Conservation and Sustainable Management of Below-Ground Biodiversity: A project executed by TSBF-CIAT with co-financing from GEF and implementation support from UNEP

What is below ground biodiversity?

In a balanced soil, plants grow in an active and vibrant environment. The mineral content of the soil and its physical structure are important for their well-being, but it is the life in the earth that powers its cycles and provides its fertility. Without the activities of soil organisms, organic materials would accumulate and litter the soil surface, and there would be no food for plants. The soil biota includes:

- Megafauna: size range 20 mm upwards, e.g. moles, rabbits, and rodents.
- Macrofauna: size range 2-20 mm, e.g. woodlice, earthworms, beetles, centipedes, slugs, snails, ants, and harvestmen.
- Mesofauna: size range 100 micrometre-2 mm, e.g. tardigrades, mites and springtails.
- Microfauna and Microflora: size range 1-100 micrometres, e.g. yeasts, bacteria (commonly actinobacteria), fungi, protozoa, roundworms, and rotifers.

Of these, bacteria and fungi play key roles in maintaining a healthy soil. They act as decomposers that break down organic materials to produce detritus and other breakdown products. Soil detritivores, like earthworms, ingest detritus and decompose it. Saprotrophs, well represented by fungi and bacteria, extract soluble nutrients from the soil complex and convert them to form that are available to plants.

The soil organism community, including bacteria, fungi, protozoa and invertebrates, constitute the below ground soil biological diversity (BGBD). The BGBD organisms are extremely diverse with, for example, over 1000 species of invertebrates identified in $1m^2$ of soil in temperate forests. The diversity of the microbial component of the soil may be even greater than that of the invertebrates yet their importance is only just

beginning to be realized through phylogenetic and ecological studies using molecular methods. Currently, few data are available from tropical regions, where the highest levels of diversity are expected to be.

Bacteria grow in the soil, acidic hot springs, radioactive waste, water, and deep in the Earth's crust, as well as in organic matter and the live bodies of plants and animals. Typically a few micrometers in length, bacteria have a wide range of shapes, ranging from spheres to rods and spirals. There are typically 40 million bacterial cells in a gram of soil and a million bacterial cells in a millilitre of fresh water; in all, there are approximately five nonillion (5×1030) bacteria on Earth, forming much of the world's biomass. Bacteria are vital in recycling nutrients, with many steps in nutrient cycles depending on these organisms, such as the fixation of nitrogen from the atmosphere and putrefaction. However, most bacteria have not been characterized, and only about half of the phyla of bacteria have species that can be grown in the laboratory.

Abundant worldwide, most fungi are inconspicuous because of the small size of their structures, and their cryptic lifestyles in soil, on dead matter, and as symbionts of plants, animals, or other fungi. They may become noticeable when fruiting, either as mushrooms or molds. Fungi perform an essential role in the decomposition of organic matter and have fundamental roles in nutrient cycling and exchange. They have long been used as a direct source of food, such as mushrooms and truffles, as a leavening agent for bread, and in fermentation of various food products, such as wine, beer, and soy sauce. Since the 1940s, fungi have been used for the production of antibiotics, and, more recently, various enzymes produced by fungi are used industrially and in detergents. Fungi are also used as biological agents to control weeds and pests. Many species produce bioactive compounds called mycotoxins, such as alkaloids and polyketides, that are toxic to animals including humans.

Why conserve and manage below-ground biodiversity?

Soil organisms contribute a wide range of essential services to the sustainable functioning of all ecosystems. The services constitute an important resource for the sustainable management of agricultural productivity including the provision of food and fibre. Apart from the importance in agriculture there is a prospect of finding new genetic resources. Thousands of undiscovered species have uses in chemical and other processes which could have wide applications in agriculture, pharmaceuticals and industry in general.

Loss of below-ground biodiversity (BGBD) occurs with conversion of forests to agricultural land and with further intensification of agricultural activities. Loss in BGBD reduces sustainability of agricultural production, due to impaired resilience of agricultural systems to adverse climatic events, pest and diseases and other threats. Likewise loss of BGBD erodes the genetic pool that is represented in the soil biota.

BGBD due to their role in carbon sequestration offers an opportunity for managing and maintaining soil carbon. This has a direct impact on global warming and climate change. Global warming is the increase in the average temperature of the Earth's near-surface air and oceans since the mid-20th century and its projected continuation. Global Earth's-near surface temperature

increased 0.74 °C and 1.33 °F between the start and the end of the 20th century. Most often, mitigations involve reductions in the concentrations of greenhouse gases, either by reducing their sources or by increasing their sinks. The main natural sinks known are the oceans, soil organic matter (SOM) and photosynthetic plants and algae.

However the activities of soil organisms and their possible role in carbon sequestration are largely ignored.

Soil carbon which is a major sink of CO_2 is generated through a series of processes. First, plant litter and other biomass accumulate as organic matter in soils, and are decomposed by chemical weathering and biological degradation. Usually, decomposition involves a succession of different organisms. One set of organisms takes over after the last one has eaten what it can, and in doing so, changed the physical and chemical composition of its environment. Thus, ecological succession takes place in the microenvironment created by any decomposing log or animal corpse. For example lignin and cellulose are the major structural components of plant material, and these compounds are very difficult to break down. Only certain organisms can produce the enzymes needed to break the chemical bonds in lignin and cellulose and thus return them to the ecosystem. Fungi and bacteria are by far the most active decomposers. They are remarkably efficient, and the smaller the pieces to be decomposed, the faster these microorganisms are able to do their job. Organic waste, such as leaf matter and the droppings of herbivores, first feeds a host of small animals including insects, earthworms and other small invertebrates living in the plant litter).

Our hypothesis is that sustainable management of BGBD will make production systems less dependent on external inputs such as inorganic fertilizers and pesticides, and thereby improving resilience, sustainability and conservation of the soil genetic resources as well as sequestering carbon into the soil and thereby mitigating global warming and climate change.

Functions of Biodiversity in Soil

Soil organisms contribute a wide range of essential services to the sustainable functioning of all ecosystems

- *They are the driving agents of nutrient cycling;*
- *They regulate the dynamics of soil carbon sequestration and greenhouse gas emission;*
- *They modify soil physical structure and water regimes;*
- *They enhance the amount and efficiency of nutrient acquisition by the vegetation through mycorrhiza and nitrogen fixing bacteria; and*
- *They influence plant health through the interaction of pathogens and pests with their natural predators and parasites.*

A global initiative for conserving and managing BGBD

An international team of scientists are investigating the wealth of life in the soil of seven tropical countries in the BGBD project. The team hopes its work will help to improve the level of soil nutrients and increase farmers' harvests.

The project is being conducted in seven countries including: Brazil, Cote d'Ivoire, India, Indonesia, Kenya, Mexico, and Uganda. Benchmark areas have been selected that represent ecoregions with global significance, ranging from the Amazonian low lands to the Himalayas highlands. A number if institutes in each of the countries is involved in this project that is administered by the Tropical Soil Biology and Fertility Institute of CIAT (TSBF-CIAT) whose headquarters are in Nairobi, Kenya. GEF is the main donor of the project, with a contribution of over 9 million US dollar to a project with a total cost amounting to nearly USD 16.5 million.

Key elements of the project

The project's purpose was to offer means by which below-ground biodiversity (BGBD) could be adequately managed and conserved in tropical agricultural landscapes as the basis for enhancing agricultural productivity and production. The project's aim was to build capacity for the conservation and sustainable management of the soil organisms, backed by South to South exchanges with training backed by institutions of international acclaim. In order to achieve the goals the project produced five primary outcomes that included:

1. Developed and published internationally accepted standard methods for characterizing and evaluating BGBD, including a set of indicators for monitoring BGBD loss.
   (a) Made an inventory of BGBD in 11 benchmark sites that represent a range of globally significant ecosystems and land-uses in seven tropical countries.
   (b) Developed a global information exchange platform including a global website and country websites where information and the projects data is stored.
2. Researched on sustainable and replicable management methods for BGBD conservation in diverse ecosystems and land use kinds in all the seven countries where the project was implemented.
3. Installed demonstration sites on farmers' fields in diverse but representative land use kinds in seven countries.
4. Are recommending alternative land use practices, and advisory support systems, with policies that will enhance the conservation of BGBD.
5. Built capacity of all associated research institutions, universities and stakeholders to implement strategies for the conservation and management of BGBD in a sustainable and efficient manner including appending BGBD curriculum in tertiary institutions of learning.
6. During the project's life-span more than 200 scientists' participated in different thematic areas with more than 150 students trained at PhD, MSc and BSc levels.
7. The project has published more than 50 papers in refereed journals, written several books, bulletins, posters and made technical presentations in local and international forums.

Partnership and organization of the project

Renowned scientists from various research institutions are allied with representatives from government research bodies and NGOs to implement the country programmes. Also included are invited scientists from internationally recognized institutions who advise the working groups on technical matters. The supervision of the project is vested upon a project advisory committee, with representatives from each of the countries and from international organizations in the field of conservation.

Wide spectrums of stakeholders are represented from the scientific community with training in BGBD taxonomy, ecology, economic valuation and management of agro-biodiversity. Aldo included are members of both the agricultural and environmental sectors from practitioner, to decision-maker including those responsible for awareness creation and dissemination of knowledge.

Sustainable management

Among the alternatives for agricultural intensification are those that deliberately retain higher levels of biodiversity. Examples include agroforestry systems, inter-cropping, rotational farming, green cover-cropping and integrated arable-livestock systems. All of these approaches are more or less closely derived from traditional practices of agriculture in the tropical regions. The values perceived in this dependence on diversity, as opposed to the homogeneity of modernized agriculture, are multiple and extend beyond the market value. They include, in addition to product profitability, the desire for multiple products, the spreading of risk, the social and cultural value of certain products and perceptions of resource conservation and enhanced pest control. The total biological diversity of such systems can be very high. The deliberate maintenance of even a limited diversity of crops and other plants (particularly if trees are included) results in substantial multiplication of the associated diversity. There is evidence that mosaics of different systems, including those at different levels of intensification, maintain a higher diversity than monotypic landscapes of any kind including natural ecosystems on their own.

Raising awareness and policy recommendations

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

Development of appropriate policies requires, in particular, reconciling the needs for meeting food-sufficiency by high levels of agricultural productivity with those for conserving biodiversity and environmental protection. Recommendations should be based on data collected on changes in diversity within changing agricultural landscapes and on the assumption that there is necessity for a trade-off between biodiversity and agricultural productivity. There is now growing evidence that farm landscapes can conserve significant levels of biodiversity.

TSBF-CIAT is dedicated to the production of international public goods for the benefit of land-users of the tropics by the application of the knowledge generated through research on soil biology.

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