Soil Biota and Biodiversity: the "Root" of Sustainable Agriculture

Given escalating population growth, land degradation and increasing demands for food, sustaining agricultural production through improved soil fertility management is critical to the issue of food security and poverty alleviation in most, if not all, developing countries.

Integrated Soil Management and Soil Biodiversity

Over the last few years, the concept of Integrated Soil Management (ISM) and Integrated Plant Nutrient Management (IPNM) has been gaining acceptance. It advocates the careful management of nutrient stocks and flows in a way that leads to profitable and sustained production. ISM emphasises the management of nutrient flows, but does not ignore other important aspects of the soil complex, such as maintaining organic matter content, soil structure and soil biodiversity.

Soil biodiversity reflects the mix and populations of diverse living organisms in the soil - the myriad of invisible microbes to the more familiar macro-fauna such as earthworms and termites. These organisms interact with one another and with plants and animals forming a web of biological activity. Environmental factors, including temperature, moisture, acidity and several chemical components of the soil affect soil biological activity. Clearly, for a productive sustainable agriculture, the complex interaction among these factors must be understood so that they can be managed as an integrated system.

Soil biota and soil ecosystem health

Soil health can be defined as the continued capacity of soil to function as a vital living system, within ecosystem and land-use boundaries, to sustain biological productivity and maintain their water quality as well as plant, animal, and human health.

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

Biological management of soil fertility

The central paradigm for the biological management of soil fertility is to utilise farmer's management practices to influence soil biological populations and processes in such a way as to achieve desirable effects on soil productivity. Biological populations and processes influence soil fertility and structure in a variety of ways, each of which can have an ameliorating effect on the main soil-based constraints to productivity:

- Symbionts such as rhizobia and mycorrhiza increase the efficiency of nutrient acquisition by plants;
- A wide range of fungi, bacteria, and animals participate in the process of decomposition, mineralization, and nutrient immobilisation and therefore influence the efficiency of nutrient cycles;
- Soil organisms mediate both the synthesis and decomposition of soil organic matter and therefore influence cation exchange capacity, the soil N, S, and P reserve, soil acidity and toxicity; and soil water holding capacity;
- The burrowing and particle transport activities of soil fauna, and the aggregation of soil particles by fungi and bacteria, influence soil structure and soil water regime.

The role of soil biota/ biodiversity in sustaining the productivity of agricultural systems.

A fundamental shift is taking place worldwide in agricultural research and food production. In the past, the principal driving force was to increase the yield potential of food crops and to maximise productivity. Today, the drive for productivity is increasingly combined with a desire and even a demand for sustainability. Sustainable agri-culture 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 will require the optimal use and management of soil fertility and soil physical properties. Both rely on soil biological process and soil biodiversity. This implies management practices that enhance soil biological activity and thereby build up long-term soil productivity and health. Such practices are of major importance in marginal lands to avoid degradation, in degraded lands in need of restoration and in regions where high external input agriculture is not feasible.

Good agronomic practices to enhance soil biological activity

Much attention has been paid in recent decades to mitigating soil erosion through physical conservation measures and to providing supplementary nutrients and water to meet crop needs. Less consideration has been paid to the soil as a dynamic living resource.

The principles to enhance soil biological activity

Capturing the benefits of soil biological activity for agricultural production requires adhering to the following ecological principles:

■ Supply organic matter

Most soil organisms rely on organic matter for food. Each type of soil organism occupies a different niche in the web of life and favours a different substrate and nutrient source. Thus a rich supply and varied source of organic matter will generally support a wider variety of organisms.

■ Increase plant varieties

Crops should be mixed and their spatial-temporal distribution varied to create a greater diversity of niches and resources that stimulate soil biodiversity.

- *Create a diverse landscape.*

Diverse habitats support complex mixes of soil organisms;

- *Rotate crops.*

Crop rotation allows nutrient demand and rooting depth to be varied, thus reducing nutrient mining and hardpans. This encourages the presence of a wider variety of organisms, improves nutrient cycling and improves natural processes of pest and disease control.

■ Protect the habitat of soil organisms

Stimulate soil biodiversity by improving soil living conditions: such as aeration, temperature, moisture, and nutrients quantity and quality.

- *Reduce tillage;*
- *Minimise compaction;*
- *Minimise the use of pesticides, herbicides and fertilisers;*
- *Improve water drainage*
- *Maximise soil cover.*

Farming practices change soil life

Direct: methods of intervening in the production system aim to alter the abundance or activity of specific groups of organisms (inoculation and direct manipulation of soil biota).

Indirect: interventions are means of managing soil biotic processes by manipulating the factors that control biotic activity (habitat structure, microclimate, nutrients and energy resources) rather than the organisms themselves.

Common constraints to the use of different soil biological management practices include the labour and time costs, monetary cost, availability of inputs e.g. planting material/inoculants and capacities, as well as social acceptability.

FARMER'S MANAGEMENT PRACTICES FOR INFLUENCING SOIL FERTILITY THROUGH MANIPULATION OF BIOLOGICAL PROCESSES

Management practices	Biological processes influenced	Soil fertility effects
Biological Inputs • Inoculation with nitrogen-fixing bacteria, mycorrhizas, etc • Introduce bacteria, nematodes, or insects that are predators of pest organism	• Nitrogen fixation • Facilitate nutrient uptake • Fauna burrowing • Decomposition	• Increase nutrient acquisition and H_2O uptake; • Increased heavy metals tolerance • Improve soil structure and porosity • Stimulation of nutrient release
Organic matter inputs • Crop residues • Root residues • Weed residues (without seeds) • Tree litters/pruning • Green manure • Farmyard manure • Precomposting • Others	• Decomposition • SOM synthesis • Soil fauna and microflora growth	• Increased nutrient availability • Increased nutrient storage / exchange • Soil physical structure improved • Soil water regimes improved • Increase soil buffer capacity • toxicity diminished • Macropore formation improved (macrofauna) • Soil aggregation improved (microfauna)
Inorganic fertiliser inputs	• Mycorrhiza function inhibited (at high P levels) • N-fixation inhibited (at high N levels) • Mineralization / immobilisation balance changed	• Direct transfer of nutrient to plant increased • Nutrient losses increased risk • Acidification risk • Increased nutrient availability
Tillage	• Decomposition stimulated by OM incorporation • SOM decay stimulated by aeration and particle size reduction • Faunal and microbial population diminished	• Short-term nutrient availability increased • Root growth in tilled layer promoted • Nutrient losses increased • Long-term nutrient storage diminished
Pesticides	In general non target organism populations diminished or eradicated	• Destabilisation of nutrient cycles • Loss of soil structure

Why soil biodiversity for farmers, extensionists and policy makers.

How can you benefit from better management of the soil biota?

Agriculture provides a major share of national income and export earnings in many developing countries, while ensuring food security, income and employment to a large proportion of the population. Farmers are increasingly indicating that declining soil fertility is becoming a major worry. As a result, controlling erosion and improving the management of soil fertility have become major issues on the development policy agenda.

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

Direct and indirect benefits of adopting biological management, of soil to sustain agriculture production are:

- ***Economic benefits***:

Reduce input costs by enhancing resource use efficiency (especially decomposition and nutrient cycling, nitrogen fixation and water storage and movement).
It is estimated that the value of "ecosystem services" (e.g. organic waste disposal, soil formation, bioremediation, N_2 fixation and biocontrol) provide each year by soil biota in agricultural systems worldwide may exceed US$ 1,542 billion.

- ***Environmental protection***

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

- ***Food security***

Improve yield and crop quality (especially through controlling pests and diseases and enhancing plant growth). Below ground biodiversity determines resource use efficiency, as well as the sustainability and resilience of low-input agro-ecological systems, which ensure the food security of much of the world's population, especially the poor. Some soil organisms are consumed as an important source of proteins by different cultures and others are used for medicinal purposes.

ESSENTIAL FUNCTIONS PERFORMED BY THE DIFFERENT MEMBERS OF THE SOIL BIOTA

Functions	Organisms involved
Maintenance of soil structure	Earthworms, arthropods, soil born fungi, mycorrhizas, plant roots, and some other microorganisms.
Regulation of soil hydrological processes	Most invertebrates like earthworms, arthropods, and plant roots.
Gas exchanges and carbon sequestration	Mostly microorganisms and plant roots, some C protected in large compact biogenic invertebrate aggregates.
Soil detoxification	Mostly microorganisms
Decomposition of organic matter	Various saprophytic and litter feeding invertebrates (detrivores), fungi, bacteria, actinomycetes and other microorganisms.
Suppression of pests, parasites and diseases	Mycorrhizas and other fungi, nematodes, bacteria and various other microorganisms, collembola, earthworms, various predators.
Sources of food and medicines	Plant roots, various insects (crickets, beetle larvae, ants, termites), earthworms, vertebrates, microorganisms and their by-products.
Symbiotic and asymbiotic relationships with plant and their roots	Rhizobia, mycorrhizae, actinomycetes, diazotrophic bacteria and various other rhizosphere microorganisms.
Plant growth control (positive and negative)	Direct effects: plant roots, rhizobia, mycorrhizas, actinomycetes, pathogens, phytoparasitic nematodes, rhizophagous insects, plant growth promoting rhizosphere microorganisms, biocontrol agents. Indirect effects: most soil biota.

The strategic framework

There are many myths and unknowns since much of soil biodiversity is invisible. How do farmers know what the organisms are and which have what effects: good or bad? The promotion of soil biological management requires efforts to bring together indigenous knowledge/innovation and conventional science through participatory research methods and ecosystem approaches to soil management that help farmers understand soil-plant-water-pest-livestock interactions.

The ecosystem approach

An ecosystem is a complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit. A hierarchical perspective that considers the different levels of organization in the system and their interconnections at various scales is ideal for characterising the components of the system and facilitating an understanding of the process. Successful land management requires approaches that protect all resources, including soil, water, air, plants, animals and humans. Soil is complex and requires an ecological approach. The ecosystem approach, as adopted under the Convention on Biological Diversity (CBD), is a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use and the fair and equitable sharing of the benefits arising out of the utilization of genetic resources. Since ecosystems are dynamic, spatial and temporal variability, they continually adapt, and evolve, so management needs to be adaptive to allow for testing of management policies.

The ecosystem approach does not preclude other management and conservation approaches, strategies and methodologies (i.e. biosphere reserves, protected areas and single-species conservation programmes), but could rather integrate all these. There is no single way to implement the ecosystem approach, as it depends on local, provincial, national, regional or global conditions.

The need for teamwork

Preserving the soil system and its inter-relationships is imperative to sustained and productive agricultural systems. The complexity of soil biodiversity calls for knowledge and teamwork from different disciplines. Adopting an integrated and holistic approach that also seeks cooperation and collaboration with stakeholders at all stages of the decision making process and coordinating actions to link programmes on soil biology management with soil fertility management is imperative.

Participatory approach: placing the farmer centre-stage

Achieving sustainable agriculture requires an approach, which combines the skills and knowledge, acquired at individual farmer level and communal level with modern scientific knowledge. Much greater commitment is needed to support effective participation by farmers in joint learning and experiential research for soil biological management and sustained soil productivity. There is increasing attention being paid at international and national levels to ways of promoting the sharing of knowledge and learning processes, which can build on the respective strengths of both farmer wisdom and scientific understanding. At FAO, the *Farmers Field School* approach has proven a successful means to enhance farmers' motivation, inherent skills, knowledge and capability to develop and disseminate their own technologies suited to their own contexts.

Why is FAO paying attention to soil biodiversity?

In the work of the Food and Agriculture Organisation of the United Nations (FAO), together with its Member countries, it has been widely recognised that there is a need for holistic consideration of soil health and integrated soil management approaches through integrating biological, chemical and physical considerations. The Conference of the Parties to the CBD identified soil biodiversity as an area requiring particular attention in regard to agricultural biodiversity. FAO is interesting in helping to promote a Soil Biodiversity Initiative, for increased attention to the role of soil biodiversity in sustainable agriculture and to efforts to enhance its conservation and effective management. This responds to both the decisions of the COP/CBD and the mandate and programme of work of the Land and Water Development Division of the Agriculture Department of FAO.

Programmes and Contact Persons.

- FAO-AGLL Portal: Soil Biodiversity: http://www.fao.org/ag/AGL/agll/soilbiod/default.htm

Join the "RooTalk Network"

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