considerations (integrated ecosystem approaches). These issues could be reflected in the revised format for the presentation of case studies.

An important consideration for agricultural productivity is the capacity to maintain and restore soil productivity, through nutrient cycling, under different land use and agro-ecological contexts. It is a misconception that the addition of organic matter leads automatically to improved soil structure. In reality, in a lifeless soil, organic matter persists unprocessed, offering little in the way of benefits until the biological components are able to thrive again. Improved soil structure is a consequence of the physical and chemical activity of soil organisms, including their processing of the organic matter through decomposition, and the delivery of available nutrients to the plant or crop.

Farmers may focus on soil biodiversity improvement through manipulations of organic inputs to improve soil fertility in their farming systems, obtain greater incomes and increase their livelihoods. Researchers should work together with farmers towards improvement of ongoing farmer initiatives for crop yield and soil productivity improvement as an immediate strategy for soil biodiversity improvement. Moreover, in order to achieve rapid development and dissemination of biodiversity conservation and management technologies, farmers must be empowered fully to train other farmers using their successful models, while researchers must work to improve existing farmer interventions (contribution from Fidelis Kaihura, Tanzania Coordinator, People, Land Management and Environmental Change (PLEC)).

Raised awareness and increased sharing of information and knowledge are necessary to strengthen farmers' capability for the biological management of soil ecosystems. In particular, such knowledge should help them make decisions and evaluate the effects of their land management practices in regard to the effective use of soil life and sustainable management.

(P.S. Ramakrishnan, Jawaharlal Nehru University, India)

Capacity building for integrated soil biological and ecosystem management

A range of case studies illustrated the needs for capacity building for agricultural education through farmer-centred training programmes that include soil ecology and soil biological management. Examples of capacity building included: a farmer-centred natural resources management approach in Latin America; a global below-ground biodiversity research and networking project; an organic resources database to guide the selection and management of organic inputs; the piloting of farmer field school (FFS) approaches for soil productivity improvement in Africa, and a regional network for promoting conservation agriculture in Africa.

Case 17 – Capacity building tools and methods for improving knowledge and skills in biological management of soil fertility by farming communities

Drawing on experience in Ecuador, it was noted that soil biological considerations are not considered in the agricultural education process and that soil microbiology and agro-ecology should be integrated into university curricula. There is also a need to bring about a policy change in order to promote more integrated agricultural approaches and to lobby governments that fertilizers are not the solution for sustaining yields. Workshop participants agreed that these are widespread problems. CAMAREN, a consortium for natural resources management training and capacity building processes in Ecuador, uses a step-by-step methodology. The process starts with a week of fieldwork for problem diagnosis, sharing experiences and visits in the field, and interaction with farmers to learn of indigenous knowledge and practices. This is followed by the development of a theoretical framework through group work and interaction in the classroom and, finally, practical work and capacity building throughout the season. This methodology, based on a farmer-centred approach, has contributed effectively to the development of sustainable agricultural practices in several regions in Ecuador. There is an opportunity to improve the work of CAMAREN by enhancing training on biological management of soil fertility, e.g. through training trainers on soil ecology, exchange of expertise, improving regional and national collaboration, etc.

(Gustavo Bernal, National Institute of Agricultural Research, and Rusvel Rios, CAMAREN)

Case 18 – The Global Environment Fund (GEF) - TSBF BGBD Network project on the conservation and sustainable management of below-ground biodiversity

The Below-ground Biodiversity (BGBD) project is an important contribution to assessment and adaptive management. It has recently been launched in Brazil, Mexico, Côte d'Ivoire, Uganda, Kenya, India and Indonesia. The objective 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 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 with simultaneous gains in sustainable agricultural production. The expected project outcomes are:

- internationally accepted standard methods for the characterization and evaluation of BGBD, including a set of indicators for BGBD loss;
- inventory and evaluation of BGBD in benchmark sites representing a range of globally significant ecosystems and land uses;
- a global information exchange network for BGBD;
- sustainable and replicable management practices for BGBD conservation identified and implemented in pilot demonstration sites in representative tropical forest landscapes in seven countries;
- recommendations on alternative land use practices, and an advisory support system for policies that will enhance the conservation of BGBD;
- improved capacity of all relevant institutions and stakeholders to implement conservation and management of BGBD in a sustainable and efficient manner.

The BGBD project strategy recognizes that soil biota require selective study because there is no single method for studying soil biodiversity and it is not possible to study simultaneously all functional groups: macrofauna/ecosystem engineers, e.g. termites and earthworms; microregulators, e.g. nematodes; microsymbionts, e.g. mycorrhiza, rhizobia; soil-borne pests and diseases, e.g. fungi, invertebrates; C and nutrient transformers, e.g. methanogens, nitrifiers; and decomposers, e.g. cellulose degraders. Benchmark sites will be established to represent a gradient of land use intensification. The forest system will be taken as a baseline for the inventory and BGBD evaluation, using site selection criteria and site characterization and participatory assessment processes.

The BGBD partnership project provides an important basis for coordinating further research work in developing countries with a view to its practical application for agricultural development. It will address the two main pathways of soil biological management: (i) direct biological control by inoculation, or genetic manipulation; and (ii) indirect ecological control by manipulation of the cropping system, the plant, organic matter and the environment. A range of soil biotechnologies will be considered, including the use of: *Rhizobium* for N_2 fixation, mycorrhiza for nutrient uptake, biological control for plant health, rhizobacteria for plant growth, decomposers for nutrient use, and macrofauna for soil structure. Cropping system designs favouring BGBD will be identified, including the link between diversity above- and below-ground and emphasizing the central role of soil organic matter. A range of optional management practices for soil conservation and enhancement of soil organic matter and soil biodiversity will be assessed such as: intercropping, legume cover crops, agroforestry, conservation tillage, livestock linkages and farmyard manure. Soil-based ecosystem services will also be addressed, including: nutrient cycles; gas exchange and climate regulation; hydrological flows and water supply; and biological control of pests.

(George Brown, on behalf of Mike Swift, TSBF Coordinator, in coordination with Fátima Guimarães, BGBD Project Brazil)

Case 19 – The organic resources database

This database, prepared by the TSBF and the University of Wye, the United Kingdom, is available through a Web site and on diskette. This database was recognized as a valuable tool. It comprises over 250 different organic materials characterized by a range of standard methods and parameters: N, P, potassium (K), Ca, lignin, polyphenols; soil and climate; decomposition and digestibility. It illustrates how N-release patterns and fertilizer equivalency values, and thus crop responses, are determined by organic resource type and quality as well as by climate and soil biodiversity. Guidelines are available for the selection and management of organic inputs through direct incorporation, mixing with fertilizers and other materials, or surface application (http://www.wye.ac.uk/sme/projects/soil/ord2.htm).

Case 20 – Use of farmer field schools for soil productivity improvement (FFS-SPI)

The FFS process was developed for IPM in Asia, replicated successfully across many regions and expanded to include production considerations. FAO is adapting the FFS process with partners in Uganda, Tanzania and Zimbabwe to promote farmer experimentation on techniques and options for soil productivity improvement (Plate 2). A curriculum and training materials are being developed for soil productivity improvement (SPI) and the approach is being piloted through training of trainers (farmers and extensionists) and adapted to local farming systems and contexts. Involvement of national agricultural research, extension, university and a range of projects is expected to lead to its wider adoption and adaptation to other farming systems. The TSBF is a partner and the Rockefeller Foundation is providing funding support. The farmer-driven approach is based on participatory diagnosis of constraints and opportunities and adapted training curricula. It is expected to facilitate rapid expansion by building on experiences. Conservation agriculture approaches including no-till, cover crops and crop rotations are being introduced among the various options for soil productivity improvement. This is expected to include a focus on soil biological management when training materials become available. A joint workshop for partners (February/March 2003) is intended to build on lessons learned in the development of a wider programme for sub-Saharan Africa (http://www.fao.org/landandwater/agll/farmspi/).

(Sally Bunning, Land and Water Development Division, FAO)

Plate 2
Extensionists participating in a farmer field school – soil productivity improvement (FFS-SPI) process in East Africa
[S. Bunning]

Case 21 – The African Conservation Tillage network

The African Conservation Tillage (ACT) network facilitates information exchange and the sharing of experiences of the introduction of conservation agriculture approaches, including expertise, equipment and tools adaptation, soil management and cropping systems and cover crop selection and adaptation (www.fao.org/act-network or e-mail: actsecre@ies.uz.ac.zw). The ACT is supported by FAO, the German Technical Cooperation Organization (GTZ) and other partners. It also benefits from experiences in other regions, for example, through South-South cooperation with experts from Brazil. In order to facilitate a multistakeholder process, several workshops have been organized: mechanization (Jinja, Uganda 2002), and training at extension and technical levels (Harare, 2000 and Zambia, 2002).

Ademir Calegari emphasized that the success behind no-tillage in Brazil was the wise selection of cover crops including properties to suppress diseases. In Africa, as farmers need to produce food and cash crops, it may be difficult to convince farmers of the need for cover crops. One can start with crop residues as surface mulch while researching solutions that demonstrate clear economic, social and environmental benefits. This illustrates the importance of research-farmer interaction as well as an enabling environment (germplasm, seeds, tools, etc.).

These cases illustrated the importance of using existing tools and methods and of ensuring participatory approaches for introducing soil biological management as a means of addressing low and declining productivity and soil degradation. Through close collaboration with the seven country teams, the TSBF BGBD Network project will provide an important base of research and expertise for further development of the Soil Biodiversity Initiative (SBI). The results from this project could be disseminated and built on in other countries through effective collaboration and partnerships.

(Richard Fowler)

Research and innovation in soil biological understanding and application

This theme was covered by four presentations on: innovative methods for monitoring soil biological activity and pest-pathogen interactions; the link between soil biological activity, sustainable land use systems and C sequestration; the proposed research programme of the Consultative Group for International Agricultural Research (CGIAR) system for the promotion of BNF; and soil and water conservation in the Sahel through enhanced biomass production.

Case 22 – Innovative methods for monitoring soil biological activity and pest-pathogen interactions

The challenges involved in the measurement and manipulation of soil biodiversity are considerable, but measurement is essential to managing manipulation. For some groups of organisms, 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 the measurement and characterization of soil biodiversity. Techniques that are well established for bacteria, such as differential gradient gel electrophoresis (DGGE) of DNA profiles extracted from soil, are starting to be used for fungi and have potential for diversity measurement in other important organism groups as well. Molecular methods can also detect particular species such as pathogens, and are potentially much more reliable than traditional baiting or isolation techniques. Modern and traditional tools can combine to give a more complete picture of soil biodiversity. These techniques can help measure differences in soil biodiversity following perturbations or changes in management practices, and help understand the relationship between pest or pathogen levels and saprobic competitors. There is evidence that agricultural practices that promote saprobic fungal diversity and biomass also lead to a reduction in pest and pathogen problems, especially in the seedling establishment stage. 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.

(Paul Cannon, CAB International [CABI])

Case 23 – Soil biological activity and C sequestration with a focus on no-tillage systems in Brazil

Climate change predictions suggest a temperature rise of 2–4 percent and changes in rainfall. What are the implications on soil carbon stocks and dynamics? Dr Lal illustrated the important impact of soil aggregation by earthworms on soil organic C and the close relationship between soil biodiversity and C sequestration (Plate 3). Hence, there is a need to enhance soil biological activity through improved management practices. Agriculture manipulates soil C through uptake (C_U), fixation (C_F), emissions (C_E) and transfer (C_T), where $C_U + C_F = C_E + C_T$. When decomposed, organic residues provide CO_2 (60-80 percent) and complex humic compounds (10-30 percent) which are more stable at depth (a 0.1-percent change in soil organic C is equivalent to 1 ppm atmospheric C). A no-till system can optimize soil organic C through the return of crop residues to the soil, cover crops and precise use of external inputs and water. There are hidden C costs in conventional tillage through residue removal, erosion from bare fallow or poor crop cover, emissions in fertilizer manufacture (0.86 kg C/kg N fertilizer), and pesticides. Carbon sequestration requires more sustainable agriculture and land use systems including conservation agriculture approaches, grazing land management and erosion control. This is so that soil degradation trends are reversed, soil quality and resilience improved, biomass production increased, and the rate of enrichment of atmospheric concentration of greenhouse gases decreased.

Plate 3
Gallery of an anecic earthworm from the Colombian "Llanos" filled with casts, the upper part having been split by a smaller endogeic earthworm species. Root development is enhanced and the implications of this process in C sequestration warrant further consideration
[P. Lavelle]

(Rattan Lal, University of Ohio, The United States of America)

Case 24 – CGIAR Challenge Programme on Biological Nitrogen Fixation (CP-BNF)

This research programme was proposed in 2002 on the basis of a stakeholder workshop (Montpellier, 2001) (http://www.icrisat.org/bnf/Reports.htm). It was expected to involve several CGIAR centres, international agricultural research centres (IARCs), NGOs, national agricultural research organization (NARs), and international BNF networks in the development of global strategies for the promotion of BNF technologies and the enhancement of soil fertility, focusing on the most vulnerable agro-ecosystems. One of its objectives is to enhance and sustain soil fertility through the development and adoption of integrated nutrient management practices and appropriate BNF technologies. The research programme would develop holistic strategies that combine appropriate technologies and policy options aimed at narrowing the soil fertility gap with a better understanding of the main biophysical and socio-economic factors and constraints. It was expected to foster scientific and technological cooperation between developing countries and leading research institutions, which are developing most of the innovative technologies. The development and adoption of new options of sustainable soil fertility management would also result in increased crop productivity and would help the resource farmers of developing countries to improve their livelihood. Although the programme was not retained as a CGIAR priority, a number of research bodies and CGIAR centres in collaboration with FAO are still soliciting funding support to promote BNF in Central and South America and East and West Africa.

(Rachid Serraj, ICRISAT)

Case 25 – Soil and water conservation research in Burkina Faso

Mention was made of the approach of a soil and water conservation research project in the Central Plateau, Burkina Faso, supported by the International Fund for Agricultural Development (IFAD) with several partners. It focuses on enhancing biomass through the use of local species, water harvesting with stone bunds, and raising awareness of the need to regenerate the primary production process.

(Abdoulaye Mando, Institut pour l'Environnement et la Recherche Agricole [INERA])

These capacity-building case studies illustrated two important points. First, the development of research and training capacities to jointly address critical economic, social and environmental issues is essential for the transition to sustainable development. Such integrated scientific and training capacities can help countries better understand their current situation and devise effective responses to meet future challenges. Scientific research may be global in scope but its applications work best when tailored to national and subnational settings. Second, coordinated efforts through the strengthening of South-South and North-South institutional partnerships would help foster the mobility of scientists and technologists as part of a larger strategy for promoting the exchange of knowledge and experiences to advance the transition towards sustainable development.

One aspect that was not well highlighted in the Londrina case studies was the use of improved understanding of soil biodiversity and soil ecosystem functioning for influencing policy. A good example is provided by BIODEPTH, a pan-European experiment investigating the impacts of biodiversity on ecosystem function in model grassland systems. It has yielded powerful data and results supporting the importance of biodiversity for providing ecosystem energy flow with implications for European environmental policy on grasslands management. Small meadow plots were created by exterminating existing plants and seed bank and then sowing wildflower and grass seeds (constant seed rate) in different species mixtures. The highest diversity of sowing was based on local species richness, with five levels of diversity reducing richness down to single species monocultures. This mimicked the gradual extinction of plant species from grasslands. Energy flow was monitored by measuring ecosystem processes, such as plant growth (above-ground and rooting) and harvest yield (productivity); breakdown of dead leaves (decomposition); and nutrient amounts in plants and soils (recycling and retention). After the establishment year, over the first two years of the experiment, a clear relationship was found between reduced ecosystem function and reduced species diversity for a wide range of ecosystem processes (across all eight field sites with different climate, soil and plant types). Table 1 shows the initial analysis of this research.

Table 1
Initial results of BIODEPTH research on the effects of biodiversity loss on ecosystem function in model grassland systems

Ecosystem process response to declining biodiversity	Environmental implications and policy relevance
Plant productivity Decrease in above-ground biomass production, plant canopy architecture and below-ground root production	**Agricultural sustainability** Reduced harvest yields of low-input agriculture Implications on sustainable nutrient and water use
Nutrient dynamics Decrease in N retention in plant biomass and soil nutrients Increase in soil nitrate leaching and varied affect on soil moisture	**Ecosystem sustainability** Reduced agricultural productivity and N sequestering Reduced groundwater quality and reduced drought resistance and reduction of runoff
Decomposition processes Not clear response of plant litter, cellulose, cotton methods	**Ecosystem sustainability** Longer term studies necessary
Plant community dynamics Increase in community invasibility by weeds and in plant parasites and fungal pathogens	**Agricultural sustainability** Reduced resistance to weed/alien invasion and to crop pests
Soil microbial dynamics Decrease in soil respiration, soil microbial biomass, bacterial functional diversity/activity and mycorrhizae (root fungi)	**Global change** Reduced C sequestering and energy flow, reduced plant-soil interactions and N sequestering
Invertebrate communities No clear response to above- and below-ground invertebrate diversity Varied response to abundance of different invertebrate groups and to above-ground herbivore damage	**Biodiversity conservation and resilience** Possible relationship with nutrient cycling and food web dynamics

Source: Extracted from: http://www.cpb.bio.ic.ac.uk/BIODEPTH/.

Chapter 3
Workshop discussions and findings on improving understanding and management of soil biodiversity and ecosystems for productive and sustainable agriculture

Soil biodiversity understanding, status and trends

Biological indicators of soil health

The workshop participants agreed on the need for technical assessments to advise farmers, policy-makers and planners on indicators and methods for the assessment and monitoring of soil health and functions. These should focus on improving knowledge: 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.

In order to facilitate comparison at many scales, it is important to agree on and adopt standardized approaches to the use of soil health indicators. Currently, standard methodology is used for most bioindicator measurements (e.g. microbial biomass) but sampling strategies may vary (e.g. depth of soil used for sample collection). Basic requirements for the development of specific bioindicators would be:

- relevance to basic attributes of soil function;
- response to management in acceptable timeframes;
- ease of assessment or measurement;
- robust methodology with standardized sampling techniques;
- cost-effectiveness;
- compatibility with physical and chemical indicators of soil health.

Soil biotic systems are extremely complex, and assessment of soil health and ecosystem function by direct measurement of overall biodiversity is impractical. Therefore, the need to develop indirect assessment methods is compelling. In order to be practical for use by practitioners, extension workers, scientists and policy-makers, the set of basic soil health indicators should be applicable over a range of ecological and socio-economic situations.

Appropriate use of soil health indicators will depend to a large extent on how well these indicators are understood with respect to the ecosystem of which they are part. Tools and methodologies to measure soil health should be adapted to end users (Table 2). Tests should be able to measure properties of soil health that are meaningful to the actor's understanding of soil and its process, and to give results that are reliable, accurate within an acceptable range, and easily understood and used.

Plate 4
An endo-anecic earthworm from the Colombian savannahs, Carimagua
[J.J. Jiménez]

Plate 5
Termite mound from Africa
[C. Rouland]

Soil organism and biotic parameters, such as abundance, diversity, food web structure, and community stability, meet most of the criteria for useful indicators of soil quality. They respond sensitively to land management practices and climate. In addition, they correlate well with beneficial soil functions, including water storage, decomposition and nutrient cycling, detoxification of toxicants, and suppression of noxious organisms. Visible indicators such as earthworms (Plate 4), biogenic structures, e.g. termite mounds (Plate 5), insects and moulds are comprehensible and useful to farmers and other land managers, who are the ultimate stewards of soil quality. Several farmer-participatory programmes for managing soil quality have incorporated abiotic and simple biotic indicators.

The activities of soil organisms interact in a complex food web with some subsisting on living plants and animals (herbivores and predators), others on dead plant debris (detritivores), on fungi or on bacteria, and others living off but not consuming their hosts (parasites). 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, i.e. what to measure and how, when to measure it, and how to interpret changes in terms of soil function.

Table 2, prepared by workshop participants, summarizes the characteristics of potential soil health indicators required at different levels. It presents examples that end users can select and use in order to provide a suitable set of indicators of soil health according to local monitoring capacities. There is also a need to ensure that they are relevant to the given region, farming system, soil type, climate, etc.

Development of an assessment and monitoring framework

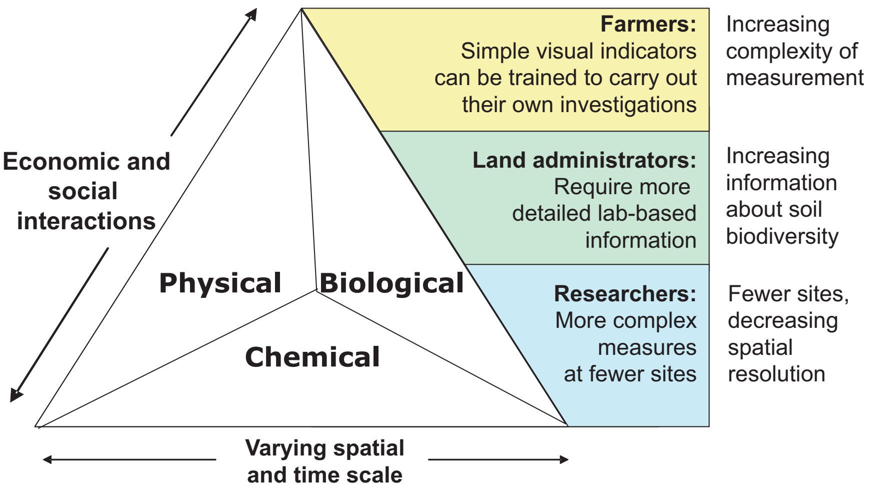
The identification of appropriate indicators of soil health assessment is complicated by the fact that they must account both for multiple dimensions of soil functions, such as productivity and environmental well-being, and the multiple physical, chemical and biological factors that control biogeochemical process, and their variation over time and space.

All of the soil parameters typically need to be measured simultaneously at a field site, although there can be gaps in the data if some analyses are not feasible or the facilities are not

TABLE 2
Practical tools for measuring soil health and their basic characteristics

Specific characteristic of soil health indicators for:			
Farmers	**Extension workers**	**Policy-makers**	**Researchers**
For use in the field: Self-assessed, easy and practical, based on visual indicators with interpretative guidelines relevant to region, farming system, soil type, climate, etc.	Visual indicators and simple low-cost field- and laboratory-based test kits that are easy to interpret	Minimum data set of soil health indicators, plus those associated with crop productivity and quality, environmental quality, off-site impacts, etc.	In-depth information on soil health, soil biodiversity, etc., including a range of laboratory-based indicators.
Practical examples of monitoring tools and indicators			
Nature of roots (density, morphology, colour, disease, depth). Decomposition of litter. Macrofauna, including indicators such as worm casts and pores. N-fixing organisms, e.g. legume root nodules. Plant population profiles (+ weeds). Smell and taste. Soil physical indicators, e.g. waterlogging and compaction.	Soil respiration measurement. Presence of pathogens (basic keys to symptoms). Soil pH, conductivity Total C/N ratio Microbial biomass. Nutrient levels. CEC. Physical indicators, e.g. bulk density, aggregate stability, and infiltration rate.	*Farm scale:* Percent of potential yield reached (based on water use efficiency). Farmer income, profitability. *Catchment scale:* Soil erosion. Depth of water table.	Enzyme activity (rapid techniques, e.g. BIOLOG) Molecular detection of mycorrhiza, biocontrol agents, etc. Molecular biodiversity assessments (e.g. DGGE of microbial populations). Nematode identification and assessment. DNA/RNA methods for detection of functional gene diversity (N-fixation, etc.)

FIGURE 2
Pyramid of soil health indicators



available. The database is most useful where the soil properties are analysed in conjunction with one another. Thus, it is more useful to have data on all soil properties at a single point, than to have separate databases of generalized properties.

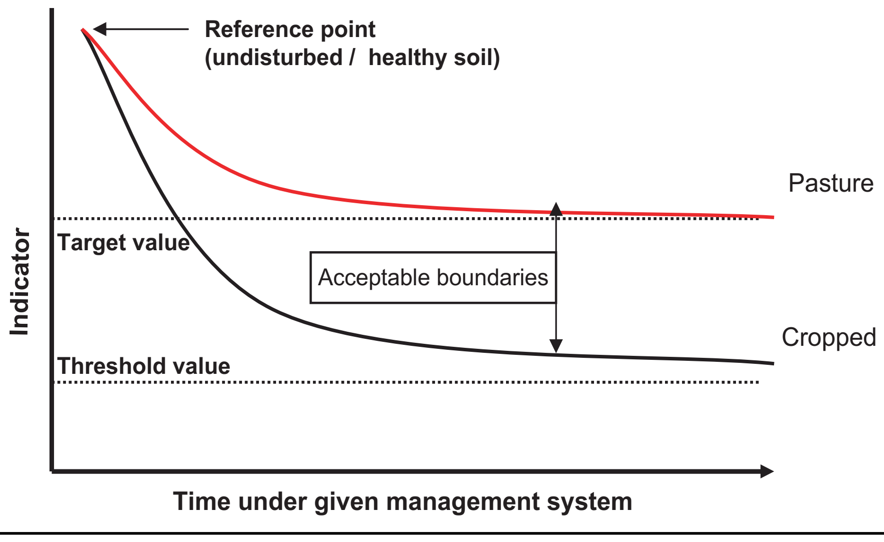
Figure 2 presents the suite of soil health assessments in the form of a pyramid, with three sides corresponding to biological, chemical and physical indicators. The top of the pyramid represents the group of simple indicators that farmers would use, linked to the more complex measures lower in the pyramid. The more technical indicators occur in the lower part, but may move up as protocols are simplified or surrogate indicators are developed. There is a decrease in spatial resolution and scale with increasing complexity of the indicators. Therefore, simple indicators higher up the pyramid (e.g. total C) will be more useful for stakeholders who require soil health information at more detailed scales.

Development of target values and thresholds

Soil biota are among the most diverse communities in the world. Soil organisms regulate a number of processes in terrestrial ecosystems that are critical for productivity and essential for maintaining ecosystem health. The loss of any biodiversity from the natural ecosystem levels should be regarded as detrimental. However, food security requires some degree of compromise even where sustainable practices are employed. Therefore, the potential for adopting target and threshold levels of biodiversity needs exploration. Data and information required for sustainability assessment are generally unavailable, sparse or incomplete. The continued development of nationally and internationally agreed methods of soil quality assessment is a priority. The group confirmed that, in view of the limited information currently available on sustainable levels of soil biodiversity, a major scientific and socio-economic research programme is justified. As illustrated in Figure 3 (prepared by the working group), determination of the direction and rate of trends would be important, and identification of those indicators that respond more rapidly than others (e.g. microbial or macrofaunal diversity, soil enzymes). The degree to which the TSBF BGBD project meets this need should be considered and complementary work proposed as appropriate.

Figure 3 shows a declining yield trend over a period of time under a consistent and continuous land management system, i.e. crops or pastures, indicating a gradual loss of soil health. Where the selected indicator or suite of indicators of a particular land management option falls below the threshold value, it can be considered as an indication of poor soil health. This threshold value is the lower limit of system performance. At this point, the land management system will become unsustainable and a high investment will be needed in the recovery of the degraded land (restoration of soil properties and function). The upper line is the optimal situation or target

Figure 3
Target values and thresholds for soil health indicators



value. It reflects the situation under a healthy pasture (deep rooting, good soil cover, etc.). In reality, the inputs and outputs vary over time (weeks, seasons and years) but should generally balance each other, so that the system oscillates between both limits, maintaining a relatively constant value.

In terms of sustainable land management, the threshold value may be considered as the level of a specific indicator beyond which the particular system of land management is no longer sustainable. However, the understanding of likely thresholds is not well developed except for a limited number of environmental indicators, such as soil acidity, nutrient status of P and K for a given soil type, and some biophysical indicators such as bulk density. It would be expecting too much for a single threshold value to represent the boundary or cutoff between sustainable and unsustainable. Consequently, a range of threshold values and temporal trends for particular indicators is required. Often, a combination of indicators may be needed.

Target values vary for different soils and for different land uses. Therefore, measurements of the indicators should be made over suitable time intervals using standard methodologies. Establishing acceptable trends requires appropriate methodologies and a common framework is essential to develop national and international standards for purposes of comparison. A key problem will be sample-to-sample variability. This will necessitate robust sampling and statistical analysis protocols if significant trends are to be discerned from a very noisy signal. The use of indicators of soil health helps to define the sustainability and health of the system (Pankhurst *et al*., 1997). There is a wide range of proposed soil health indicators. However, in terms of productivity, perhaps the best indicator relates to the yield trends under a given management system (Figure 3).

In developing indicators, target values and thresholds, the following projects are notable:

- the above-mentioned TSBF BGBD Network project on the Conservation and Sustainable Management of Below-ground Biodiversity supported by the GEF (US$9 million; with cofinancing an estimated total of US$22 million) for seven countries (Brazil, Mexico, Côte d'Ivoire, Uganda, Kenya, India and Indonesia) to be executed by the TSBF of the International Center for Tropical Agriculture (CIAT). (http://www.tsbf.org/index.htm);
- the European BIOASSESS research project (cofunded by the EC under the Global Change, Climate and Biodiversity Key Action of the Energy, Environment and Sustainable Development Programme) is developing biodiversity indicators or tools for the rapid assessment of biodiversity. It is also measuring the impacts on biodiversity, including that in the soil, of major land use change in eight European countries. (http://europa.eu.int/comm/research/eesd.html);
- the Land Degradation Assessment in Drylands (LADA) project, a GEF-funded project supported by the United Nations Environment Programme (UNEP). FAO is executing this project, for which the methodology development is ongoing under the project development phase with Argentina, China, Tunisia, Senegal and multiple partners. (http://www.fao.org/ag/agl/agll/lada).

Both projects respond to the needs of parties to the CBD and to the Convention to Combat Desertification (CCD). They deserve close coordination among experts and supporting efforts in order to ensure the prompt dissemination of research findings and tools for promoting sustainable agricultural systems and practices and the restoration of degraded lands.

National capacities need strengthening for improved soil biological management, especially in agricultural research and extension, including participatory technology development and adaptation, soil health monitoring and evaluation, and priority setting, with attention to agricultural policy and planning. South-South cooperation, allowing intercountry exchange, could help disseminate appropriate technologies, for example:

- between Latin America and Africa on no-tillage approaches and technology dissemination processes for BNF;
- between Australia and other countries on soil health reporting and indicator development;
- between Cuba and other countries on organic matter and nutrient cycling technologies, such as vermicomposting and N fixation.

Development and adaptation of productive and sustainable agricultural management practices

Integrated ecosystem and adaptive management approaches for soil health

As a basis for the discussions on adaptive management, reference was made to the operational objectives for adaptive management as defined by the CBD (annex to Decision V/5): "To identify management practices, technologies and policies that promote the positive and mitigate the negative impacts of agriculture on biodiversity, and enhance productivity and the capacity to sustain livelihoods, by expanding knowledge, understanding and awareness of the multiple goods and services provided by the different levels and functions of agricultural biodiversity."

Specific attention was drawn to the International Workshop on Soil Health as an Indicator of Sustainable Management, held at the GAIA Environmental Research and Education Centre, Kifissia, Greece, 25-29 June 1999 (Box 1). This provides an important basis for the discussions.

In addressing this theme, reference was made to the meaning of adaptive management (Box 2). This is a formalized process of decision-making for improving continually the interactive management of ecosystems by learning from the outcomes of operational plans. The concept was developed to address the problems of natural resource managers, who typically face an enormous set of variables as they make decisions affecting the environment. Gathering and digesting huge amounts of information to eliminate uncertainty often leads only to more questions, which lead to more information gathering, more questions and, ultimately, deferred decisions.

The Londrina workshop confirmed that, in order to improve agro-ecosystem management, stakeholders need a greater appreciation and recognition of:

- the effects of soil biota on soil physical, chemical and biological properties and processes and on the air and water resources with which the soil interacts;
- the benefits of those interactions in terms of crop and rangeland productivity and of enhanced C sequestration and mitigation of greenhouse gases.

Soil biota can increase or reduce agricultural productivity depending on their composition and the effects of their different activities. Vice versa, farming practices modify soil conditions and, hence, soil life, including the total number of organisms, the diversity of species, the activity of the individual organisms and the aggregate functions of soil biota. These changes can be beneficial or detrimental to the functions and regenerative capacity of the soil biota. Thus, the activity of soil organisms and land management practices requires effective management for maximum productivity and sustainable use of resources.

Box 1: The Kifissia workshop on soil health as an indicator of sustainable management

The workshop:

- Emphasized the links of soil quality to society and health, environmental degradation, novel ecological production systems and the land manager.
- Noted that soil health and quality indicators, and the changes in those indicators, can be a major link between the strategies of conservation management practices and achievement of major goals of sustainable agriculture.
- Noted that confirmation of the effectiveness of systems for residue management, organic matter formation, N and C cycling, soil structure maintenance and biological control of pests and diseases will assist in discovering and developing system approaches that are both profitable and environmentally friendly.
- Recognized that the challenge is to make better use of diversity and resilience of the biological community in soil to maintain a quality ecosystem, thus fostering sustainability. Strategies could be fine-tuned using practices, such as crop rotation for greater crop diversity and tighter cycling of nutrients; reduction of soil disturbance to maintain soil organic matter and reduce erosion; and development of systems that make better use of renewable biological resources such as legume companion crops and animal manuring.

It identified the following critical issues and needs for sustainable management:

- An ecological approach to sustainable management for multiple land uses.
- Consideration of the size of farms for which sustainable farming systems are developed.
- Communicating to a broad and diverse audience the critical importance of soil as related to the environment, society and economics.
- Prescriptive and descriptive assessment of the sustainability of agricultural systems for the land manager and for scientists.

The Kifissia workshop concluded that an increased understanding must be sought of the linkages between soil properties, soil processes and ecosystem functions in order to improve the methodology for sustainable productivity, biodiversity and environmental protection. Moreover, efficient implementation of sustainable policies requires educational outreach to various segments of society and the translation of science into practices that land users can use.

The workshop proposed that soil health indicators and sustainable management strategies must be linked through agricultural systems that:

- reduce inputs and reliance on non-renewable resources;
- maintain productivity at acceptable levels;
- minimize impact on the environment;
- are economically viable and socially acceptable

Box 2: Adaptive management

"Adaptive management can be defined as an iterative approach to managing ecosystems, whereby, contrary to other approaches, the methods of achieving the desired objectives are unknown or uncertain" (Holling, 1978; Walters, 1986). It is a process of testing alternative hypotheses through management action, learning from experience, and making appropriate change to policy and management practice. The process is useful because:

- Unexpected detrimental events may affect the site/ecosystem, requiring consideration of corrective measures, e.g. invasion by an exotic species.
- It may not be completely clear how to achieve one or more of the objectives. Experiments or trials using different methods may be needed.
- Something beneficial may happen unexpectedly. If so, a decision will be required on whether to capitalize on such events.

Critical steps in the process include:

- acknowledgement of uncertainty about which policy or practice is 'best' for the particular management issue;
- thoughtful selection of the policies or practices to be applied;
- careful implementation of the plan of action;
- monitoring of key response indicators;
- analysis of the outcome in the light of the original objectives;
- incorporation of the results into future decisions.

The web of life in the soil is a very complex and rich component of agricultural biodiversity and has important interrelationships with other components of the ecosystem. Human management practices influence its functions and activity both directly and indirectly. Thus, it needs to be addressed through an ecosystem approach.

Land managers need unbiased information that will enable them to develop biologically based management strategies to control or manipulate soil stabilization, nutrient cycling, crop diseases, pest infestations, and detoxification of natural and human-made contaminants. Such improved management strategies depend on a good understanding of soil organisms and their ecological interactions and of the effects on soil biota of habitats, food sources, host interactions, and the soil physical and chemical environment. The ecology regulating both beneficial and detrimental organisms is essential to harnessing and controlling their activity in agro-ecosystems. Such knowledge will yield great benefits in terms of the production of abundant, high-quality agricultural products with less dependence upon external inputs.

A vast range of innovative soil management practices involving biota and biotic products is available. Moreover, many of these practices are sustainable, environmentally friendly, affordable and applicable to developing nations. Many of the tools are based on traditional agricultural practices, while others are novel and take advantage of recent major advances in biotechnology. Biotic solutions should be encouraged in order to address the wide range of soil-related physical, chemical and biological problems.

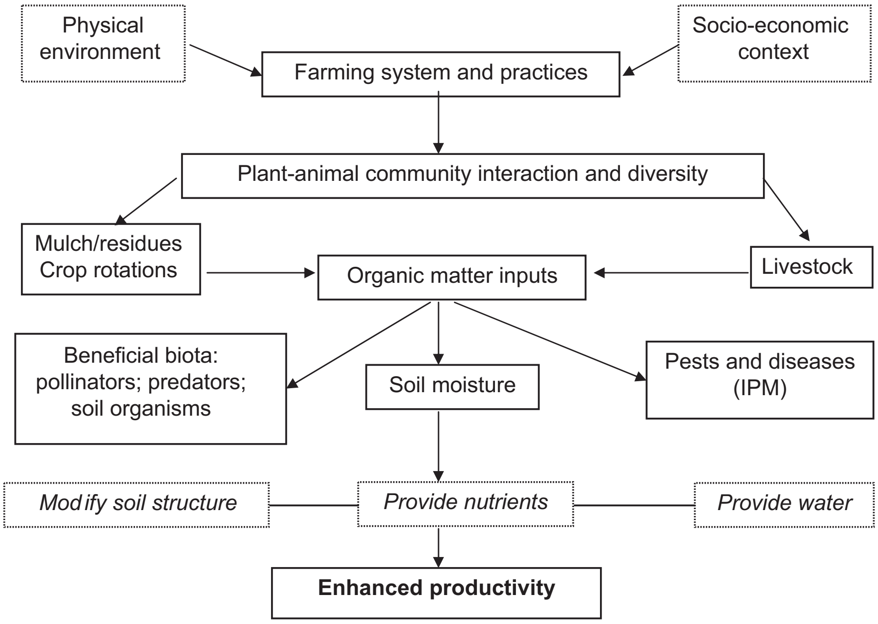
The goal is to understand the soil biota and to utilize this living component of the soil for the benefit of agricultural systems in order to increase crop productivity and quality, reduce input costs, and reduce negative environmental impacts.

The review of cases and discussions during the workshop led to the following general guidelines for soil management and sustainable agriculture:

- An integrated agro-ecosystem management approach is required for the review and development of better soil biological and other farming practices in view of the interactions among plant diversity and other resources, management practices, knowledge and organizational capacity (resource use in space and time). Attention needs to focus on biophysical, socio-economic and policy aspects, as well as on cultural and knowledge considerations that influence decision-making processes.
- The process must be interdisciplinary in order to address the interactions among plants, the soil, organic matter inputs, moisture, pests and diseases, soil biological activity and productivity.
- Farmers' needs and problems, such as labour, weed control, and water or pest management, should be addressed through an initial entry point. This can facilitate a process to build an integrated soil biological management approach. Such a process should combine biological, physical and chemical management issues. It should address productivity and environmental sustainability.
- Adaptive management and integrated ecosystem approaches require scientific rigour and a joint learning process among different actors. This should build on farmers' knowledge and on scientific knowledge and research. The farmer's perspective is essential as the management practices and opportunities in terms of soil biological management depend on socio-economic conditions and local knowledge systems.
- Sustainable biological management is not simply a question of managing nutrients. Primarily, it entails restoring the productive potential (as many lands are already degraded) and enhancing the efficiency of soil management (soil-crop-water interactions).

- There is a need to value the ecosystem services provided and to quantify the on- and off-farm benefits provided by sustainable biological management in agriculture (reduced costs of water purification and infrastructure maintenance; C sequestration; biodiversity conservation; etc.).
- There is a need to expand the education process to: (i) build capacities at field and planning scales for integrated agro-ecological approaches at all levels, from schools to universities; (ii) to educate and sensitize policy-makers on the importance of soil biological functions and sustainable agriculture; and (iii) to empower communities and civil society organizations for lobbying, decision-making, etc. This recognizes that on certain sensitive issues, e.g. access to and safe use of pesticides and fertilizers, international processes may be better placed to convince policy-makers than scientists, in view of issues of status, neutrality, etc.
- There is a need to promote participatory, grassroots-driven processes to facilitate the adoption of better soil biological management and sustainable agriculture. This requires attention on how to build on and promote community organization and networking; concepts of land care and stewardship; gender issues; and appropriate technology options for end users.
- Cooperatives and farmers' associations that are farmer-driven, as in the case of no-tillage in Brazil, can help reduce initial risks for individual farmers, improve awareness and access to information, facilitate negotiation, and enhance farmer empowerment and lobbying capacity to bring about policy change.
- FFS approaches and other learning-by-doing (experiential) approaches are very useful for improving technology adaptation and exchange, taking into account local constraints and opportunities.
- Economic considerations are the primary driving force for the adoption of unsustainable agricultural practices (e.g. steep-slope cabbage production in Haiti; and the shift from coffee to annuals in monoculture and the degradation of common property resources such as pastures and range in Brazil). The low benefit-cost ratio of agriculture is a key issue. Is compensation for the ecosystem services provided by farmers the only option, or are there other ways (e.g. certification for good practice, added value for farm produce through organic agriculture)?
- The search for good practice also requires incentives to encourage adaptive management approaches, e.g. in regard to access to credit and extension, security of tenure and access to resources: (i) to encourage farmer investment in sustainable land use there is a need for security of access to resources; (ii) to promote holistic and flexible credit systems to meet multiple needs and replace credit that is linked directly to cash crops, as was the case with the green revolution process; and (iii) to move away from package approaches to adaptive management approaches that take into account sustainability issues in relation to the complex of different types of farmers and farm households.
- There is also a need to mobilize a sense of responsibility and accountability: (i) for the adoption and promotion of good farming practice by farmers; (ii) for government compliance to fulfil commitments to implement conventions and agreements at all levels; and (iii) for responsible practice by agro-industry. In the case of no-tillage, for example, the private sector is interested in sales of herbicides and seeds rather than in cover crops and crop rotations, which are essential for sustainability and help minimize the use of chemicals.
- There is a need to document the processes and methodologies for intervention, technology development and adaptation, as well as activities and impacts. In this regard, case studies should document both successes and failures.

Figure 4
Diagram of an adaptive management framework for soil ecosystems: entry points and opportunities for intervention



- Besides the agriculture sector, there is a need to consider wider development issues of rural exodus, the desire for modern amenities (education, television, etc.), the need for greater recognition of agriculture and well-being in rural areas (air quality, quality of life, etc.), and the provision of basic services and amenities (electricity, communication, etc).

The Londrina workshop participants suggested the preparation of a schematic diagram of an adaptive management framework for soil ecosystems (Figure 4).

Sharing experiences and lessons learned and identification of gaps and priorities

The basis of all efforts to conserve biodiversity and natural ecosystems effectively while supporting economic development lies in the ability of scientists, resource managers, policy- and decision-makers, and the concerned public to have the widest possible access to the existing body of knowledge on biodiversity and ecosystem resources and processes. Much information exists on biodiversity and ecosystems (from a legacy of past research and inventories), and much more is being collected. However, it is still not possible for all potential beneficiaries to locate, retrieve, integrate and apply this information in a consistent fashion. In many cases, public and private funds are spent unknowingly on re-collecting information that may already exist in some undocumented or unavailable fashion. Much existing biodiversity and ecosystem information cannot be used widely (and may be in danger of being lost) because, for example, it is not yet converted into an electronic format or other readily usable form.

There was a suggestion to make a user-friendly inventory of projects and activities upon which to build for the development of guidance, tools, approaches and materials for different scales, systems, etc., for example, the TSBF, the IRD, FFS-soil productivity improvement, watershed management projects, promoting farmer innovation and local knowledge systems, PLEC. The products and expertise of these projects and processes could provide guidance for specific systems and situations for, *inter alia*:

- restoration of soil productivity and degraded systems;
- reclamation of degraded and contaminated lands (salinity, toxicity, etc.);
- minimizing use and negative effects of agrochemicals;
- improvement of resource use efficiency;
- enhancement of agricultural biodiversity (systems, habitat, landscape, above-below-ground links);
- enhancement of specific soil biological functions (nutrient cycling; C sequestration and reduction of greenhouse gas emissions; biological control of pests and diseases), and water movement and soil moisture retention;
- sustainable intensification.

There was also a suggestion to develop a checklist and format for case studies in order to enhance their usefulness in terms of clarity and eventual replicability. There was also a proposal to prepare a conceptual diagram linking the different dimensions, to facilitate review and analysis, as initiated by the adaptive management group. The case-study format should specify, *inter alia*, the following information:

- agro-ecological zone and geographical area (e.g. dryland; subhumid; tropical, temperate; and soil, water and vegetation resources);
- farming system type including farm size and level of intensification (e.g. smallholder low external input agriculture (LEIA) or commercial high external input agriculture (HEIA), crop and livestock focus and range of enterprises);
- spatial scale (field, farm, region, country) and temporal scale (season, year, decadal growth cycle, e.g. of tree crops);
- actors/stakeholders and their roles and interactions;
- specification of the problem and farm household type being addressed. Who identified the problem? Who identified the solution?
- socio-economic and cultural context;
- ecosystem approach: extent to which the activity fits within an integrated ecosystem approach;
- processes and methodologies for interventions, technology development and adaptation (i.e. extent to which they are multidisciplinary, multistakeholder and participatory, and farmer-, extension- or research-driven processes);
- activities and expected results: e.g. categorized in terms of assessment and monitoring, capacity building, adaptive management and technology development, mainstreaming through dissemination, policy advice, advocacy and awareness raising;
- social organization and processes for farmer experimentation and building on farmer innovation;
- marketing, institutional and policy considerations;
- products, impacts and lessons learned (specific to the site and applicable elsewhere) with a focus on practical outputs (approaches, tools, capacity, expertise, know-how, i.e. number of

farmers reached or technicians trained) and including attention to productivity, sustainability, biodiversity and ecosystem resilience.

A particular strategic issue that the workshop identified was the need to enhance understanding of the benefits and value of soil biological activity and soil ecosystem functioning, illustrating, *inter alia*:

- the relationship between good soil properties (physical, chemical and biological) and crop yield and health (e.g. synergies and interaction between integrated production and pest management (IPPM) and integrated soil and nutrient management (ISNM) - balanced plant nutrition, beneficial organisms, etc);
- the effect of excess inorganic fertilizers, herbicides and pesticides on plant health, growth and production, and on agro-ecosystem function (including issues of resilience, nutrient uptake, food web, etc.);
- the effect of monocultures on soil biological activity compared to crop rotations and mixes that provide organic matter inputs;
- the performance of organic agriculture and agro-ecological agriculture (intercropping, organic matter inputs, etc.) and their capacity for biological buffering and gradual release of nutrients to meet plant needs (major, secondary and trace elements);
- the benefit-cost analysis of different practices, with a focus not just on market-driven considerations (production and income) but on assessing and valuing the range of goods and services provided by integrated soil biological management (food security, environmental and human health, etc.).

The other main strategic issue identified was the need to develop an approach that focuses on organic matter within a systems approach including technical, socio-economic, cultural and policy and institutional considerations, specifically:

- the identification of resource- and input-efficient systems that balance internal and external resources (energy, fertilizers, pesticides, soil capital, etc.);
- increased attractiveness of agriculture through reduced drudgery and enhanced well-being of farming communities;
- building on indigenous knowledge, where appropriate, and modern scientific knowledge so as to enhance credibility of the local practices, knowledge and decision-making processes.

It was suggested that case studies be compiled for each category of soil biological solutions in order to demonstrate the valuable role and functions of soil biodiversity and related ecosystem functions in different farming contexts. Three key areas of intervention include the production system as a whole, organic matter management, and the cropping system or plant-soil interface.

Sustainable production systems

Soil quality, landscape quality, soil biota, nutrient cycling and biodiversity are integral aspects of sustainable development. A holistic, ecological approach is required for future research on soil-plant-animal systems. This will enable redesign of farming systems from an overemphasis on production towards more quality and internal regulation. This will result in lower mineral fertilizer losses, lower pest and disease pressure, and reduced susceptibility to climate extremes, thereby contributing to sustainable land management on-farm and at regional scale.

Plate 6
A mixed arable-livestock system from the Eastern Plains of Colombia
[J. J. Jiménez]

Organic matter management and the soil ecosystem

Primarily at a functional group level, soil biota regulate vital ecosystem processes such as decomposition (the breakdown of complex organic compounds into nutrients available for plant growth), C sequestration, and nutrient cycling. The rate of decomposition is dependent on the interaction of climate, biota and the quality and quantity of organic matter.

Agricultural practices that provide good soil protection and maintain high levels of soil organic matter favour higher biodiversity. Examples include agroforestry systems, intercropping, rotational farming, conservation agriculture, green-cover cropping and integrated arable-livestock systems (Plate 6). Actions that target the joint conservation of both above- and below-ground components of biological diversity directly will have environmental benefits at ecosystem, landscape and global scales.

The cropping system and the soil ecosystem

The successful functioning of most ecosystem processes requires a balance of biotic interactions in a complex soil biota community (detritus food web). Availability of C is one of the important regulating factors of biological activity in soils, which affects the composition of the microbial community and the food-web structure. In addition, the number of trophic levels in a terrestrial food-web community and its stability depend upon the amount and quality of C input and the level and type of disturbance (e.g. tillage, genetically modified (GM) crops and use of agrochemicals).

Plants are the main drivers of the dynamics of soil microbial communities via their input of various C sources into the system. Plant residues are the primary source of C in soils, with the majority of biota populations concentrated near residues and in the rhizosphere of plants. Therefore, any changes to the quality of crop residues and rhizosphere inputs will modify the dynamics of soil biota. Hence, a change in vegetation as a result of changes in land use is a major factor affecting the diversity of the microbial community. Moreover, changes in agricultural practice including the intensity of the use of fertilizers and pesticides and crop cover, e.g. grass versus arable crops in rotation, may lead to shifts among and within groups of the microbial community.

Diverse habitats support complex mixes of soil organisms. Diversity can be achieved with crop rotations, vegetated field borders, buffer strips, strip cropping, and small fields. Crop rotations provide different food sources into the soil each year and encourage a wider variety of organisms and prevent the buildup of a single pest species.

Soil resilience and risk alleviation

Because of time constraints during the workshop, the working group on innovation and risk management agreed to exclude the important issue of genetically modified organisms (GMOs), and to concentrate on other organisms, technologies and methods, including peri-urban and waste management issues (e.g. vermicompost). The knowledge and experience among participants was reviewed, taking into account the different biophysical conditions and range of functional groups: the producers, consumers and decomposers (N fixers, P solubilizers, C and N mineralizers, predators, pests and pathogens, soil aggregation engineers, antibiotics). It was agreed to keep a focus on food security, environmental quality and economic sustainability goals. A holistic systems view is needed to address extensively managed systems, such as shifting cultivation, intensive diverse systems and monocultures.

The first role of biodiversity is to ensure the multiplicity of functions that soil organisms perform. A secondary but important role of biodiversity is to ensure the maintaining of these functions in the face of perturbations. Genetic variability within and between species confers the potential for resistance to perturbations, whether they be short or long term. Understanding the relationship between biodiversity and more complex functions requires the combined study of taxonomically distant groups of organisms that can perform specific functions, and thus belong to the same functional group.

The group considered available solutions for addressing a range of soil fertility deficiencies and land degradation problems that are mediated by soil organisms and their functions, summarized in Table 3. The analysis in Table 3 can be updated through further consultation and sharing of examples, e.g. in FAO's electronic workshop on composting (http://www.fao.org/landandwater/agll/compost/).

Soil microbial communities represent the largest source of biodiversity on earth. Given the extremely high species diversity in soil, it is estimated that microbial communities contain such high levels of redundancy as to make small changes in soil microbial diversity insignificant. Rather, shifts among groups or species within the microbial community are considered to be of much more relevance for the functioning of terrestrial ecosystems. Shifts that might be relevant for sustainable land use include those in the relative abundance of bacteria and fungi and within groups with specific functions, such as nitrifying bacteria. These shifts could affect vital functions of the soil ecosystems, such as nutrient retention and antagonism against plant diseases.

A greater degree of biodiversity between or within a given species or functional group should logically increase the inherent variability in tolerance or resistance to stress or disturbance. Implicit in these arguments is the assumption that a multiplicity of organisms can perform a particular function, and that the replication of the ability to perform a particular function implies a degree of functional redundancy. Whether organisms are ever truly redundant is a matter of debate. Though redundancy in a single function may be common among many soil biota, the suite of functions attributable to any one species is unlikely to be redundant. Furthermore, functionally similar organisms have different environmental tolerances, physiological requirements and microhabitat preferences. As such, they are likely to play quite different roles in the soil system.

TABLE 3
Soil biological solutions for soil fertility and land degradation problems

Physical problems	Chemical problems	Biological problems
Compaction	Nutrient depletion	Low biodiversity
Low water content	Excessive acidity or alkalinity	Low microbiological activity
Poor drainage	Low phosphate levels	Low humus content
Erosion	Heavy-metal contamination	High pest or pathogen levels
Loss of silt or clay	High salinity	Lack of natural enemies
	Pesticide contamination	Low organic matter

Possible soil biological solutions:

Aggregation, porosity, regulation of soil hydrological processes – these are improved by bioturbating organisms, plant root, fungal hyphae, microbial secretions.

Bioremediation.

Nutrient cycling, decomposition of organic matter, nutrient mineralization, N fixation.

Crop diversity over space and time (intercropping, diverse rooting depths, rotations).

P solubilizing bacteria and plant nutrition and plant growth promoters.

Suppression of pests, parasites and diseases.

Problems	Bioremedial	N fixing	Compost	Manure	Rotation	Extracts	Inoculants
Degraded soils-low aggregation	-	+	+	+	- +	?	+
Degraded soils-low organic matter	-	- +	+	+	- +	-	-
Low saprobes	-	-	+	+	-	+	+
High pesticide levels	+	-	- +	-	+	-	-
High salinity	+	-	+	- +	+	-	-
High pollutants	+	+	- +	-	- +	?	-

- Unlikely to have beneficial impact
+ Positive impact expected

However, given the estimates for the vast numbers of species present in soils, and the rather limited number of functions that can be ascribed to the soil biota as a whole, a degree of functional redundancy seems inevitable even allowing for the fact that decomposition of plant material may require hundreds of enzymes. The greater the degree of functional redundancy, the greater will be the ability of a particular function to withstand stresses or disturbances, i.e. the greater the resilience.

Any novel method for manipulating and managing soil biodiversity and biotic products *in situ* requires an analysis of risk. There has been considerable interest in evaluation of risks associated with GM crop varieties. However, apart from these cases, little serious attention has been paid to environmental impact. This is the case especially where microbial treatments or manipulations are carried out. For example, little is known of the effect of *Rhizobium* inoculation on natural microbial populations. Similarly, the effects of herbicide-resistant plants and the use of herbicides on the soil ecosystem are not well known. It is not acceptable to assume that biosafety assessments can be made using external measurements, such as plant health or productivity, without doing the basic research to establish the necessary links.

Risk analysis is more complex than the simple establishment of safety in isolation from the environment in which the new product or process is to be employed. The following issues need to be addressed:

- Toxicity: is the product safe to eat for consumers (humans or animals) or can it produce toxic products or by-products?
- Environmental impact: what are the effects on non-target organisms? Assessments should be made of effects on a range of organisms, including providers of key ecosystem services and prominent species such as birds and butterflies.
- Genetic drift: what is the risk of genes from novel crops flowing into the environment? This may happen through hybridization between new varieties of traditional crops and their wild relatives as well as from GM varieties (i.e. the loss or fixation of specific alleles due to random effects associated with breeding in very small populations, technically, in populations below the effective breeding size - D. Bennack, personal communication, 2003). Terminator gene technology can eliminate this risk for GM crops, but some consider it unacceptable.
- Agronomic merit: do the new varieties perform better than those currently in use; and will pesticide needs be smaller or greater?
- Socio-economic issues: will the crops be acceptable to farmers, and do the farmers have access to any specialized handling equipment needed? For example, a crop designed for mechanical harvesting in the American prairies may not perform well in the small plots of subsistence farmers in Africa.
- Financial: can farmers afford the product, and will increases in production lead to greater income, or a consequent fall in crop price? Will consumers buy the new product? For example, even if *Rhizobium* inoculants give proven yield increases, farmers will not adopt them unless their availability is accompanied by information and training on their use and demonstration of the potential benefits of investing in such a product.

Chapter 4
Strategy and actions for implementing the Soil Biodiversity Initiative

Guiding principles and objectives

The workshop participants agreed that the strategy for the implementation of the International Initiative on Conservation and Sustainable Use of Soil Biodiversity should adhere to the following principles (bearing in mind that many of these principles have already been emphasized through other processes or forums):

- focus, as an overriding priority, on food security and improvement of farmers' livelihoods through support actions that will have tangible, positive and measurable effects on agro-ecosystems and on the well-being of the communities that depend upon soil health and productivity;
- build on previous experience and knowledge through combining the skills and wisdom of farmers with modern scientific knowledge;
- focus on integrated holistic solutions and technical adaptation to local contexts within a clear framework that builds on the principles for application of the ecosystem approach (Annex 6);
- use participatory technology development and adaptive approaches to develop agricultural systems and land resource management practices for specific situations and farmer typologies that are technically and environmentally appropriate, economically viable, and socially and culturally acceptable;
- develop partnerships and alliances that enhance synergy and multistakeholder participation (from farmer and civil society to research and the private and policy sectors) and build on specific knowledge and experiences (by region, ecosystem and thematic area);
- promote cross-sectoral approaches to address different perspectives (social, economic, political and environmental) and to achieve a range of benefits at different scales (local, national and global);
- prioritize actions on the basis of country goals and the needs of direct beneficiaries and validate such actions locally through the full participation of all actors;
- promote innovative and flexible solutions that are adapted to local conditions and relevant to the continuously evolving contextual situation of the beneficiaries.

Taking into account the above principles, and building on the opportunities and approaches discussed during the workshop, two main objectives were formulated for the SBI: (i) promote awareness, knowledge and understanding of the key roles of functional groups and of the impacts of diverse management practices in different farming systems and agro-ecological and socio-economic contexts; and, more important, (ii) promote ownership and adaptation by farmers of integrated soil biological management practices as an integral part of their agricultural and sustainable livelihood strategies. It was suggested that progress could be made by focusing on the following strategic areas of action:

- increasing recognition of the essential services provided by soil biodiversity across all production systems and its relation to land management through: information sharing and networking; raising public awareness; education and capacity building;
- capacity building to promote the adoption of integrated approaches and coordinated activities and processes for the sustainable use of soil biodiversity and enhancement of agro-ecosystem functions, especially in the areas of: assessment and monitoring; adaptive management; and R&D;
- developing partnerships and cooperative actions through mainstreaming and cooperation.

It is intended that the suggested principles, development process, strategy and priority actions presented in this report provide a basis for stimulating exchange of information and experience among countries and relevant institutions. This should lead to a coordinated process for the establishment and conduct of the SBI as a cross-cutting initiative within the CBD programme of work on agricultural biodiversity, and through FAO's interdisciplinary programmes, with a focus on:

- mobilizing work at country level and within institutions concerned with agricultural development;
- providing expert advice, through country programmes and at international level, through the SBSTTA/COP process for the assessment of ongoing activities and existing instruments;
- strengthening partnerships and cooperative action with FAO and other relevant organizations through the identification and development of complementary and synergistic activities.

Strategic framework on soil biodiversity and agro-ecosystem management

Increasing recognition of the essential services of soil biodiversity across all production systems and its relation to land management

As soil biota can have both positive and negative effects on agricultural production, participants agreed that it is necessary to be able to measure or assess the impacts of individual soil management practices on soil biodiversity functions. In particular, if sustainable agricultural production systems are to be realized, there should be clarification of the impact of land management change, including agricultural intensification and other trends, on both the short- and long-term functioning of soil ecosystems. This requires the development of appropriate indicators to improve understanding of land use and soil-biodiversity interactions and to assist in monitoring and assessing the trends and impacts, both in terms of degradation and restoration of an agricultural ecosystem, and the progress in promoting conservation and sustainable use. Such indicators should facilitate monitoring at various spatial scales. They should also provide a tool for adequate management of biodiversity both locally and at national level, as well as for regional and global overviews of biodiversity status and trends.

To date, there has been little progress in developing indicators of biodiversity. This is because of the low level of scientific knowledge and understanding regarding biodiversity, in particular of ecosystem processes and functions. Nonetheless, the recent increased attention to holistic, systemic approaches has widened knowledge and understanding of effects of changing land use and management practices on biological diversity from a focus on intra- and inter- species diversity to consideration of diversity at the ecosystem and landscape levels. In particular, there have been advances in understanding the importance of sustaining ecosystem functions and life-support systems, such as the nutrient, hydrological and C cycles, climate regulation, and pest and disease management processes at local and watershed or landscape scales. This knowledge needs to be made available for use by various actors (policy-makers, technical support personnel and farmers and other land managers) through targeted materials and case studies and through capacity-building processes.

Capacity building to promote the adoption of integrated approaches and coordinated activities for the sustainable use of soil biodiversity and the enhancement of agro-ecosystem functions

There is a need for strengthening capacities and coordinating activities in order to promote integrated agro-ecosystem approaches and the conservation, sustainable use and enhancement of soil biological functions. In particular, improved information flows and better cooperation are needed among actors, institutions and development organizations (farmers, extensionists, researchers, policy-makers and soil, crop, livestock, environment specialists and sectors). This should provide the basis for promoting improved soil biological management and thereby achieving more productive and sustainable agricultural systems. Such cooperation and multidisciplinary approaches are essential for furthering work in the areas of: (i) assessment and monitoring; (ii) promoting the participatory development and adaptation of technologies and practices, building on farmers' knowledge and innovation as well as scientific advances; (iii) extension of successful approaches and technologies through the development of tools and training materials for capacity building and awareness raising; and (iv) the provision of enabling policy and legal frameworks. In this regard, priority was given to:

- facilitating greater sharing and exchange of information among farmers' groups and organizations, technicians, extensionists and policy-makers using appropriate communication strategies or entry points;
- stimulating collaborative actions among the range of stakeholders and beneficiaries (e.g. farmers, policy-makers, research projects and commercial organizations) on enhancing soil health and adapting improved soil biological management of soil ecosystems;
- developing targeted tools, approaches and activities for different audiences and for a broad range of applications through promoting on-farm experimentation and effective dissemination of lessons learned;
- promoting multidisciplinary activities that allow participants to work innovatively and cooperatively on tool and technology development by linking complementary development efforts, sharing resources and leveraging resources and investments;
- strengthening efforts to remove any significant barriers (policy, regulatory and institutional) to the pursuit of these innovative, cooperative opportunities.

Partnership development and cooperation

Partnership development is envisaged in order to establish close cooperation between FAO and partners for the development and implementation of the SBI and, in particular, for the development and promotion of improved practices for soil biological and ecosystem management for sustainable and productive agriculture. This requires cooperation at two levels. First, a process is required that ensures the participation of and feedback among a broad range of stakeholders, including policy-makers and local leaders, throughout the different stages of the development process. Second, it requires the development among relevant institutions and organizations (governmental, civil society and private sector) of complementary programmes and actions and effective collaborative mechanisms. In this regard, participants agreed that the development of partnerships, strategic alliances and collaborative actions could focus on:

- building on available case studies and information on the range of activities that address soil biodiversity and soil biological management in specific agricultural systems and support programmes worldwide;
- the identification and selection of specific agricultural systems and support programmes where farmers could test and adapt improved practices for soil biological management, through participatory technology development, experiential learning processes and cooperation among stakeholders (farmers, extension, research, NGOs and the private sector);
- promoting the widespread adoption of proven practices for the biological management of soil ecosystems, which contribute to productive and sustainable agriculture and the restoration of degraded lands.

Annex 5 presents suggestions for cooperative activities proposed by workshop participants in the form of a matrix table. These suggestions should be further developed together with other potential partners as a basis for implementing the priority activities identified at local and national levels.

The findings and recommendations in regard to the three main thematic areas considered at the Londrina workshop are presented in the form of a framework for action that outlines proposed objectives and activities. It is envisaged that this will provide the basis for the further development of the strategy and action plan for implementation of the International Initiative on the Conservation and Sustainable Use of Soil Biodiversity, further referred to as the SBI, as an integral part of the programme of work on agricultural biodiversity. It will be a partnership effort among FAO, the CBD Secretariat and parties, and other interested partner organizations and bodies.

Operational mechanisms

The workshop discussed the following operational issues and made suggestions regarding the development process for implementation of the SBI, focusing on the biological management of soil ecosystems for sustainable agriculture:

- Key partner institutions and types of resource users should be identified in each beneficiary country and region and among stakeholders (government, civil society and private sector) with a view to the development of clear common objectives and strategies. This will facilitate the targeting of required support to farmers and other users of land resources to help them in sustaining agricultural biodiversity and ecosystem functions while meeting livelihood goals.
- Efforts are needed to improve understanding of the relevance of soil biodiversity issues in regard to other national and international initiatives, and to promote partnerships and coordinated approaches. In particular, the SBI should be developed and implemented in synergy with and as an integral part of: (i) the ongoing CBD-FAO collaboration towards the agricultural biodiversity programme of work, taking into account other programmes of work (drylands and forest biodiversity) and cross-cutting issues (indigenous knowledge, benefit sharing, etc.); and (ii) national agriculture sector strategies and environmental action plans, in particular, with regard to national biodiversity strategies and action plans (NBSAPs),

implementation of the CCD and activities towards the Framework Convention on Climate Change (FCCC).

- A support system is needed to enable FAO and other partners (to be identified) to coordinate the process of developing and monitoring the SBI. This could include support for secretariat functions and the identification of regional and national focal points and support from members of FAO and parties to the CBD. The support mechanism should have, *inter alia*, the following functions: (i) promotion of multidisciplinary activities and integrated approaches as well as synergy and complementarity among relevant programmes and processes; (ii) coordination of the programme among all actors and assistance in leveraging and channelling of existing resources, with a focus on soil biodiversity conservation and sustainable use for sustainable and productive agriculture and food security, in accordance with FAO's mandate and the programme of work on agricultural biodiversity; and (iii) sharing experiences, lessons learned and resulting proposals for action among partners and preparing progress reports on a regular basis for consideration by FAO governing bodies and by SBSTTA for consideration in the further development and implementation of the SBI and its integration with the programme of work on agricultural biodiversity.

Framework for action as a basis for the further development of the Soil Biodiversity Initiative

Objective 1 – Sharing of knowledge and information and awareness raising

There is a need to combine and make better use of existing information and knowledge from relevant disciplines (biology, ecology, soil science, agronomy, etc.) in order to guide practical action for conserving and sustaining the functions and value of soil biodiversity in agricultural systems (including forestry). Compiling existing information and targeting it to specific clients (e.g. different types of farmers and other land users, technicians and policy-makers) is a top priority. In particular, and in response to the invitation by the COP, case studies on soil biodiversity and ecosystem management and sustainable agriculture are required as a means to promote local and national initiatives for integrating improved soil biological management in mainstream agricultural R&D programmes.

Activity 1.1 – Compilation and dissemination of case studies for use in awareness raising and capacity building

a. Case studies that are being compiled and made available through the CBD and FAO Web sites should also be made available on CD-ROM, for downloading and dissemination by partners for use at local and national level. The case studies will be analysed according to the extent that they reflect the ecosystem approach and with a view to identifying: gaps in knowledge; opportunities for synergies amongst activities; and options for promoting improved soil management.

b. Further contributions of relevant activities, achievements and lessons learned are to be invited through national processes. Case studies could emanate from pilot activities, farmer innovation, agricultural projects, and research programmes. They should include monitoring and assessment and adaptive management activities in specific agro-ecosystems and farming systems. A wide range of experiences from all concerned actors in the agriculture and environment sectors will facilitate the review and prioritization process for further work.

c. A standard format will be prepared for the presentation of case studies, with reference to the indicative outline for case studies on agricultural biodiversity (Annex 6), including, *inter alia*: the type of problem addressed; proposed solutions; specific techniques and management practices; tools and approaches for improved management and assessment; analysis of the principles and lessons learned from such experiences; and possibilities of replication and adaptation.

d. A matrix will be developed to record and classify case-study information on soil biological management according to: type of farming system, climate conditions, socio-economic context, spatial and temporal scales, and application of the ecosystem approach. This can be built up from the case studies provided for or presented at the Londrina workshop, summarized in Chapter 2 and in matrix form in Annex 4.

e. The resulting matrix of cases and lessons learned will be analysed with a view to providing a framework and strategy to guide wider adaptation of soil biological and ecosystems management in different regions and farming systems as well as tools for the assessment and monitoring of soil health and sustainable productivity and for participatory on-farm research and the adaptation of techniques.

Activity 1.2 – Creation and strengthening of networking arrangements for sharing of information, experiences and expertise with a focus on supporting local initiatives on the ground rather than institution building

a. Networking activities will be initiated or strengthened in order to mobilize interested stakeholders and to facilitate regional and thematic coordination and cooperation among partners, especially in the areas of assessment and monitoring and adaptive management. They will build on ongoing networking activities, for example through the TSBF BGBD project, the IRD-TSBF macrofauna network, and the United Nations Development Programme (UNDP) - GEF Alternatives to Slash and Burn (ASB) network, and networks on integrated production and pest management (IPPM). The activities will also catalyse new networks on areas requiring more attention such as soil biodiversity and soil biological management in dryland areas facing degradation and drought as well as on mountain areas in view of the species gradient with altitude and management implications. They will encourage South-South sharing of information and know-how, for example among regional networks on BNF and among conservation agriculture and organic agriculture networks.

b. Interdisciplinary processes will be promoted and ongoing actions extended to targeted production systems and geographical areas, such as agricultural systems in drylands and in mountain regions.

c. FAO's RooTalk newsletter and other relevant newsletters should be used for information coordination and dissemination and knowledge generation among interested groups of actors. This could catalyse a knowledge-sharing process on specific themes in response to demand from the field and invited contributions on relevant experiences and expertise. This should focus on sharing of practical experiences and good practices across sectors, partners and existing networks, demonstrating an integrated soil biodiversity and ecosystem management approach where possible.

Activity 1.3 – Enhancing public awareness, education and knowledge on integrated soil management and agro-ecological approaches

a. Develop materials and methods for integrating soil biodiversity and soil biological management into agricultural and rural development programmes and training processes for farmers and technicians. This could include, *inter alia*: (i) policy briefs for decision-makers on the importance of soil life for a range of ecosystems services: agricultural productivity, C sequestration, water quality, etc.; and (ii) the production of manuals and methods for farmers' training and training of technicians and development workers on soil ecology and participatory approaches that allow the integration of indigenous and scientific knowledge and technologies.

b. Strengthen interdisciplinary teaching processes within universities and colleges in order to train researchers, technicians and extension staff on how to address soil management from a more comprehensive and systemic perspective. This should include the development of technical college and university curricula and training materials for extensionists on agro-ecological principles and practices for sustainable and productive agriculture.

Activity 1.4 – Development of information systems and databases

a. Integration of soil biodiversity and soil biological management in existing information systems and databases including wider ecological tools such as ECOPORT (http://www.ecoport.org). This will require coordination among the various concerned partners and institutions. For example, the TSBF BGBD project intends to construct an international information system on patterns of land use change, below-ground biodiversity and its management. This will take into account ongoing work on database development and use, for example, the IRD-TSBF macrofauna database and the UNDP-GEF ASB database.

Objective 2 – Capacity building for the development and transfer of knowledge of soil biodiversity and ecosystem management into farmers' practices

Activity 2.1 – Evaluating capacity building needs of farmers and other land managers, researchers and development programmes for integrated soil biological and ecosystems management

a. Evaluation of relevant on-farm skills and educational and professional training needs for the adaptation and development of improved soil biological management in different farming systems and by farmers with different socio-economic contexts (small and large; commercial and subsistence). This should include the determination of capacity building needs with respect to farmers and other land users, researchers and development programmes for: (i) the monitoring and assessment of different farming systems, technologies and management practices in regard to their effects on soil biodiversity and its functions; (ii) integrating soil biodiversity issues into agricultural and land management processes, including training materials and relevant programmes and policies (guidelines, compendia of best practices, etc.); and (iii) facilitating participatory research and technology development on soil biodiversity and biological management, with a view to promoting sustainable and productive agriculture and improved land management.

Activity 2.2 – Development of soil bioindicators and tools for assessment and monitoring of soil health and ecosystem functioning

a. Bioindicators of soil health and assessment tools are needed in order to identify, guide and realize the benefits of improved biological management of soil ecosystems in terms of enhanced productivity and sustainability. The challenge in identifying land use management practices that are sustainable is the lack of data on the impact of agricultural practices on soil biodiversity, and on the effect of reported declines in soil biodiversity on agricultural systems. Holistic approaches for assessing soil health and simple reliable bioindicators at different scales are needed for use by farmers, technicians, scientists and policy-makers. Activities should include: (i) development of a clear conceptual framework that provides the criteria and tools to help guide land users, technicians and policy-makers to develop a soil health indicator plan; (ii) creation and strengthening of existing country-based groups working on soil bioindicators, and coordinating their contributions towards the establishment of global monitoring plans and networks building from existing data in selected well-documented areas; and (iii) establishment of an ad-hoc expert group to assist in the development of a set of soil biological indicators for integration with existing indicators and processes, in the assessment and monitoring of soil and agro-ecosystem health at local and national scales, as well as in understanding the causes and consequences of changes in soil health, agricultural productivity and sustainability. The monitoring process should contribute to the identification of remedial action to restore soil biological functioning. The ad-hoc group should build upon ongoing projects, regional groups and processes and will contribute to development of a framework facilitating adaptation and interpretation of existing methodology.

The above activities should be further developed in consultation with relevant projects and activities such as TSBF BGBD and BIOASSESS (above) to avoid duplication and to ensure complementarity and, in particular, to facilitate the application and use of various products.

Activity 2.3 – Promote adaptive management approaches for the development and uptake of improved soil biological management practices, technologies and policies that enhance soil health and ecosystem function and contribute to sustained agricultural productivity and livelihoods

a. Promote integrated soil management approaches for farmers and agricultural or rural development workers through participatory technology development and adaptive management processes. These should build on the participatory diagnosis of constraints and opportunities and on problem-based learning approaches that address interactions among soil, water, plants, livestock and human management. They should focus on good practices and innovative solutions for soil biological management and build, in particular, on progress and achievements in promoting conservation agriculture, organic agriculture and IPPM approaches.

b. Strengthen local capacity through farmer field training, short courses and mainstreaming of soil health and soil biological management in agricultural programmes and activities. This should facilitate improved decision-making and selection by farmers, with the support of extension and research, of best options and technologies. The FFS approach is already in use in parts of Asia and its methods and tools are being piloted in East Africa in FFS-SPI (www.fao.org/ag/agl/agll/farm-spi).

c. Develop tools and strategies for sustainable management of soil biodiversity and ecosystems using farmers' experience and lessons learned from case studies. Emphasis should be placed on: agro-ecological principles that enhance soil-ecosystem functioning and the multiple services of well functioning systems; and participatory processes and capacity building for successful expansion of agricultural R&D programmes that integrate soil biodiversity and ecosystems management.

d. Identify opportunities for direct and indirect management of soil ecosystems with a focus on: organic matter management (type, timing, associated technologies, etc.); cropping system design (crop selection, spatial and temporal arrangements, etc.); and tillage methods. These practices have a major influence on soil biodiversity and its functions and provide the most important and flexible options for widespread adoption by farmers. The most attractive entry points, highlighted during the workshop, for increasing farm productivity while sustaining rural development and protecting the environment are: conservation agriculture, organic agriculture and IPM. BNF, through the symbiotic relationship between plant roots and mycorrhizal fungi or *Rhizobium* bacteria, is also considered an attractive option, in view of the positive international and national experiences and the renewed interest by the CGIAR, FAO and other partners.

e. Develop a set of principles and good practices for improved soil biological management as an integral part of land resources management and sustainable agricultural ecosystems, with reference to specific systems.

Activity 2.4 – Mobilize targeted participatory R&D in order to enhance understanding of soil biodiversity functions and ecosystem resilience in relation to land use and sustainable agriculture

There is a need to target further applied research on soil biodiversity and soil biological management in order to provide clarifications and enhance understanding on the functions of soil biodiversity and ecosystem resilience in relation to land use and sustainable agriculture. It is well known that soil biota provide key ecosystem services that are responsible for naturally renewable soil fertility. However, there are important gaps in understanding and opportunities for further R&D. Activities should include efforts to:

a. Mobilize targeted on-farm participatory research in order to further clarify the most effective methods of organic matter management and their impact on soil life and plant-pest control for specific production systems (human and biophysical considerations).

b. Study and compile comprehensive data on specific dryland systems and mountain ecosystems, with a view to identifying opportunities and promoting concerted efforts in such areas for the biological restoration of soil health and fertility. This recognizes that these areas are fragile and require careful management, but have been relatively less studied and documented than other agricultural ecosystems in regard to soil biodiversity and soil biological management.

c. Encourage the conduct of case studies on the range of goods and services provided by soil biodiversity and well-functioning soil ecosystems, including nutrient cycling, C sequestration, soil and water conservation, pest and disease control and bioremediation, and, where possible, highlight costs and benefits. The case studies could focus initially on enhanced soil functioning under conservation agriculture, organic agriculture and IPM approaches compared to conventional practices.

d. Conduct economic benefit-cost analyses of changes in soil biodiversity, community composition and their relationship to soil ecosystem function and soil health and productivity, highlighting the externalities at farm and country scales. Priority is given to the identification of case studies or pilot activities that provide data on and demonstrate: (i) the impact of biological management of soil ecosystems, with emphasis on the economic and environmental benefits of soil biodiversity and its management; and (ii) the economic importance of soil biota and biological activity through the review and assessment of the direct and indirect values of soil biodiversity and its functions.

e. Analyse the application of the ecosystem approach across a range of case studies, and provide further technical guidance for implementing the ecosystem approach in agriculture and land management.

These activities will complement the research-based work of the TSBF BGBD project.

Objective 3 – Strengthening collaboration among actors and institutions and mainstreaming soil biodiversity and biological management into agricultural and land management and rehabilitation programmes

Collaboration and mainstreaming activities should focus on promoting widespread adoption of practices for enhancing soil biodiversity functions with a view to improving the productivity and sustainability of agriculture, and thereby generating socio-economic and environmental benefits. Such benefits should be achieved at farm, ecosystem and national scales. Efforts should build on existing programmes, networks, and relevant work of research institutes and national and international bodies. In this regard, several areas for collaboration have been identified and could be further developed through partnerships as outlined in Annex 5. These activities are more development-oriented compared with the complementary, more research-oriented work of the TSBF BGBD project and the IRD, which will strengthen the knowledge base.

Activity 3.1 – Mainstreaming soil biodiversity and ecosystem management in agricultural and land management programmes and policies

a. Promote the wider application in agricultural and land management programmes of soil bioindicators and practical methods for monitoring and assessing soil biodiversity and its functions, and of adaptive management processes for the participatory development of improved soil biological management and land use practices for maintaining soil quality and health under different agro-ecological and socio-economic conditions;
b. Harmonize and strengthen national policy and planning mechanisms through integrating soil biology management in land use planning, agricultural development, environmental impact assessment, programmes and projects addressing soil fertility, soil and water conservation practices, rehabilitation and reforestation.

This work should build on the work of the TSBF BGBD project and be developed in consultation with it. That project will develop recommendations of alternative land use practices with a focus on tropical forests, and will establish an advisory support system for policy-makers at different levels.

Activity 3.2 – Develop partnerships and collaborative activities for the development and implementation of the SBI as an FAO-CBD partnership

a. Develop cross-sectoral partnerships with participation at local, country and international levels to advance the implementation of the initiative. The extent of FAO's participation and its role in the SBI will depend on strategic partnerships with organizations and experts in the field and on its in-house capacity and the support of member governments through the Regular and Field Programmes, in accordance with its mandate, as set by the Strategic Framework (2001-2015) and Medium Term Plan (2002-07).

b. Select and initiate collaborative activities, through FAO collaboration with the EMBRAPA, workshop participants and other partners and projects, with emphasis on those with direct benefits on the ground, and on those providing a logical starting point for the further development of activities and setting of priorities for new work with farmers and R&D partners.

c. Organize and conduct a second technical workshop at the end of 2003, at an interesting soil biological management project site, to discuss progress and lessons learned and to develop a more concrete programme for the SBI for consideration by the SBSTTA.

d. Invite and compile further information from all actors on potential partnerships and ongoing and planned activities that contribute to the SBI. This should enable FAO and partners to facilitate a more comprehensive assessment of ongoing activities, expected outputs and the priority setting process. Further work should build on local knowledge systems and experiences including aspects that were not considered in the Londrina discussions, such as the use of soil organisms as an important part of the diet of certain indigenous people, e.g. Amerindians (case study by Paoletti and collaborators).

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Annex 1
Workshop agenda

DAY 1, MONDAY, 24 JUNE 2002

8:30-9:00	Bus from hotel to EMBRAPA Soybean
9:00-9:30	Registration and orientation
9:30-9:45	Opening session and general welcome from Brazilian host (Caio Vidor, Director EMBRAPA Soybean)
9:45-10:05	Introductory presentation by FAO and CBD representatives. 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 (Michele Gauthier, CBD Secretariat)
10:25-10:45	*Coffee break*
	PRESENTATIONS OF EXPERIENCES ON BIOLOGICAL MANAGEMENT OF SOIL ECOSYSTEMS
10:45-11:00	Overview of workshop process and sessions (Adriana Montañez, FAO)
	1. Assessment and monitoring
11:10-11:30:	Bioindicators of soil health: assessment and monitoring for sustainable agriculture (Clive Pankhurst, CSIRO)
	2. Adaptive management
11:30-11:50:	Adaptive management of soil ecosystems and soil biodiversity: an overview and examples (Lijbert Brussaard, Wageningen Agricultural University)
	3. The role of innovative technologies
11:50-12:10	Organic farming management with biological agriculture in drylands (Klaus Merckens, Egyptian Biodynamic Association/GTZ)
12:10-12:30	Research and innovation in biological management of soil ecosystems (Paul Cannon, CABI, UK)
12:45-13:45	*Lunch break*

13:45-14:30	**PLENARY: PRESENTATION AND AGREEMENT ON SCOPE AND AIMS OF WORKING GROUP SESSIONS**
14:30-16:30	**WORKING GROUPS (SESSION 1)**
	OVERVIEW OF KNOWLEDGE AND ISSUES AND IDENTIFICATION OF AVAILABLE PRACTICAL APPROACHES AND TOOLS, BASED ON WHAT IS KNOWN AND WHAT CAN BE USED AND HOW.
	Group 1: Assessment and monitoring
	Group 2: Adaptive management
	Group 3: Innovative technologies and risk alleviation
16:00-16:30	*Coffee break*
	WIDER IMPLICATIONS OF SOIL BIOLOGICAL MANAGEMENT
16:30-17:00	Soil carbon sequestration for sustaining agricultural production and improving the environment (Rattan Lal, Ohio State University)
17:00	Discussion

DAY 2 – TUESDAY, 25 JUNE 2002

8:30-9:10	Plenary: Report back from working groups and discussion. Reformulate questions and step forwards based on results and experience of day 1.
	PRESENTATION OF CASE STUDIES
9:10-9.30	Practical tools to measure soil health and their use by farmers (Martin Wood, Reading University, UK)
9:30-9:50	Mycorrhizae in Cuban agricultural systems (Eolia Treto, INCA, Cuba)
9:50-10:10	No-till agriculture for smallholder cropping in Brazil (Ademir Calegari, IAPAR, Brazil)
10:10-10:30	Use of vermicompost to reduce soil Al toxicity in Brazil (Patrick Lavelle, IRD, France)
10:30-10.50	*Coffee break*
10:50-11:10	The role of innovative technologies (Felix Dakora, University of Cape Town, South Africa)
11:10-11:30	The role of ecosystem engineers in soil rehabilitation process (Abdoulaye Mando, INERA, Burkina Faso)
11:30-11:50	Insect pest in biologically managed soil and crops (Om Rupela, ICRISAT, India)
11.50-12.30	Discussion
12:30-13:45	*Lunch break*

13:45-14.45	**WORKING GROUPS: SESSION II**
14:45-15.40	Report back from working groups and plenary discussion
15:40-16:00	*Coffee break*
16:00-17:30	**WORKING GROUPS (SESSION II CONT.)**
	Plenary discussion and feedback from working groups (2nd session)
19:30-22:00	*Workshop dinner*

DAY 3 – WEDNESDAY, 26 JUNE 2002

8:30-9:30	Plenary: Report back from working groups and discussion based on presentations of day 2.
	CAPACITY BUILDING AND MAINSTREAMING IN ASSESSMENT, MANAGEMENT AND RESEARCH
9:30-10:10	Introduction of theme on capacity building and mainstreaming (George Brown and Mariangela Hungria, EMBRAPA, Brazil)
10:10-10:30	Adaptive management for redeveloping traditional agro-ecosystems (P.S. Ramakrishnan, Nehru University, India)
10:30-10.50	*Coffee break*
10:50-11:10	Capacity building tools and methods used to improve knowledge and skills in biological management of soil fertility by farming communities (Rusvel Rios, CAMAREN, Ecuador)
11:10-11:30	The GEF TSBF BGBD network project on the conservation and sustainable management of below-ground biodiversity (George Brown, EMBRAPA, Brazil)
11:30-11:50	Transition from traditional to monocropping and more recently to weed-free mixed cropping and no-tillage systems (Richard Fowler, ACT Network, South Africa)
11:50-12:10	Management of macrofauna in traditional and conventional agroforestry systems from India with special reference to termite and earthworms. (Bikram Senapati, Sambalpur University, India)
10:00-10:20	*Coffee break*
10:20-12:00	**WORKING GROUPS: SESSION III**
	STRENGTHENING CAPACITIES AND PARTNERSHIPS AND MAINSTREAMING: DEVELOPING A PROPOSED STRATEGY AND CONCRETE ACTIONS (specifying partnerships, responsibilities, timing and funds)

	Local level and policy and research level with a regional or national focus • Monitoring and assessment • Adaptive management • Research, participatory technology development and risk management (local level) • Research and technology development and risk management (policy and research level) • Information management, awareness raising, exchange and networking, public education • Agricultural training, extension and research strategies and farming systems approaches (e.g. FFS and participatory technology development) (local level) • Agricultural policy, regulatory issues and agro-ecosystems approaches (policy level) • International initiatives (actions, responsibilities, timing, funds)
12:00-19.30	**Day field trip: Humanitas Project, São Jerônimo** (100 km)

Day 4 – Thursday, 27 June 2002

8:30-9:30	**Plenary Session: Strengthening capacities and partnerships and mainstreaming** Report back from working groups on proposed strategy and concrete actions (specifying partnerships, responsibilities, timing and funds)
10:30-10:45	*Coffee break*
10:45-12:15	Steering committee pulls together results with reporter and chairperson of each group
10:50-12:15	Tour of EMBRAPA station (laboratories, greenhouses, field projects) for other participants
12:25-13:50	*Lunch break*
14:00-16:00	**Final plenary session. Workshop conclusions**
16:30-17:30	Workshop evaluation. Reports. Commitments for follow-up activities, timing.
17:30	Close

Annex 2
Workshop participants and contact details

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Annex 3
Working group composition and guiding questions

A series of questions were designed to help guide the discussions in each working group towards practical solutions and approaches on how to use the existing knowledge.

Working groups addressed three main themes during two sessions:

Theme 1. Assessment and monitoring;

Theme 2. Adaptive management;

Theme 3. Innovative technologies and risk alleviation.

The first session concentrated on identifying and characterizing the available practical approaches and tools, based on what is known and what can be used, and how. It focused on building and describing the available knowledge base in each of the themes.

The second session focused on identifying and characterizing the various gaps (knowledge, resources, policy environment, etc.) in each theme, and how these can be overcome.

The gap identification helped create a common understanding and background for the third session, when the working groups discussed capacity building and mainstreaming under each of the three themes.

A. Working group on assessment and monitoring

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Eleusa Barros, Brazil
George Brown, Brazil
Julio Centeno, Brazil
Jefferson Costa, Brazil
Tsewang Dorji, Bhutan
Dirceo Gassen, Brazil
Abdoulaye Mando, Burkina Faso
Adriana Montañez, FAO
Fatima Moreira, Brazil
Clive Pankhurst, Australia
Nuria Ruiz, France
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Session 1 – Objective

Overview of knowledge base and issues to help land users, technicians and policy-makers understand soil health and the value and use of soil bioindicators to measure or observe and evaluate soil health now and in the future.

Issues for discussion

1. Which indicators
   - What to measure and how. Bioindicators and observation and measurement techniques.
   - What are the basic requirements for effective bioindicators of soil health?
   - What is a suitable framework for developing a soil health indicator programme?
   - Identify which indicators are universal (for most systems and conditions) and which are site or condition specific.
   - Which bioindicators should be used by different stakeholders (list) and what are their specific constraints (e.g. which indicators would be most suitable for farmers in different agro-ecological conditions and socio-economic contexts)?
   - Which soil health indicators could be used as appropriate indicators or measurements for different purposes, e.g. monitoring, early warning and management or maintenance?
   - Which indicators shoe or control key ecosystem functions (functional groups), without which systems may collapse or go into chaotic disequilibrium?
   - Which indicators reveal particular environmental constraints that must be overcome?
   - Can clear baseline data be defined and established to create reference databases for healthy soils (define)?
   - Which bioindicators show consistency (usefulness is maintained) at different temporal and spatial scales?
2. How to identify indicators of value to farmers and how to establish a soil health monitoring process with them.
   - How to make farmers aware of the importance of soil health and how to get them involved in soil health monitoring.
   - What are the minimum resources that must be available for monitoring or assessment?
   - How to identify the locally available resources (human, technical, equipment, laboratories, and other support) for bioindicator work.
   - How to use and develop local indicators of soil health, based on the farmers' degree of experience.
   - How to integrate soil health concepts into current and future farm management practices.
   - How to interpret and present results (what do they indicate).

Session 2 – Objective

What are the gaps in terms of knowledge and technical constraints, and how can they be addressed through projects, guidelines, capacity building etc.?

Provide clear principles and practical approaches, materials and means to guide land users, policy-makers and planners in the selection and use of bioindicators to improve land management practices and understand the linkages between soil biodiversity and the maintenance of soil functions.

Issues for discussion

1. How to develop and provide a framework or guide for soil health.
   - Need for using soil health indicators for different systems and users.
   - Needs for standardization in the use of indicators (across soil types, climate conditions and land uses).
   - Development of standardized sampling methods, data collection and interpretation, etc. (timing, number, spacing, features, measures, tools, etc) and how to make adaptations according to specific needs.
   - How to develop target values or thresholds for soil health indicators (i.e. what is good and what is bad). Approaches for this may include use of agronomic data, expert knowledge, databases. etc.
   - Need to couple the use of soil health indicators with demonstration of best farming or land management practices, i.e. recommended solutions to soil health problems.
   - Need for multidisciplinary monitoring processes and techniques and actions on the ground.
   - Need for integrated indicators or sets of multiple indicators (holistic approaches).
   - What developments in indicator research can be expected in the near future? Working around taxonomic barriers.
2. Identify resource persons, institutions and partnerships to be in charge of training and capacity building on different topics for different stakeholders (technicians, students, and especially farmers and other land managers), and identify current programmes where various representative pilot sites are well characterized and documented to obtain baseline data on healthy soils under different conditions.
3. Identify ongoing or recent research, field experiences and expertise on soil health indicators that can be built on. How to capacitate or train the farmer in the use of bioindicators (participatory approaches). Collation of available materials and creation of new materials (e.g. interpretive guidelines for the use of soil health indicators). How to develop networking and materials development and dissemination capacity.
4. Mainstreaming.
   - Need for involvement of the private sector without creating dependency for farmers.
   - How to promote use of bioindicators for comparisons of agricultural systems; degradation assessment; environmentally sound agricultural policies; C sequestration and other ecosystem services.
   - Mechanisms for influencing policy-makers and planners locally, nationally and regionally; lessons learned from cooperatives, FFSs and other lessons still to be learned.
   - How to calculate or predict economic benefits, losses and thresholds, and influence policies.
   - Expected results: Establish clear and concrete approaches and methods to overcome the specific gaps, needs and constraints identified during the discussion. Present a draft plan of action with short- and long-term goals.

B. Working group on adaptive management

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Arnaudo Colosi, Brazil
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Fatima Guimarais, Brazil
Patrick Lavelle, IRD, France
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Session 1 – Objective

Provide the basis for the development of practical guidelines on the basis of existing know-how, experiences and materials to promote on-farm research and technology development in integrated soil biological management (i.e. strategies, approaches and technologies) with a view to enhancing the productivity and sustainability of diverse land use systems and conserving soil and associated agricultural biodiversity.

Issues for discussion

1. Brief overview and agreement on adaptive management and integrated biological management concepts for soil and agro-ecosystems.
   - Adaptive management techniques and practices: essential components (social, biological, ecological, physical, cultural, economic, technical; approaches; lessons learned, etc.).
   - Essential components of integrated (biological) management of soil ecosystems (crop, animal, soil, water, human resources and agricultural systems); linkages and synergy between soil biological, chemical and physical management schemes.
   - The ecosystem concept (definitions and principles).
2. Discussion on opportunities for integrated biological management of soils in different farming contexts (basic principles, techniques, practices and approaches; contributions to agricultural sustainability).
   - How to move away from a focus on mechanical soil conservation to a focus on soil health and life.
   - How to maintain or enhance soil organic matter quality and quantity (roots, mixed crops, systems).
   - How to minimize the use of chemicals and develop alternatives (cost, safety, etc.).
   - How to enhance resource use efficiency (i.e. diversity at different scales; balance use of external inputs with recycling of locally available resources; reduce losses; efficient use of energy).
   - How to restore degraded soils and manage problem soils and fragile soils.

- How to intensify soil management (over time and space) without degrading the resource base (sustained productivity and income for subsistence and commercial farmers).
- What techniques are available for managing the living soil components (biota) to enhance agricultural production and what is their potential in certain systems (BNF, plant genetic resources, earthworms, etc.; build on traditional and modern techniques; link above- and below-ground biodiversity)?
- What lessons and successes can be built upon from each region in terms of useful approaches (i.e. promoting participatory on-farm research technology development; ecosystem or agro-ecological approach; participatory monitoring; networking)?

3. Identify major approaches with wider potential such as organic agriculture, conservation agriculture, diversified systems and other promising approaches and techniques, and suggest how to build on them, for example building on the following examples for representative farming systems.
   - Increase plant diversity at various scales (field to landscape).
   - Field margins, windbreaks, forest refugia and other landscape-scale preserved areas to increase landscape biodiversity and associated ecosystem services.
   - Linking above-ground with below-ground diversity; management implications; protect the habitat, key functions and biodiversity of soil organisms.
   - Minimize negative effects of various agricultural inputs; use of integrated plant nutrition and IPPM approaches.

Session 2 – Objective

Evaluate farmers' needs and constraints for adoption of biological management of soil ecosystems and adaptation of current practices in a range of different managed systems

Issues for discussion

1. What is known and where are the gaps? With a focus on solutions on how to overcome constraints and lack of knowledge in different agro-ecosystems and socio-economic context, in particular opportunities to strengthen collaboration and capacity building in the different regions, themes, etc.
   - How to move from technology transfer to adaptive management or participatory technology development approaches.
   - Review and identify good and bad traditional and modern techniques, and ways to move from bad practice to good practice. Suggest clear examples to build on.
   - How to enhance cooperation and shared understanding among farmers, extensionists, technicians and scientists on integrated biological management of soil ecosystems (institutional mechanisms; examples of dynamic processes): (i) identify any specific requirements or problems for specific farming systems - contexts or target groups (examples) and major technical gaps in terms of management practices and their impact on soil biological functions and on ecosystem productivity and resilience; (ii) needs for dynamic iterative learning process (not wide application of standard techniques) and for multidisciplinary activities and techniques; (iii) how to stimulate the capacity of local or

regional farmers to adapt, improve and share experiences (capacity building and training of the farmer, researcher and technician for integrated and adaptive management and participatory approaches); and (iv) what is known in terms of determining economic benefits, losses and thresholds (tools; know-how).

2. Identification of major technical gaps and farmer needs and potential solutions.
   - Plant breeding needs; inoculants.
   - Microbial and fauna management.
   - Organic matter management and soil conservation.
   - Landscape and agro-ecosystem biodiversity for pest and disease control, economic gains, nutrient management, etc.
3. Concrete suggestions for addressing major gaps and implementation of potential solutions.
   - Proposals for capacity building and training in integrated soil management (where, when, by whom).
   - Collation of available materials and creation of new materials on farmers' integrated soil management techniques. Who takes the lead?
   - Use of current networks and training courses to incorporate various stakeholders (farmers, technicians, students, researchers and agribusiness) in disseminating these techniques.
   - How to link agribusiness, NGOs and public institutions in the process of adopting integrated biological management of soil ecosystems.
   - Problems of scale: integrated management at the local scale must be scaled up to the landscape level (with wider adoption of practices) for true benefits of integration of soil use and management to be realized at the regional level.
   - Establish network of projects and experiences for incorporating integrated soil management (global, national).
   - How to obtain support at the various levels (from farmer to international governments) for integrated soil biological management (policy level, technical collaboration, financial resources).
   - International agendas and conventions on soil management and conservation (IUSS; Agenda 21; UN-CCD; UN-FCCC; UN-CBD; FAO-CGRFA; etc.).

Expected results

Identify solutions in terms of capacity building, partnerships and mainstreaming to overcome constraints (technical, human, socio-economic, cultural and organizational) in different agro-ecosystems and socio-economic contexts and regions.

C. Working group on innovation and risk management

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Rattan Lal, University of Ohio, United States of America

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Josef Steinberger, Bar-Ilan University, Israel

Session 1 – Objective

Overview of available innovative and promising new technologies and opportunities for their wider use and adaptation with a focus on risk alleviation (human and environmental) and systems approaches.

Issues for discussion

Promising techniques and their potential and evaluation of risks and application of ecosystem approach.

- The techniques: bioremediation, inoculation, genetic engineering, molecular marking, organic agriculture, integrated approaches (IPNM, etc.).
- The organisms: BNF, genetic manipulation or engineering of micro-organisms and plants, GMOs, arbuscular mycorrhizal fungi and other symbionts, natural antagonists, phosphate solubilizers, earthworms, biofertilizers, plant growth promoters. Understanding their role and ecological interactions in soils, and the means of promoting their wider use and adaptation (when possible). Improving their efficiency in agricultural systems.
- Urban and peri-urban agriculture - using industrial, domestic and agricultural wastes.
- GMOs and their implications and international property rights.
- Remediation - using microbes for decontamination.
- Industrial use of soil organisms and bioprospecting.
- Interactions between above- and below-ground biodiversity (e.g. flavonoids and other rhizospheric exudates).

Session 2 – Objective

Identify strategies and approaches for the well-informed and safe use and adaptation of techniques or biological methods including policy, institutional and organizational strategies and actions.

Issues for discussion

- Alleviation of risks and constraints. How to promote the precautionary approach.
- Needs for further research (field testing and assessment) with a focus on systems approaches, e.g. crop-soil interactions.
- Need for balanced and unbiased private and public sector research and government policy. What role for partnerships (e.g. to commercialize, publicize or promote sound innovations; collaborative research)?
- Need for community awareness and lobbying capacity of smallholder farmers, associations and support groups.
- Need for balanced information for all stakeholders (impact assessment, equal access).
- The importance of policy and regulatory frameworks; role of global conventions and standards.
- Identify initiatives/networks that can be built upon for cooperation and partnerships; roles and responsibilities; representatives and programme/project interactions.
- IRD-Biofonctionnement du Sol.
- TSBF Programme.
- ASB Programme and African Highlands Initiatives of CGIAR.
- CYTED Network and MIRCEN Network.
- Mycorrhizal and BNF networks, e.g. ALAR, CGIAR Challenge Programme on BNF.
- Piloting participatory technology development (building on private and public sector collaboration as appropriate) for wider use of soil biodiversity related technologies and products.

Expected results

Promote the wider use and local adaptation of safe and promising technologies to enhance the use of soil biodiversity and efficiency of soil biological activity through the identification of concrete opportunities for collaboration, training, networking and piloting activities within a conducive and supportive policy environment.

Annex 4
Matrix of case studies on soil biodiversity and ecosystem management

Case studies on soil biodiversity and ecosystem management

Country, region and land use	Case study / actors	Problem to be solved (objective)	Actions			Outcomes	Lessons learned and comments
			Assessment, monitoring	Adaptive management	Capacity building		
1. **Burkina Faso** Sahel Region Cowpea Semi-arid (400-700 mm rainfall)	Integrated management of termites and organic mulch Academic researchers and their institutions	Restore soils in order to extend arable lands and increase productivity. (To manage termites and local organic matter in order to rehabilitate crusted soils).	Monitoring is robust and easy to use and interpret by farmers.	Technology innovation. Mulch applied to soils, thus stimulating termites to improve soil structure and soil processes.	Technique needs to be tested by farmers. With experience guidelines can be developed and methods included in farmer training materials	Severely crusted soils were restored. Soil compaction was reduced, infiltration and drainage were increased. Decomposition and mineralization enhanced by termite activity. Cowpea yields were 100 times those in soils without termites.	Soil structure degradation results from eradicating native soil organisms (termites). Applying surface organic matter feeds termites and promotes their regenerative activities. Technological innovation to use macrofauna to restore degraded soils.
2. **Egypt** Nile Valley Cotton Arid (< 255 mm rainfall)	Biodynamic agriculture for reclamation and cotton production Organic matter management Farmers and agricultural engineers	Reclaiming desert land for agriculture due to lack of fertile and productive soil, with a market-focused process to enhance value of products.		Organic matter management and compost preparation using agricultural waste and animal manure.	Training on organic farming and compost preparation from small scale to large industrial systems.	2 200 ha of biodynamically certified desert margins in the Nile Valley. The organic cotton was intercropped successfully with basil and lemon grass.	Importance of micro-organisms for developing soil fertility. Organic farming in desert margins is considered "black gold", i.e. high-value market focus is important.
3. **Brazil** Paraná Crop (*Phaseolus vulgaris*) Subhumid (1 400-2 500 mm, extreme 1 000 mm rainfall)	Symbiotic N fixation in the common bean crop Academic researchers and their institutions	Improve low bean crop yields on N-poor tropical soils through N-fixing soil bacteria. (Effect of rhizobia on bean cultivars / biodiversity of *Rhizobium)*.	Select efficient rhizobia strains from local bean production sites.	Use of *Phaseolus. vulgaris* cultivars from the Meso-American and Andean pools as trap hosts	Needs further development.	Common beans inoculated with competitively superior, native rhizobia produced high yields in N-poor tropical soils.	Superior strains of rhizobia can be selected from the diversity of native soil bacteria with no need for genetic modifications. Not clear how farmers were involved in the process.
4. **Brazil** Paraná Cereals (sorghum, cotton, maize and soybean) Subhumid (1 400-2 500 mm rainfall)	No-tillage (NT) agriculture benefits soil macrofauna Private farm owners with academic researchers and their institutions	Restore and maintain soil fertility on severely eroded agricultural lands. (To provide the best environment for macrofauna and their soil fertility functions).	Compare NT vs. conventional tillage (CT) practices for conserving soil macrofauna. Understanding how crop residues influence bio-physico-chemical properties of soils.	NT and crop rotation systems are keys to integrated soil fertility management.	Some attempts were made to raise awareness. Techniques and training materials need further development.	Millions of hectares of NT for cereal production with cover crops. NT systems provided better environmental conditions for macrofauna than CT systems Soil macrofauna diversity higher in NT than in CT systems.	NT can help re-establish a diversified soil biological activity after CT disturbances NT systems are ecologically and stress resistant. A collaborative process fosters adoption by smallholder farmers (farm sizes up to 40 ha)

Country, region and land use	Case study / actors	Problem to be solved (objective)	Actions			Outcomes	Lessons learned and comments
			Assessment, monitoring	Adaptive management	Capacity building		
5. **Brazil** Peri-urban locations	Use of vermicompost to reduce Al toxicity	Low fertile soils for vegetable production. (Reduction of Al toxicity).	Earthworm inoculation and chicken manure to process sawdust waste.	Vegetable production in peri-urban areas.	Despite excellent results, adoption of the technology failed.	Al toxicity was reduced significantly (exch. Al from 85 to 45 percent), and CEC improved.	Adoption of technology failed due to inadequate extension and communication strategies.
6. **Cuba** Crops (coffee, rice, vegetables, etc.) Across the island Subtropical (900-1400 mm rainfall)	Biofertilizers (arbuscular mycorrhizal fungi, AMF and *Rhizobium* bacteria) for mixed agriculture Farmers, national institutions, universities.	Productivity and yield decline in agricultural soils, plus economic constraints and lack of fertilizers. (Inoculation of AMF varieties in different crops and soils)	Application of AMF in on-farm trials with different soil types to determine effectiveness of infection.	Use of AMF inoculants in different crops and soils to combat yield decline.	Practical research conducted with farmers. Capacity enhanced through agro-ecological fairs, education and extension.	Successful adoption of AMF inoculants by farmers (no data).	Improved organic matter management is central to the functioning of the technology.
7. **India** Tamil Nadu High-input tea plantations Subhumid (900-1 000 mm rainfall)	Managing earthworms and organic matter can improve crop and soil productivity Agro-industry representatives, farm managers and academic researchers and their institutions.	Restoring soil fertility and increasing yields in tea plantations Search for a practical, economic and conservation-minded solution to soil degradation. (Rehabilitate plantation lands degraded by decades of intensive tea cultivation).	Tea prunings and other organic materials are trenched with earthworms.	Use of soil fauna and local organic matter to increase tea production.	Dissemination of technology to other areas and countries for large-scale implementation.	Use of soil fauna and local organic matter improved soil organic matter and structure; hence tea production was increased and maintained. Bio-organic fertilization (FBO) technique ensures positive response of up to 50% enhancement in production. A patent has been deposited.	Renewal of soil fertility in sites of intensive agriculture is possible. FBO needs the regular attention of trained personnel. Interdisciplinarity led to the outstanding results observed. Local assimilation of this technology is low due to deep-rooted tradition of conventional technologies. More effective promotion and adoption are needed.
8. **Australia** Queensland. Sugar-cane crops. Subhumid (1 150 mm rainfall)	Management practices to improve soil health and reduce effects of detrimental soil biota associated with yield decline of sugar cane Sugar-cane growers, representatives of industry and sugar research bodies.	Soil compaction and yield decline under intensive tillage of sugar cane. (Achieve a sustainable and more productive system: reduce negative effects on soil biota, restore soil fertility and structure).	Monitoring of better and more sustainable practices for improvement of soil fertility and structure.	Adapt practices to improve crop growth and soil health. Technical impact assessment of management options on soil ecosystem functions and ways to optimize benefits and reduce harmful effects.	Demonstration trials are tools to facilitate this process.	Increased soil organic matter and CEC led to higher activity of beneficial organisms and reduction of detrimental effects. Uptake and monitoring of better practices promoted by sugar-cane industry.	Unsustainable practices in agro-industry can be transformed into sustainable and productive systems. Involvement of all relevant sectors of society and scientific disciplines achieves impact.

Country, region and land use	Case study / actors	Problem to be solved (objective)	Actions			Outcomes	Lessons learned and comments
			Assessment, monitoring	Adaptive management	Capacity building		
9. **Bhutan**	Methods for assessment of soil health and quality Farmers, researchers and technicians	Lack of tools for measuring soil health that can be adopted and used by farmers. (To raise farmer awareness about soil life by working together).	The overall soil biological activity is measured through soil respiration (O_2 uptake and CO_2 production).	A tool for management decisions.	An educational tool that needs further development.	A tool for management decisions and for raising awareness of farmers about the living nature of soil.	Usefulness of a simple and easy-to-use method for farmers. Simple methods can be used for decision management.
10. **Ecuador**	Capacity building tools and methods used to improve knowledge and skills of farming communities in biological management of soil fertility CAMAREN, a consortium for NRM, with farmers.	Lack of consideration of soil biological issues in agricultural education. Lack of policy on promoting integrated agricultural approaches. (To establish a step-by-step process with farmers).	Field work for identification of problems in farming systems.	Group work interaction to achieve a multiscale impact.	Training of trainers on soil ecology. There is a need to enhance training facilities on biological management of soil fertility.	Important contribution to development of sustainable agricultural practices in several regions of Ecuador.	A multiscale impact can be achieved through participation of all farmers. A farmer-centred approach has been shown to contribute to the development of sustainable agricultural practices.
11. **E Uganda, NW Tanzania**: banana, maize beans, ground nuts (1 500-1 800 mm rainfall) **Zimbabwe:** Sorghum cowpea etc. (400-600 mm rainfall)	Use of FFSs for SPI Farmers, NARs, extensionists, University, FAO and TSBF-CIAT.	SPI with a focus on soil biological management. (Increase the adoption of integrated soil management practices).	Identification of best practices for each site and farming system. Training of trainers is a priority when training materials are available.	Conservation agriculture approaches, no-till, organic matter and soil biological management for successful adoption by farmers.	Training of trainers, guidelines and manuals on SPI are being developed.	Curriculum development and training materials are being developed. An upcoming workshop will outline the progress made and success of adoption.	A farmer-driven approach based on participatory research is expected to lead to wider adoption.
12. **Colombia** Carimagua Crops and pastures Humid (2 230 mm rainfall)	Soil macrofauna communities in a range of land use systems of the Colombian Llanos Students, researchers, institutions, NARs	Understanding the role of earthworms in different soil processes; clarification of their beneficial activities. Biology and ecology of earthworm species.	Assessment and monitoring of soil macrofauna communities along gradient of agricultural intensification (inventory of organisms and their functions across a range of land uses). Typology of biogenic structures – responsible species and physico-chemical properties.	Adaptive management of soil-crop system and practices. Linkages between specific soil organisms management and effects on soil processes.	Further development of tools for farmers' use and interpretation is needed.	A CIAT-edited book in English and Spanish (forthcoming) compiling the most significant achievements. Inventory of soil macrofauna, including abundance, diversity and their specific ecologies. Details on the effects of earthworms on physical, chemical and biological properties of savannah soils are provided.	Knowledge of biology and ecology of earthworms is a key to further address the impact of soil macrofauna on ecosystem functioning.

Country, region and land use	Case study / actors	Problem to be solved (objective)	Actions			Outcomes	Lessons learned and comments
			Assessment, monitoring	Adaptive management	Capacity building		
13. **Philippines** Mindanao Tropical maritime (up to 2 800 mm rainfall)	Adaptive management and technology innovation Universities, NARs, Institutions, DGIS net and FAO IPM facility.	Lack of research on the technology innovation process for integrated crop-soil management. Ineffective information sharing on soil-crop management practices between private and public sectors.	A biodiversity research programme conducted along a landscape gradient (from uplands to the coast)	Interactions among partners with complementary roles lead to agro-ecological innovation and impact.	Rural people rely on variety and variability and are involved actively in the management process. Sharing information among all participants at different levels.	No results yet.	Agro-ecological innovations emerged from interactions among partners with complementary roles. Change is achieved, driven by non-satisfied needs of farmers.
14. **Tropical worldwide** (Mexico, Brazil, Colombia, Cuba, Côte d'Ivoire & India). From natural ecosystems to agricultural lands.	Participatory assessment of macrofauna functional groups for rehabilitation and improved productivity of pasture, cropland and horticulture Students, farmers, researchers, NARs, CGIAR centres.	Lack of a global assessment of soil macrofauna communities in the tropical region (To conduct an in-depth study on the composition of soil macrofauna communities in different agro-ecosystems and their functions)	Tools and standard methods to assess and quantify soil macrofauna groups. Basic biology and ecology of earthworms specifically addressed.	Effect of earthworms on plant growth and physico-chemical properties of soils.	Perception, beliefs and use of earthworms in different sites of tropical farming systems. A guideline for farmers and technicians is intended to be available soon (IRD-FAO).	A macrofauna database with more than 1 000 sites sampled. Articles in peer-reviewed journals, a CABI book and dissemination of results. Development of in-soil technologies based on the stimulation of earthworm activities.	Participatory approach to collect and identify soil macrofauna groups. Soil macrofauna is a sensitive indicator of soil quality.
15. **Tropical intercountry** (Mexico, Brazil, Côte d'Ivoire, Uganda, Kenya, India & Indonesia). From tropical forests to agricultural lands.	The GEF-funded project on the conservation and sustainable management of below-ground biodiversity (2002-07) Students, farmers, researchers, NARs, CGIAR centres.	Identify critical thresholds for loss of functions in soil.	Inventory of organisms and their functions across a range of land uses. Relationship between above- and below-ground biodiversity. Development and use of indicators and assessment tools.	Valuation of ecosystem services provided by soil biota (from bacteria to macrofauna).	Capacity building and information sharing (FAO). Training of trainers in standard methods of looking and assessing soil biota for use in FFS-SPI.		A set of globally accepted standard methods for evaluation of BGBD. Valuable data on types of management practices and soil biota composition.
16. **South Africa** Crops	Selection of legumes that produce beneficial plant flavonoids for various functions.	Weed suppression and control of pathogens and pests. (Promote nodulation and enhance nutrient cycling).	Selection of legumes	IPM strategies developed to overcome declining productivity.		Flavonoids promote microbial growth and induce *nod* genes in root nodule bacteria. These non-N-fixing benefits of nodulated legumes are greater in cowpea than in soybean.	Antibiotics provided by root exudates can control insect pests and suppress weeds such as *Striga*. Unavailable oligo-elements in alkaline soils are mobilized.

Country, region and land use	Case study / actors	Problem to be solved (objective)	Actions			Outcomes	Lessons learned and comments
			Assessment, monitoring	Adaptive management	Capacity building		
17. **Asia** Crops	IPM and biomass management for armyworm control and enhanced productivity	Control of armyworm (*Myrthimna separata*)	Seeding the soil with natural allies including beneficial micro-organisms.	IPM strategies developed to enhance plant productivity			Increasing soluble N and free protein amino acids in plant tissues lead to pest damage by armyworm and other pests. Balanced plant nutrition is crucial.
18. **Kenya** Common bean (*Phaseolus vulgaris*)	Plant parasitic nematodes associated with common bean: an integrated management approach in Kenya	To avoid yield losses up to 60% due to nematode infection. (Control of root-knot nematode on beans through organic amendments and *Bacillus* inoculation).	Effectiveness of organic amendments for nematode suppression	Integrated management approach.		Chicken manure was the most effective amendment for nematode suppression.	The potential of organic amendments to suppress root-knot nematodes and reduce yield losses in bean production. *Bacillus* strains reduced egg hatching and modified root exudates, which affects host-finding processes.

Annex 5
Ongoing activities and potential collaborative actions

ONGOING ACTIVITIES AND POSSIBLE COLLABORATIVE ACTONS

Activity, aim and opportunity for collaboration; reference and contact	Agro-ecological zone; farming system	Problem to be addressed; actors	Available tools; applicability	Expected products and tools; timing	Results: capacity building, mainstreaming
CUBA					
INCA-Instituto Nacional de Ciencias Agrícolas Eolia Treto Hernandez Perez.cardero@hotpop.com 1. **Biofertilization: inoculation with mycorrhizae (AMF)** Economic AMF inoculum production. Publication of results and validation of inoculum methodology (with farmers) in Cuba, Bolivia and Colombia Ramon Rivera, rrivera@yahoo.com **Possible collaboration:** - with Rusvelt Rios (Project Promusta, CARE, Ecuador). - with Dr. Rattan Lal, who is interested in publishing results in Agricultural Encyclopædia Ohio Agriculture.	Caribbean region, C. & S. America, and Africa. Low- and high-input agricultural systems: coffee nurseries; grain, roots, tuber crops (crop rotations and residual effects); intensive, diverse vegetable crop production.	Lack of fertilization, degraded soils, Excess mineral fertilization, economic problems, poor information on use of mycorrhizal inoculum. Researchers, government, farmers, extensionists, NGOs.		Increase yields, improve soil fertility, save inputs. INCA: education, awareness. INIFAT: case studies, publications. Instituto de investigacion y produccion de pasturas y forrajes en Cuba: 5 years practical experience. Methodology validated. Manual information for farmers.	Training farmers and technicians in use of inoculants. Collaborate to mainstream agro-ecological approach in soil biological management
Urban agriculture Application of agro-ecological principles. Publication of 10 years' work (1994-2002) by Adolfo Rodriguez Nodels, Instituto de Investigaciones Fundamentales en Agricultura Tropical "Alejandro de Humboldt" (INIFAT). Ecuador INIFAT@ceniai.inf.eu	Tropical regions. Vegetable production with agro-ecological management.	Loss of biodiversity, low production. Researchers, government, farmers, extensionists, NGOs.		2. Enhanced peri-urban production; enhanced biodiversity.	Training farmers and researchers.
Integrated animal-crop production with agro-ecological management methods. Fernando Funes Monzole & Marta Monzole Fernandez Mgahora@ip.etersa.eu	Mixed crop–animal farms (1-5 ha).	Loss of biodiversity, low production. Researchers, government, farmers, extensionists, NGOs.			Training farmers and researchers.

Activity, aim and opportunity for collaboration; reference and contact	Agro-ecological zone; farming system	Problem to be addressed; actors	Available tools; applicability	Expected products and tools; timing	Results: capacity building, mainstreaming
ECUADOR					
CAMAREN Network (Sistema de Capacitación para el Manejo de Recursos Naturales Renovables) Rusvelt Rios rusveltrios@yahoo.com Introduce into CAMAREN training modules on soil life issues. Coordinated action for sustainable agro-ecological development (through CAMAREN, Red Agro-ecologica, Universities, research, farm families). **Collaboration:** - with Cuba on inoculum production and peri-urban (organic) agriculture (proposal in formulation for technical information and *Rhizobium* use to be implemented with Ecuador municipalities); - with INIAP for farmers experiments.	Andean region. Small-scale farming.	CAMAREN network has overlooked soil biology. Lack of farmer training material. Peri-urban areas demand for food security. Project proposal: organic horticulture.	CAMAREN has material and experience on adult education, participatory and gender approaches, and training material based on farmer experience. Manuals, CD-ROMs, field training material on natural resource management.	Raised awareness on soil biology and ecology. Incorporation of soil biology in curriculum of CAMAREN. Peri-urban agriculture project with families and schools. CAMAREN to train NGO technicians, farmers, leaders of agro-ecological institutions, etc.	Workshop to explain soil biology and exchange information. Meeting within CAMAREN (several institutions).
INIAP- National Institute of Agricultural Research Gustavo Bernal g.bernal@andinanet.net Use of legumes and actinorhizal plants by farmers. Production of inoculants (*Rhizobium* and possibly *Frankia* (actinomycete)).	Ecuadorian highlands (subsistence farming system).	Soil erosion.	Protocols available for research. Methods in extension and transfer of technologies. Participatory research for farmers. Publications on soil microbiology	Inoculant information (products) for farmers.	Adoption of FFS approach.
INIAP Gustavo Bernal g.bernal@andinanet.net To gain information on soil biota within an agro-ecological approach. Teaching activities on soil microbiology with emphasis in BNF. Gaining information on relevant research activities. Collaboration with CAMAREN, other NGOs.	Inter-Andean region in Ecuador.	Lack of information on soil biota. Lack of information in research of INIAP.	Background and knowledge of scientists on soil microbiology. Tools and methods for participatory approach.	Information for small farmers in highlands and students. Provide research information through courses and brochures.	To adapt microbiological processes in order to improve soil conditions. Improved research activities leading to improved soil conditions.

Activity, aim and opportunity for collaboration; reference and contact	Agro-ecological zone; farming system	Problem to be addressed; actors	Available tools; applicability	Expected products and tools; timing	Results: capacity building, mainstreaming
BRAZIL					
EMBRAPA Pecuaria Sudeste Odo Primavesi odo@cppse.embrapa.br Indicators: biological, physical and chemical.	Intensive cattle production systems in tropical grasslands.	Impacts on soil, water and air. Researchers looking for micro-indicators (NO_3, PO_4 & CH_4). Farmers not aware.		Preliminary new publications.	Ongoing work.
EMBRAPA Pecuaria Sudeste Odo Primavesi odo@cppse.embrapa.br General pictorial analysis of problems: hydrological regime, pollution, agricultural expansion, settlement, deforestation, etc. (environmental purposes).	Tropical and watershed level.	General to watershed– or landscape-scale problems. Researchers and farmers, based on case studies.	Journals.	Pictoral analysis of environmental problems available for research, extension and farmers. All groups of rural and urban society.	Young, improving educational network.
Universidade Estadual de Londrina. Fatima Guimaraes mfatima@uel.br Education and research in soil management (efforts underway to develop a focus on interaction between morphological, physical, chemical, biological, social and economic aspects).	North of Paraná, Cerrados and Amazonian regions. In pastures, NT and conventional farming systems (cereals and sugar cane).	Land degradation, soil conservation, soil management, identified by farmers and extensionists, (and students) through a “crop profile” (French descriptive method for structures of cultivated soils). University work with actors to find best solution for the system (pedologic, agrarian, social and cultural).	Maximum data collected and analysed. Solutions for problems found through discussion around a crop profile. Data on economics, history of farm, farming communities, agrarian system. Results of analysis mainly on macrofauna.	Systemic vision: crop profile is a tool for gathering information (also physical, chemical, biological & economic analysis). Papers on pastoral systems and no-tillage systems. CD-ROM on management of savannahs (French and Portuguese). Need funds for publications and translation in Spanish & English.	For students: to build open minds more capable of considering various aspects (physical, chemical, biological, social, cultural and economic). For farmers: to find a sustainable agro-ecological and economic solution.
EMBRAPA Soybean George Brown browng@cnpso.embrapa.br Monitoring of soil fauna populations as indicators of soil quality. Adaptation of management systems to enhance soil organic matter, soil cover, and reduce pesticide use. Soil C stocks and potential for sequestration under conservation agriculture practices.	North of Paraná A range of agro-ecosystems. NT and minimum till agro-ecosystems in Brazil.	Loss of diversity of soil fauna and their contribution to ecosystem function. Loss of C stocks in soil and soil fertility and productivity decline. Researchers & farmers.	Methodology available and applicable is established for soil macrofauna (TSBF-ASB and IBOY).	Reduced use of external inputs and enhancement of soil functions. Database with indicative values and ranges of the biological indicators produced. Work to be performed during several seasons/years. Data available on the potential of different management systems to contribute to C sequestration.	Monitoring of soil quality can be done by trained farmers. Students and researchers. A field manual for farmers and extensionists must still be produced to facilitate its dissemination.

Activity, aim and opportunity for collaboration; reference and contact	Agro-ecological zone; farming system	Problem to be addressed; actors	Available tools; applicability	Expected products and tools; timing	Results: capacity building, mainstreaming
EMBRAPA Julio Centeno Systems analysis. Agro-ecology. Platform building Set up of indicators: concepts, framework and strategy.	South of Brazil. Integrated rice and cattle production system.	Need of indicators of sustainability identified by farmers.	Ongoing research by farmers and researchers.	Maximum of 10 indicators for economic, environmental, agronomic aspects. For soil, identify indicators of physical, biological chemical aspects. (5 years: 2007).	Farmers able to collect, analyse and take action based on indicators. Farmers could send queries to research based on problems identified by indicators.
EMBRAPA Cerrados Ieda de Carvalho Mendes mendesi@cpac.embrapa.br Impacts of different management systems on soil microbial biomass, activity (soil enzymes, microbial respiration and diversity). Enhancement of BNF in agricultural ecosystems.	Brazilian savannahs (Cerrados region).	Loss of soil quality. Increasing problems related to soil degradation.	Use of microbiological and biochemical parameters as early indicators of changes in soil as result of different types of management systems.	Simple and useful (meaningful) biological indicators that could be used by farmers. Methodologies are described, especially in the SSSA book on soil quality.	To identify management systems able to keep the soil biologically active and productive, avoiding or reducing the need to convert new areas (native areas) into agricultural lands.
Assessoria e Serviços a Projetos em Agricultura Alternativa (ASPAA) Gabriel Bianconi Fernandes aspta@alternex.com.br Family farmers organization for the promotion of sustainable farming systems based on agro-ecology, supported by ANGO.	Centre-south Paraná State, Brazil. Family farming systems based on animals, polyculture and extractivism.	Rebuild soil productive capacity. Problem identified on a participatory rural appraisal by farmers and NGO technicians. NT, no fire, and no herbicide.	Review on green manure species available for S. Brazil. Publication: Petersen, P., Tardin, J.M. and Martochi, F. 1999. Participatory development of no-tillage systems without herbicides for family farming: experience of C.S. Region of Paraná. Envt. Devt. and Sustainability 1: 235-252.	Farmer-led experimental areas. Field days: exchanges between farmers and their communities. Green manure. Seed production. Techniques are site specific, principles can be generalized. Participatory methodologies.	Develop tillage systems based on cover crops, direct sowing and no herbicide. Farmers enabled to multiply the practice and its principles. Enhanced dialogue among farmers' organizations, NGOs, extensionists and researchers.
EMBRAPA Avilio Franco Avilio@enpab.embrapa.br Land reclamation and sustainability of cropping systems.	Hilly agroforestry area.	C and N addition to the system. Soil protection, increase in quantity and quality of water. Problems of society in general. Principle known but need to identify legume species, rhizobial strains and management for specific ecological and cropping systems.	Use of nodulated and mycorrhizal legume trees as a factor in land reclamation and sustainable agriculture. By farmers, extensionists and scientists. May be applied to any farm. Publications: Franco *et al.*, 1992, 1998, etc.	Integrated soil management. Genetic conservation. Sustainability.	Build up awareness in society in general.

Activity, aim and opportunity for collaboration; reference and contact	Agro-ecological zone; farming system	Problem to be addressed; actors	Available tools; applicability	Expected products and tools; timing	Results: capacity building, mainstreaming
EMBRAPA Jefferson Luis da Silva Costa jcosta@cpatc.embrapa.br Assessment and monitoring and reclamation of degraded areas for farming and reforestation use.	Drylands and hydrographic basins.	Reclaim degraded areas and find a way to monitor their efficiency.	Use of suitable bioindicators to guide solutions or monitor efficiency. Research results indicate efficiency of fluorescent diacetate hydrolysis method as an easy tool to monitor microbial activity.	Reclaimed areas monitored by appropriate bioindicators.	Share bioindicators efficiency with other communities, scientists, extensionists, etc.
EMBRAPA Jefferson Luis da Silva Costa jcosta@cpatc.embrapa.br Inducing soil suppressiveness to control soil-borne plant diseases.	Organic no-till and till systems Plant and soil management techniques can be applied to any farming system.	Farmers who have their lands condemned by high incidence of soil-borne plant disease. Plant pathogen techniques and research results applied and validated on farms.	Quantification of soil pathogen inoculum. Reducing soil inoculum density by using correct agricultural practices. Tools available to farmers, extension and research.	Control of soil-borne diseases by using soil management, cover crops and suitable rotations.	Trained agronomists in extension services. Web site under construction.
TSBF-GEF Project 2002-07 Regina Luizao rccl@inpa.gov.br Groups of below-ground biodiversity specialists in seven countries.	Amazonia: different land use types by indigenous people.	Decreased below-ground biodiversity with land use intensification.	TSBF handbook of methods, TSBF Web site, integrated multidisciplinary action. Results to be applied in two demonstration sites in order to convince farmers and decision-makers.	Standardized methodologies. Conservation and sustainable land use practices and management for farmers, extensionists, researchers and decision-makers.	Strengthened collaboration within and among seven countries.
EMBRAPA-Soybean Mariangela Hungria hungria@cnpso.embrapa.br Production, quality control and use of inoculants for N-fixing crops such as soybean and beans.	19 million ha in Brazil.	Inoculants with rhizobial strains adapted to Brazilian conditions have to be maintained and improved continuously. Farmers and researchers.	Methodology is established for inoculant production, quality control and strain collection. Diffusion methods are available for farmers and extensionists.	Several publications available.	No need for N-fertilizer application. Environmentally friendly solution to sustain and enhance productivity.
EMBRAPA-Soybean Mariangela Hungria hungria@cnpso.embrapa.br Group working with soil bioindicators in Brazil for different ecosystems.	Five different Brazilian ecosystems.	Farmers started asking for biological parameters to evaluate soil quality. Methods need to be validated in other areas by farmers, extensionists and researchers.	Evaluation of microbiological parameters. Methodology has been validated for all parameters with data for two Brazilian ecosystems (Londrina and Cerrados)	Biological parameter kits for farmers.	EMBRAPA-Soybean can include other groups and countries in the study. Web site soon.

Activity, aim and opportunity for collaboration; reference and contact	Agro-ecological zone; farming system	Problem to be addressed; actors	Available tools; applicability	Expected products and tools; timing	Results: capacity building, mainstreaming
URUGUAY					
Instituto Nacional de Investigacion Agricola (INIA), La Estanzuela, Colonia Maria Stella Zerbino stella@inia.org.uy Researchers, entomologists on soil macrofauna and soil pests.	No-tillage system in Uruguay and S. America.	Soil health and quality indicators, comparing tillage with no-tillage for sustainability; bioindicators and relationships among beneficial soil organisms; monitoring abundance and composition of soil macrofauna in different no-tillage farming systems. Researchers.	Macrofauna composition and abundance explain soil quality and health. TSBF method is practical for researchers, but may need some modification for farmers. (www.inia.org.uy/iniaendirecta/) Zerbino, M.S. Macrofauna del suelo en siembra en directa.	A bioindicator that is useful and practical for farmers.	Trained extensionists and farmers.
FRANCE					
IBOY- IRD, Institut de Recherche et Developpement Patrick Lavelle and Nuria Ruiz Camacho Patrick.lavelle@bondy.ird.fr, Nuria.Ruiz-Camacho@bondy.ird.fr Integrative study of the principal factors of parameters identifying soil capacity to function; Ph.D. thesis on soil macro-invertebrates, soil quality.	Brazil. No-tillage system vs. conventional tillage Intensification of land use,. Organic waste: composition and application. Manure uses.	Sustainability of agricultural systems regarding soil quality.	A synthetic index of soil quality based on abundance and diversity of macro-invertebrate communities. TSBF method for assessment of soil macrofauna in natural systems.	Protocol or manual for the application of the soil macrofauna index and interpretation. IBOY network (in development).	Training for technicians and farmers. Two manuals, one for researchers (actually applied) and a simplified version for farmers.
THE NETHERLANDS					
Wageningen University Lijbert Brussaard and Thom Kuyper Lijbert.brussaard@bb.benp.wau.nl, thom.kuyper@bb.benp.wau.nl 1. Convergence of sciences for better integrated crop and soil management (collaboration with TSBF). 2. Efficient N use and enhanced manure and soil quality in dairy farming (collaboration with ETC, The Netherlands).	1. Benin and Ghana Cash crops: cotton, cacao Food crops: cowpea Orphan crops: sorghum. 2.The Netherlands Pasture lands.	1. Soil fertility depletion. Scientists through participatory approach. 2. Enhancement of soil biological processes following drastic reduction of external inputs. Farmers - identified and science-supported	1. Not yet identified. Different solutions are expected given the different socio-economic and cultural conditions. Anthropology and sociology studies for participatory problem identification. 2. Feeding cattle with more fibre and less protein. Application of additives to manure or field. Applying slurry aboveground instead of injection.	1. Not yet identified. Different products and tools are expected through participatory approach, given the different socio-economic and socio-cultural conditions. Method developed by Paul Richards, Wageningen University, The Netherlands. 5 years (2001-05) 2. Web site, reports, magazines, courses. Excursions on-farm. Extension materials. Scientific articles available.	1. Institutions strengthened. Government agencies, market stakeholders & NGOs. 2. Empowered farmers. Changed attitudes with suppliers, dairy factories, local/regional/national government agencies and scientists. Special Issue of Netherlands Journal of Agricultural Science (Wiskerke, Verhoeven and Brussaard Eds.), 2002.

Activity, aim and opportunity for collaboration; reference and contact	Agro-ecological zone; farming system	Problem to be addressed; actors	Available tools; applicability	Expected products and tools; timing	Results: capacity building, mainstreaming
AUSTRALIA					
CSIRO - Land and Water Davies Laboratory, Queensland Clive Pankhurst Clive.pankhurst@csiro.au Sugar yield decline. Joint Venture: crop rotations and minimum tillage research, supported by Australian Sugar Research and Development	Subtropical. Sugar cane	Yield decline due to continuous monocropping, tillage, burning of residues, compaction, & poor root health. Sugar industry with researchers, farmers, extensionists.	New farming options for cane growers within next systems. Soil health indicators, soil biodiversity (molecular approach).	Raising awareness about soil health; also useful to other similar situations of highly mechanized agriculture.	Research papers (clive.pa nkhurst@csiro.au)
ISRAEL					
Bar-Ilan University Biology Dept, Yosef Steinberger Steinby@mail.biu.ac.il Understanding the roles and functions of terrestrial ecosystem.	Arid and semiarid ecosystems in the Mediterranean. Natural and human-made systems (grazing and desert systems).	Overgrazed desertified systems, nutrient cycling.	Methodology adapted to desert ecosystems. Assessment of soil properties: C/N, organic matter decomposition, soil biota, functional groups, population dynamics, diversity, abiotic variables.		
INDIA					
School of Life Sciences, Sambalpur University, Bikram K. Senapati bikramsenapati@hotmail.com and IRD, France, Patrick Lavelle Patrick.Lavelle @bondy.ird.fr Microfauna biodiversity and soil management: project on microfauna level with the EC, private industries including Parry Agro Ind.	Tropical and temperate. Applicable for plantation crops, agroforestry, landscape management.	Soil conservation. Synergy between organic residues and biodiversity below- and above-ground. Agro-industries, large farmers, cooperative farmers.	A biofertilizer patent was deposited (PCT/ FR97/01363) on behalf of all three parties. Being transferred to nine areas in China. Senapati and Lavelle, co-inventors.	This project has been evaluated in benefit-cost analysis at international verification by multidisciplinary groups.	FAO Soil Biodiversity Portal (http://www.fao.org/ agl/agll/soilbiod/ default.htm) Book: P. Lavelle, L. Brussaard & P.F. Hendrix, eds. 1999. Earthworm management in tropical agro-ecosystems, pp. 199-237. Wallingford, UK, CABI.
Jawaharlal Nehru University Prof. P.S. Ramakrishnan psr@mail.jnu.ac.in Shifting agriculture and sustainable development.	N.E. India; Central Himalayas; Western Ghats. Farming systems, natural ecosystem and landscape management.	Sustainable agriculture. Researchers, NGOs, local communities.	Developed indigenously through adaptive methodology development.	Sustainable agriculture and livelihoods. Outputs since 1970s.	More than 350 research papers by the author, 14 research volumes, audiovisual material.

Activity, aim and opportunity for collaboration; reference and contact	Agro-ecological zone; farming system	Problem to be addressed; actors	Available tools; applicability	Expected products and tools; timing	Results: capacity building, mainstreaming
CCS Haryana Agricultural University, Hisar, Haryana Dr. A. P. Gupta apgupta@hau.nic.in Punjab Agricultural University, Ludhiana Prof. V. Beri virajberi@hotmail.com Use of rice-straw for integrated nutrient management. Ecofriendly use of rice-straw instead of its burning.	Indo-Gangetic plain. Irrigated areas, rice- and wheat-based cropping system with inclusion of legumes.	Low or no profits from uneconomical and ecologically unsafe cropping systems due to intensive use of chemical fertilizers and pesticides. Farmers.	Suitable low-cost machinery with ability to sow crops in low or no-till systems.	Technology of using manually harvested rice-straw (with or without *ex situ* composting) as surface mulch – a technology for cash-poor farmers. Biological management of soils is enhanced.	Technology is available with different researchers. Adaptation research and upscaling are key to application in farmers' fields.
ICRISAT, Patancheru Dr. O.P. Rupela o.rupela@cgiar.org Managing insect-pests through microbial pesticides and by enhancing ecological (both soil and crop) biodiversity through use of trap crops and natural enemies of insect-pests.	Semi-arid lands of S. & S.E. Asia. Pigeon pea and cotton-based systems.	Researchers, extensionists and policy-makers.	Use of herbal extracts and microbial pesticides to protect crops. Applied to other regions if more research is conducted.	Biopesticides of commercial value intended to be available for wider use in 5 years. Some farmers are marketing herbal pesticides with the help of NGOs in the region.	Expected research products need to be combined with traditional knowledge. Publications. Systemwide programme on IPM coordinated from IITA.
BHUTAN					
National Soil Service Centre Thimphu Tsewang Dorji Tsewangd2001@yahoo.com Soil biological indicator assessment: integrated agrobiodiversity indicator for policy monitoring and evaluation. Support soil fertility protection through conservation of biodiversity and microbial activity, nutrient cycling.	Low-input traditional farming system.	Land degradation: organic matter depletion, decrease of soil biodiversity. Researchers, extensionists and farmers.	Field-based bioindicators for visual assessment by farmers: measuring kits for solid respiration, pH, organic matter, total C, total N.	Contribution and cooperation with international and national initiatives related to biodiversity indicators.	
BURKINA FASO and SENEGAL					
Institut pour l'Environnement et la Recherche Agricole (INERA) Abdoulaye Mando abdoulayem@hotmail.com Soil rehabilitation using organic resources and soil fauna.	Sahelian and savannah region. Agro-pastoral and sylvo-pastoral systems.	Production loss, soil degradation, biodiversity loss. Researchers and farmers.		Soil management technologies and principles; already available and improved in 2004.	Training of farmers, training of masters and Ph.D. students.
Institut pour l'Environnement et la Recherche Agricole (INERA) Abdoulaye Mando abdoulayem@hotmail.com Biological indicators (soil fauna, soil micro-organisms and C stocks) research along a climatic gradient in W. Africa.	Agro-pastoral and sylvo-pastoral systems.	Lack of knowledge. NGOs, project funders, and research institutes			Ph.D. training, scientist training during short visits.

Activity, aim and opportunity for collaboration; reference and contact	Agro-ecological zone; farming system	Problem to be addressed; actors	Available tools; applicability	Expected products and tools; timing	Results: capacity building, mainstreaming
SOUTHERN AND EASTERN AFRICA					
1. SEARCA Research, Natal Agricultural Department ZIMBABWE ACT Network, Richard Fowler rmfowler@iafrica.com Communal Land Project – Denmark-supported project on sustainable land use.	S. & E. Africa. Small communal arable farmers.	Production and preservation of surface mulches. Researchers, extensionists and farmers.		System to reduce soil water loss. In 3-5 years (2005-07)	Enhanced adoption by farmers of conservation tillage.
2. African Conservation Tillage Network (ACT) ZIMBABWE, TANZANIA, SOUTH AFRICA ACT Network, Richard Fowler rmfowler@iafrica.com Pilot projects on conservation agriculture.	S. & E. Africa. Small-scale agriculture and livestock.	Dissemination of conservation agricultural technologies. Researchers, extensionists and farmers.		Adoption of conservation tillage systems. In 2-3 years (2004-05).	Enhanced adoption by farmers of conservation tillage.
3. FAO/COSPE/ARC SWAZILAND, MOZAMBIQUE, SOUTH AFRICA ACT Network, Richard Fowler rmfowler@iafrica.com Identification and utilization of indigenous plants in conservation agriculture systems COSPE - Cooperazione per lo Sviluppo dei Paesi Emergenti, Italy. ARC - Agricultural Research Council, S. Africa.	Small-scale communal system.	Conservation of natural resources. Researchers, extensionists and farmers.		In 5 years (2007).	Extensionists empowered. Understanding of soil biological processes enhanced.
University of Cape Town, Felix D. Dakora dakora@botany.uct.ac.za BNF and root activity in soils, nutrient management in cropping systems. Visualization of root clusters as evidence of plant's search for P.	Small- and large-scale farming systems as well as natural ecosystems.	N and P nutrition in cropping systems. Business and researchers, farmers and technical extension staff.	Routine methods used in University of Cape Town and colleagues' laboratories. Indigenous farmers' and business knowledge (Rooibos Tea Co.)	Identification of high-N_2-fixing grain legumes resistant to insect pests. Technologies for improving P and N nutrition in Rooibos tea legumes. Result: 2004-06)	Shared experience between University of Cape Town and farmers. Training of young scientists in soil biology.
EAST AFRICA MIRCEN, Nairobi Nancy Karanja biofix@arcc.or.ke 1. Biofertilizers (Rhizobia inoculants) used leading to improved soil fertility under smallholder farming systems, crop production. 2. Reduced urban pollution through solid/liquid waste recycling.	1. Organic farming systems (subsistence). 2. Industrial crops, eg. coffee, pineapple and fruit trees.	1. Infertile and highly degraded soils (low crop productivity). 2. Environmental pollution in urban areas. Farmers, extensionists, researchers and policy-makers.	1. Rhizobia inoculants' technology. Availability of bioproducts. 2. Composting by earthworms.	Appropriate education materials for various groups.	Training farmers, extensionists and scientists on benefits of soil micro-organisms, e.g. rhizobia inoculants, mycorrhiza and vermicomposting. Strong collaborative links established among stakeholders. Institutional strengthening.

Annex 6
Indicative outline for case studies on agricultural biological diversity and checklist for their analysis

Background

The programme of work on agricultural biodiversity adopted by the COP in Decision V/5 makes provision for case studies on various topics to identify management practices, technologies and policies that promote the positive and mitigate the negative impacts of agriculture on biodiversity, and enhance productivity and the capacity to sustain livelihoods.

Specifically, Activity 2.1 of the Programme of Work calls for a series of case studies in a range of environments and production systems, and in each region:

- to identify key goods and services provided by agricultural biodiversity, needs for the conservation and sustainable use of components of this biological diversity in agricultural ecosystems, and threats to such diversity;
- to identify best management practices;
- to monitor and assess the actual and potential impacts of existing and new agricultural technologies.

Such case studies should address the multiple goods and services provided by the different levels and functions of agricultural biodiversity and the interaction between its various components with a focus on certain specific and cross-cutting issues, such as:

- the role and potential of wild, underutilized or neglected species, varieties, breeds and products;
- the role of genetic diversity in providing resilience, reducing vulnerability, and enhancing adaptability of production systems to changing environments and needs;
- the synergies and interactions between different components of agricultural biodiversity;
- the role of pollinators, with particular reference to their economic benefits, and the effects of introduced species on indigenous pollinators and other aspects of biological diversity;
- the role of soil and other below-ground biodiversity in supporting agricultural production systems, especially in nutrient cycling;
- pest- and disease-control mechanisms, including the role of natural enemies and other organisms at field and landscape scales, host plant resistance, and implications for agro-ecosystem management;
- the wider ecosystem services provided by agricultural biodiversity;
- the role of different temporal and spatial patterns in mosaics of land use, including complexes of different habitats;

- possibilities of integrated landscape management as a means for the conservation and sustainable use of biodiversity.

In addition, COP Decisions V/6 and V/24 call for case studies on the application of the ecosystem approach and on best practices for the sustainable use of biological diversity, including studies within the context of the thematic areas of the CBD.

The use of a common framework can facilitate synthesis of lessons learned from the case studies and integration of the ecosystem approach and considerations of sustainable use. The following indicative outline for case studies was originally made available to the COP in document UNEP/CBD/COP/5/INF/10. It has been revised in the light of COP decisions.

Indicative outline

Overview

In one page, please provide a summary of the case study using bullet points to highlight: the context/problem to be solved; the objectives; the approach; application of the ecosystem approach; and lessons learned.

i. Background and problem statement

Please describe the context or situation of the case study, and identify problem that is addressed by the activities of the case. Consideration of threats to biological diversity, the goods and services derived from it, and the distribution of benefits among stakeholders may be included, and, where known, the underlying causes of such threats may be described.

ii. Objectives and purpose of the activities

Please provide, in one or few sentences the main objective (or main objectives) of the activities proposed and/or carried out.

iii. Details of the case study and the approach taken

Please describe the activities, the approach taken, and the main actors involved.

iv. Analysis of the case study

Please analyse the case study in the framework of the various programmes of the Convention, using, as appropriate the checklist in Appendix 1. (Note, this should be used as an aide-mémoire, i.e. it is not necessarily appropriate to address each and every part in the appendix). This section might be presented in tabular form, and should complement section III.

v. Conclusions

Outcome of the activities. Please provide a brief note of the results achieved or expected of the case study, and the extent to which the objectives were met.

Lessons learned. Please highlight any critical factors that led to the success or failure of any of the activities carried out. It will be useful to note any practical conclusions that would assist others in carrying out similar activities, as well any policy-relevant lessons.

Checklist for the analysis of the case study

Application of the ecosystem approach

1. Describe how the case study illustrates any of the 12 principles of the ecosystem approach under the Convention (COP Decision V/6), and identify any constraints in applying these principles.

2. For the case study:

   a. Identify goods and services provided by biodiversity in the area of case study (and additional ones that could be provided with improved management), and identify the components of biodiversity and the functional relationships between these components which give rise to such goods and services.

   b. Identify the beneficiaries of these goods and services as well as additional groups who could become beneficiaries, and identify any barriers to their access to the benefits.

   c. Describe approaches to adaptive management noting what is most effective and what is least effective.

   d. Describe the scale (or scales) of management used, additional scale (or scales) of management that may be needed to address the problem, and any barriers to exercising management at the appropriate scales.

   e. Identify sectors involved, those that should be involved, and identify any changes required to provide an enabling policy environment.

Relevance to the operational objectives of the Programme of Work on Agricultural Biological Diversity

3. Indicate whether and how the case study contributes to:

   a. An assessment of the status and trends of the world's agricultural biodiversity and of their underlying causes.

   b. The identification of management practices, technologies and policies that promote the positive and mitigate the negative impacts of agriculture on biodiversity, and enhance productivity and the capacity to sustain livelihoods.

   c. A strengthening of the capacities of farmers, their communities and organizations, and other stakeholders, including agro-enterprises, to manage agricultural biodiversity, and the promotion of increased awareness and responsible action.

   d. The development of national plans or strategies for the conservation and sustainable use of agricultural biodiversity and their mainstreaming and integration in sectoral and cross-sectoral plans and programmes.

Relevance to the thematic work programmes of the Convention

4. Indicate whether or not the case study is relevant to the biological diversity of the following environments, and describe the nature of its relevance:

   a. forests;

   b. marine and coastal areas;

c. inland waters;

d. dry and subhumid lands (including Mediterranean, savannah and grasslands);

e. mountain areas.

Relevance to the cross-cutting work programmes of the Convention

5. Indicate whether or not the case study is relevant to the identification of invasive alien species, their control, or the mitigation of their effects.
6. Indicate whether or not the case study employs indicators of biological diversity, or of impacts on biological diversity.
7. Indicate whether the case study employs impact assessments (environmental, socio-economic) or indicates the need for impact assessments.
8. Indicate whether or not the case study furthers the taxonomic understanding of the organisms concerned, or elucidates the need for further taxonomic work.
9. Indicate whether the case study employs the use of incentive measures for the conservation and sustainable use of agricultural biodiversity, or identifies negative incentives.
10. Indicate whether the case study employs the use of benefit-sharing measures.
11. Indicate whether the case study draws upon the knowledge, innovations and practices of indigenous and local communities and whether it contributes to the protection and wider application of such knowledge, innovations and practices.
12. Indicate any other measures taken to promote the sustainable use of biological diversity.
13. Indicate if the case study is part of, or contributes to, a national biodiversity strategy and action plan.

Annex 7
The ecosystem approach and adaptive management

As described by the COP, the ecosystem approach is the primary framework for action under the Convention. The COP, at its 5th Meeting, endorsed the description of the ecosystem approach and operational guidance and recommended the application of the principles and other guidance on the ecosystem approach (Decision V/6).

CBD Decision V/6: The ecosystem approach

The Conference of the Parties

1. Endorses the description of the ecosystem approach and operational guidance contained in sections A and C of the annex to the present decision, recommends the application of the principles contained in section B of the annex, as reflecting the present level of common understanding, and encourages further conceptual elaboration, and practical verification;

2. Calls upon Parties, other Governments, and international organizations to apply, as appropriate, the ecosystem approach, giving consideration to the principles and guidance contained in the annex to the present decision, and to develop practical expressions of the approach for national policies and legislation and for appropriate implementation activities, with adaptation to local, national, and, as appropriate, regional conditions, in particular in the context of activities developed within the thematic areas of the Convention;

3. Invites Parties, other Governments and relevant bodies to identify case studies and implement pilot projects, and to organize, as appropriate, regional, national and local workshops, and consultations aiming to enhance awareness, share experiences, including through the clearing-house mechanism, and strengthen regional, national and local capacities on the ecosystem approach;

4. Requests the Executive Secretary to collect, analyse and compare the case studies referred to in paragraph 3 above, and prepare a synthesis of case studies and lessons learned for presentation to the Subsidiary Body on Scientific, Technical and Technological Advice prior to the seventh meeting of the Conference of the Parties;

5. Requests the Subsidiary Body on Scientific, Technical and Technological Advice, at a meeting prior to the seventh meeting of the Conference of the Parties, to review the principles and guidelines of the ecosystem approach, to prepare guidelines for its implementation, on the basis of case studies and lessons learned, and to review the incorporation of the ecosystem approach into various programmes of work of the Convention;

6. Recognizes the need for support for capacity building to implement the ecosystem approach, and invites Parties, Governments and relevant organizations to provide technical and financial

support for this purpose;

7. Encourages Parties and Governments to promote regional cooperation, for example through the establishment of joint declarations or memoranda of understanding in applying the ecosystem approach across national borders.

A. Description of the ecosystem approach

The ecosystem approach is a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way. Thus, the application of the ecosystem approach will help to reach a balance of the three objectives of the Convention: conservation; sustainable use; and the fair and equitable sharing of the benefits arising out of the utilization of genetic resources.

An ecosystem approach is based on the application of appropriate scientific methodologies focused on levels of biological organization, which encompass the essential structure, processes, functions and interactions among organisms and their environment. It recognizes that humans, with their cultural diversity, are an integral component of many ecosystems.

This focus on structure, processes, functions and interactions is consistent with the definition of ecosystem provided in Article 2 of the CBD: "'Ecosystem' means a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit." This definition does not specify any particular spatial unit or scale, in contrast to the Convention definition of habitat. Thus, the term ecosystem does not necessarily correspond to the terms biome or ecological zone, but can refer to any functioning unit at any scale. Indeed, the scale of analysis and action should be determined by the problem being addressed. It could, for example, be a grain of soil, a pond, a forest, a biome or the entire biosphere.

The ecosystem approach requires adaptive management to deal with the complex and dynamic nature of ecosystems and the absence of complete knowledge or understanding of their functioning. Ecosystem processes are often non-linear, and the outcome of such processes often shows time lags. The result is discontinuities, leading to surprise and uncertainty. Management must be adaptive in order to be able to respond to such uncertainties and contain elements of 'learning by doing' or research feedback. Measures may need to be taken even when some cause-and-effect relationships are not yet fully established scientifically.

The ecosystem approach does not preclude other management and conservation approaches, such as biosphere reserves, protected areas, and single-species conservation programmes, as well as other approaches carried out under existing national policy and legislative frameworks, but could, rather, integrate all these approaches and other methodologies to deal with complex situations. There is no single way to implement the ecosystem approach, as it depends on local, provincial, national, regional or global conditions. Indeed, there are many ways in which ecosystem approaches may be used as the framework for delivering the objectives of the Convention in practice.

B. Principles of the ecosystem approach

The following 12 principles are complementary and interlinked:

Principle 1: The objectives of management of land, water and living resources are a matter of societal choice.

Rationale: Different sectors of society view ecosystems in terms of their own economic, cultural and societal needs. Indigenous peoples and other local communities living on the land are important stakeholders and their rights and interests should be recognized. Both cultural and biological diversity are central components of the ecosystem approach, and management should take this into account. Societal choices should be expressed as clearly as possible. Ecosystems should be managed for their intrinsic values and for the tangible or intangible benefits for humans in a fair and equitable way.

Principle 2: Management should be decentralized to the lowest appropriate level.

Rationale: Decentralized systems may lead to greater efficiency, effectiveness and equity. Management should involve all stakeholders and balance local interests with the wider public interest. The closer management is to the ecosystem, the greater the responsibility, ownership, accountability, participation, and use of local knowledge.

Principle 3: Ecosystem managers should consider the effects (actual or potential) of their activities on adjacent and other ecosystems.

Rationale: Management interventions in ecosystems often have unknown or unpredictable effects on other ecosystems; therefore, possible impacts need careful consideration and analysis. This may require new arrangements or ways of organization for institutions involved in decision-making to make, if necessary, appropriate compromises.

Principle 4: Recognizing potential gains from management, there is usually a need to understand and manage the ecosystem in an economic context. Any such ecosystem-management programme should:

a. reduce those market distortions that adversely affect biological diversity;
b. align incentives to promote biodiversity conservation and sustainable use;
c. internalize costs and benefits in the given ecosystem to the extent feasible.

Rationale: The greatest threat to biological diversity lies in its replacement by alternative systems of land use. This often arises through market distortions, which undervalue natural systems and populations and provide perverse incentives and subsidies to favour the conversion of land to less diverse systems.

Often those who benefit from conservation do not pay the costs associated with conservation and, similarly, those who generate environmental costs (e.g. pollution) escape responsibility. Alignment of incentives allows those who control the resource to benefit and ensures that those who generate environmental costs will pay.

Principle 5: Conservation of ecosystem structure and functioning, in order to maintain ecosystem services, should be a priority target of the ecosystem approach.

Rationale: Ecosystem functioning and resilience depends on a dynamic relationship within species, among species and between species and their abiotic environment, as well as the physical and chemical interactions within the environment. The conservation and, where appropriate, restoration of these interactions and processes is of greater significance for the long-term maintenance of biological diversity than simply protection of species.

Principle 6: Ecosystems must be managed within the limits of their functioning.

Rationale: In considering the likelihood or ease of attaining the management objectives, attention should be given to the environmental conditions that limit natural productivity, ecosystem structure, functioning and diversity. The limits to ecosystem functioning may be affected to different degrees by temporary, unpredictable or artificially maintained conditions and, accordingly, management should be appropriately cautious.

Principle 7: The ecosystem approach should be undertaken at the appropriate spatial and temporal scales.

Rationale: The approach should be bounded by spatial and temporal scales that are appropriate to the objectives. Boundaries for management will be defined operationally by users, managers, scientists and indigenous and local peoples. Connectivity between areas should be promoted where necessary. The ecosystem approach is based upon the hierarchical nature of biological diversity characterized by the interaction and integration of genes, species and ecosystems.

Principle 8: Recognizing the varying temporal scales and lag effects that characterize ecosystem processes, objectives for ecosystem management should be set for the long term.

Rationale: Ecosystem processes are characterized by varying temporal scales and lag effects. This inherently conflicts with the tendency of humans to favour short-term gains and immediate benefits over future ones.

Principle 9: Management must recognize that change is inevitable.

Rationale: Ecosystems change, including species composition and population abundance. Hence, management should adapt to the changes. Apart from their inherent dynamics of change, ecosystems are beset by a complex of uncertainties and potential ‘surprises’ in the human, biological and environmental realms. Traditional disturbance regimes may be important for ecosystem structure and functioning, and may need to be maintained or restored. The ecosystem approach must utilize adaptive management in order to anticipate and cater for such changes and events and should be cautious in making any decision that may foreclose options, but, at the same time, consider mitigating actions to cope with long-term changes such as climate change.

Principle 10: The ecosystem approach should seek the appropriate balance between, and integration of, conservation and use of biological diversity.

Rationale: Biological diversity is critical both for its intrinsic value and because of the key role it plays in providing the ecosystem and other services upon which we all ultimately depend. There has been a tendency in the past to manage components of biological diversity either as protected or non-protected. There is a need for a shift to more flexible situations, where conservation and use are seen in context and the full range of measures is applied in a continuum from strictly protected to human-made ecosystems.

Principle 11: The ecosystem approach should consider all forms of relevant information, including scientific and indigenous and local knowledge, innovations and practices.

Rationale: Information from all sources is critical to arriving at effective ecosystem management strategies. A much better knowledge of ecosystem functions and the impact of human use is desirable. All relevant information from any concerned area should be shared with all stakeholders and actors, taking into account, *inter alia*, any decision to be taken under Article 8(j) of the CBD. Assumptions behind proposed management decisions should be made explicit and checked against available knowledge and views of stakeholders.

Principle 12: The ecosystem approach should involve all relevant sectors of society and scientific disciplines.

Rationale: Most problems of biological-diversity management are complex, with many interactions, side-effects and implications, and therefore should involve the necessary expertise and stakeholders at the local, national, regional and international level, as appropriate.

C. Operational guidance for application of the ecosystem approach

In applying the 12 principles of the ecosystem approach, the following five points are proposed as operational guidance.

Focus on the functional relationships and processes within ecosystems

The many components of biodiversity control the stores and flows of energy, water and nutrients within ecosystems, and provide resistance to major perturbations. A much better knowledge of ecosystem functions and structure, and the roles of the components of biological diversity in ecosystems, is required, especially to understand: (i) ecosystem resilience and the effects of biodiversity loss (species and genetic levels) and habitat fragmentation; (ii) underlying causes of biodiversity loss; and (iii) determinants of local biological diversity in management decisions. Functional biodiversity in ecosystems provides many goods and services of economic and social importance. While there is a need to accelerate efforts to gain new knowledge about functional biodiversity, ecosystem management has to be carried out even in the absence of such knowledge. The ecosystem approach can facilitate practical management by ecosystem managers (whether local communities or national policy-makers).

Enhance benefit-sharing

Benefits that flow from the array of functions provided by biological diversity at the ecosystem level provide the basis of human environmental security and sustainability. The ecosystem approach seeks that the benefits derived from these functions are maintained or restored. In particular, these functions should benefit the stakeholders responsible for their production and management. This requires, *inter alia*: capacity building, especially at the level of local communities managing biological diversity in ecosystems; the proper valuation of ecosystem goods and services; the removal of perverse incentives that devalue ecosystem goods and services; and, consistent with the provisions of the CBD, where appropriate, their replacement with local incentives for good management practices.

Use adaptive management practices

Ecosystem processes and functions are complex and variable. Their level of uncertainty is increased by the interaction with social constructs, which need to be better understood. Therefore, ecosystem management must involve a learning process, which helps to adapt methodologies and practices to the ways in which these systems are being managed and monitored. Implementation programmes should be designed to adjust to the unexpected, rather than to act on the basis of a belief in certainties. Ecosystem management needs to recognize the diversity of social and cultural factors affecting natural-resource use. Similarly, there is a need for flexibility in policy-making and implementation. Long-term, inflexible decisions are likely to be inadequate or even destructive. Ecosystem management should be envisaged as a long-term experiment that builds on its results as it progresses. This 'learning-by-doing' will also serve as an important source of information to gain knowledge of how best to monitor the results of management and evaluate whether established goals are being attained. In this respect, it would be desirable to establish or strengthen capacities of Parties for monitoring.

Carry out management actions at the scale appropriate for the issue being addressed, with decentralization to lowest level, as appropriate

As noted in Section A above, an ecosystem is a functioning unit that can operate at any scale, depending upon the problem or issue being addressed. This understanding should define the appropriate level for management decisions and actions. Often, this approach will imply decentralization to the level of local communities. Effective decentralization requires proper empowerment, which implies that the stakeholder both has the opportunity to assume responsibility and the capacity to carry out the appropriate action, and needs to be supported by enabling policy and legislative frameworks. Where common property resources are involved, the most appropriate scale for management decisions and actions would necessarily be large enough to encompass the effects of practices by all the relevant stakeholders. Appropriate institutions would be required for such decision-making and, where necessary, for conflict resolution. Some problems and issues may require action at still higher levels, through, for example, transboundary cooperation, or even cooperation at global levels.

Ensure intersectoral cooperation

As the primary framework of action to be taken under the Convention, the ecosystem approach should be fully taken into account in developing and reviewing national biodiversity strategies and action plans. There is also a need to integrate the ecosystem approach into agriculture, fisheries, forestry and other production systems that have an effect on biodiversity. Management of natural resources, according to the ecosystem approach, calls for increased intersectoral communication and cooperation at a range of levels (government ministries, management agencies, etc.). This might be promoted through, for example, the formation of interministerial bodies within the Government or the creation of networks for sharing information and experience.

The adaptive management process and its characteristics

Adaptive management has been defined in various ways by different individuals and organizations since its development in the early 1970s:

"....a systematic process for continually improving management policies and practices by learning from the outcomes of operational programs. Its most effective form – 'active' adaptive management – employs management programs that are designed to experimentally compare selected policies or practices, by evaluating alternative hypotheses about the system being managed. (USDA, 1993)

"... 'learning to manage by managing to learn'..." (USDA, 1993)

"...an innovative technique that uses scientific information to help formulate management strategies in order to 'learn' from programs so that subsequent improvements can be made in formulating both successful policy and improved management programs." (Halbert, 1993)

"...embodies a simple imperative: policies are experiments; learn from them." (Lee, 1993)

"...is a policy framework that recognizes biological uncertainty, while accepting the congressional mandate to proceed on the basis of the 'best available scientific knowledge'. An adaptive policy treats the program as a set of experiments designed to test and extend the scientific basis of fish and wildlife management." (Lee and Lawrence, 1986)

"The rigorous combination of management, research, and monitoring so that credible information is gained and management activities can be modified by experience. Adaptive policy acknowledges institutional barriers to change and designs means to overcome them." (Scientific Panel for Sustainable Forest Practices in Clayoquot Sound, 1995)

The adaptive management process is often presented as a cycle with a number of essential steps: assess problem -> design -> implement -> monitor -> evaluate -> adjust and so forth.

Some of the differentiating characteristics of adaptive management are:

- acknowledgement of uncertainty about what policy or practice is 'best' for the particular management issue;
- thoughtful selection of the policies or practices to be applied (the assessment and design stages of the cycle);
- careful implementation of a plan of action designed to reveal the critical knowledge that is currently lacking;
- monitoring of key response indicators;
- analysis of the management outcomes in consideration of the original objectives;
- incorporation of the results into future decisions.

Linking the ecosystem approach with adaptive management

The need to link the ecosystem approach with adaptive management is most obvious at spatial and temporal scales where biodiversity loss and ecosystem malfunctioning become evident to local stakeholders, i.e. at spatial scales beyond parcels of land or water and beyond temporal scales of years. Irrespective of scale, it is important that people are considered as part of, rather than actors external to, the ecosystem. However, human populations are not straightforward players in the ecosystem. Although it is possible to make useful distinctions between primary producers (food, raw materials), processors, retailers/merchandisers, public servants and consumers in terms of resource use, one person or household will fulfil more than one role and these roles may be associated with a plethora of cultural and social activities with different effects on biodiversity, other natural resources and ecosystem functioning.

As the scale of observation becomes larger than the ‘home range’ of the individual, the possible interference of that person’s activities with those of others will increase, as will the possible impacts on biodiversity and other natural resources. At every level of observation, the stakeholders will be most receptive to changes in resource use that have a negative effect on biodiversity and associated ecosystem functioning if the disadvantages of current resource use are clearly visible and felt (e.g. erosion, fish stock depletion, fuelwood depletion, decreasing soil productivity, declining mineral resources, disappearance of medicinal plants and other non-timber forest products, etc.). Under such circumstances, cooperation among stakeholders in designing and adopting more sustainable ways of natural resource use, in rehabilitating degraded ecosystems, and in providing adequate legal and policy measures is imperative.

Moreover, there is often a lack of sound knowledge of viable alternatives for current use of natural resources. Adaptive management is a strategy that allows stakeholders to operate in the face of uncertainty, learning from the effects of their resource management practices on resource quality and quantity (sustainability), including biodiversity, at certain scales, and its links with ecosystem functioning at the same or larger scales. Only through expanding the knowledge base on the relationships between human activities and natural resources, biodiversity and ecosystem functioning, and through continuous experimentation and adaptation to cope with change, will a more sustainable use of natural resources come within reach. To the extent that successes are achieved under certain circumstances, adaptive management experiences can then be extrapolated to other regions with similar problems, and with a view to avoiding irreversible resource depletion and loss of biodiversity and ecosystem services.

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