Chapter 5
Effect of land-use and management practices on soil macrofauna

IMPORTANCE OF MANAGEMENT PRACTICES AND TRENDS IN SOIL MACROFAUNA COMPOSITION

Land-use management has an important impact on soil and its functional role in maintaining ecosystem processes. It generally results in dramatic and rapid changes in vegetation that are likely to affect soil invertebrate communities significantly (Box 2).

BOX 2

Impact of land management on soil macrofauna in the savannahs of Colombia

Burned and grazed savannahs:

- fire (short-term effect):
  - low population density, biomass and diversity,
  - fauna accumulated in deeper soil layers (10–20 and 20–30 cm),
  - earthworms dominant;
- fire (after six months):
  - soil fauna regenerated,
  - no differences compared with the initial savannah;
- grazing:
  - decrease in diversity,
  - decrease in earthworm biomass,
  - increase in the biomass of termites, Coleoptera, Arachnida and Myriapoda.

Improved pastures (with forage grasses and legumes):

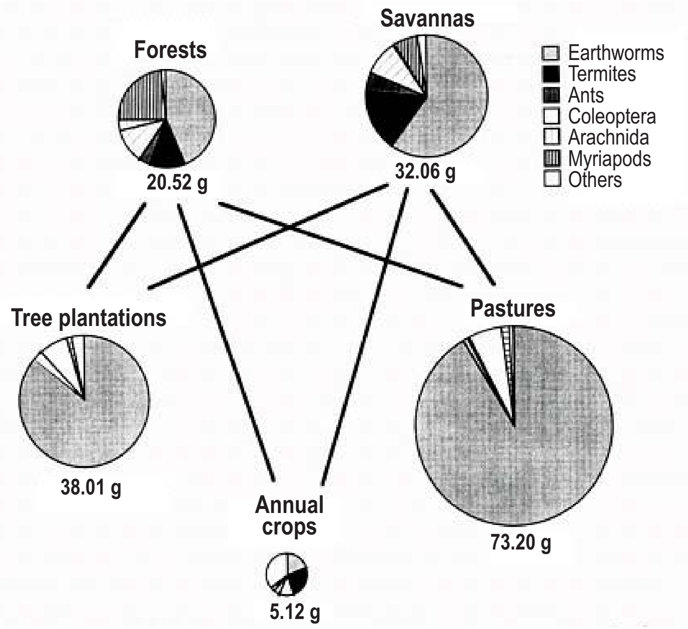
- earthworms predominate,
- high densities of Coleoptera, Arachnida and other invertebrates.

Annual high-input cropping (tillage + fertilizers + pesticides):

- lowest biomass, density and diversity.

Source: Decaëns et al. (1994).

FIGURE 4
Composition of soil macrofauna communities under various conditions



Source: Lavelle *et al.* (1999).

The biodiversity of animals and plants generally declines as an inverse function of the intensity with which crops are cultivated using mechanized methods and agrochemicals, that is agricultural intensification. The intensity with which soils are cultivated also depletes soil-organism communities as a consequence of the toxic effects of agrochemicals, the physical disruption of their habitats, and the reduction in litter availability and hence the SOM resource base. Thus, management practices have important consequences on the composition and abundance of soil macrofauna communities (Figure 4).

Lavelle *et al.* (1994) identified the major trends in tropical soil macrofauna composition as follows. Termites and/or earthworms tend to be dominant in most cases. Termites have adapted to a wide range of semi-arid systems where earthworms are not found. Earthworms are best represented in grasslands in tropical humid areas. They are sensitive to the nutrient status and organic content of soil (Fragoso and Lavelle, 1992). Litter arthropods are predominant where sufficient litter is available. They are represented mainly by millipedes or beetles.Lands with natural vegetation like forests have a highly diversified vegetation. The quality and quantity of leaf litter and the important root production create a particular soil environment that favours the development of a rather diverse and abundant soil macrofauna. When vegetation is cleared and the soil used for cropping, the communities of soil macrofauna are highly depleted as a consequence of an important modification of soil microclimate, the reduction in the quantity and quality of organic matter, the physical perturbation induced by tillage, and the effects of fertilizers and non-targeted pesticides. Earthworms and litter communities soon disappear and are not replaced. Other macrofauna groups such as termites (mainly humivorous) tend to be more persistent. Soils under pasture are more favourable for earthworm development as there is an improvement in leaf-litter quality, a great quantity of manure brought to the soil, and a more limited physical soil perturbation unless seriously overgrazed. Other soil management practices, such as palm tree plantations with herbaceous legume cover or cocoa with a layer at the soil surface and high trees, usually have diverse soil biotic communities (Lavelle *et al.*, 1999).

BOX 3

Management intensification and its effects on macrofauna

- Characteristics of management intensification:
  - reduction in vegetation diversity;
  - decrease in the quantity of leaf litter (organic matter);
  - decrease in the density of the root system;
  - modification of soil microclimate;
  - application of non-targeted pesticides.
- Effects on soil macrofauna communities:
  - decrease in diversity, density and biomass of soil organisms;
  - reduction in or disappearance of epigeic and anecic categories of earthworms and litter epigeic fauna;
  - soil macrofauna is mainly located deep in the soil;
  - dominance of persistent groups such as termites and ants;
  - increase in pest organisms;
  - the activity of beneficial organisms (earthworms and ants) may become detrimental because of the lack of other soil-organism activities (complementarity).

Thus, land management has a dramatic effect on soil macrofauna communities (Box 3). Primary forests have rather diverse and abundant fauna with density and biomass two to three times higher than that in managed systems. Epigeic and litter fauna is well represented and the biological activity is mainly concentrated in the top 20 cm of soil.

Cropping results in a dramatic decrease in taxonomic richness, density and biomass. Termites are the major component. Earthworms are mainly represented by endogeic species and their distribution in the soil profile is relatively deep (20–30 cm).

Pastures can have very different communities with an overwhelming dominance of populations of the peregrine (wandering) earthworm *Pontoscolex corethrurus*. This is an endogeic earthworm frequently present in disturbed areas and it may build up very large populations in pastures. Other groups of importance are termites and ants. Litter-dwelling populations represent only 4.3–10.5 percent of individuals, most of them concentrated in the upper 10 cm.

Short fallows present low taxonomic richness but increased densities and a slight evolution towards the original forest situation. The association of palm trees with a leguminous cover crop appears to be the most conservative system with both elements of the primary forest and introduced ones. This kind of system can present a large earthworm community with forest and pasture species and high densities of termites and epigeic litter detritivores, which live and feed on the soil surface (Lavelle and Pashanasi, 1989).

MANAGEMENT PRACTICES WITH POSITIVE IMPACTS ON SOIL MACROFAUNA

Examples of positive impacts

Some agricultural management practices have positive impacts on soils, increasing SOM levels and improving soil functioning and plant productivity. For example, conservation agriculture can increase crop production while reducing erosion and reversing soil fertility decline. SOM and biological activity in the rootzone are stimulated by continual additions of fresh organic matter (crop residues, cover crops and manure).

Indirect management practices

Where indirect management practices are used, interventions are a 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 (Hendrix *et al*., 1990). Examples of indirect interventions include most agricultural practices, such as application of organic materials to soil, tillage, fertilization, irrigation, green manuring and liming as well as cropping system design and management.

In conventional agriculture, soil tillage is considered one of the most important operations for creating favourable soil structure, preparing the seedbed and controlling weeds. However, mechanical implements destroy the soil structure by reducing the aggregate size, and conventional tillage methods are a major cause of soil loss and desertification. A study in France showed that, in fields under reduced or no-tillage and with permanent soil cover, soil organisms can increase by up to four times and the diversity may almost double (Ruiz, 2004). In this kind of management system, the biomass produced is kept on the soil surface and serves as a physical protection of the soil and provides food for the soil fauna.

In general, the vegetal cover on the soil surface creates a more humid environment, which is conducive to the activity of soil organisms. The larger number of earthworms, termites, ants and millipedes combined with a high density of plant roots results in more large pores, which in turn increase water infiltration (Roth, 1985).

Pest management can also benefit from conservation practices that enhance biological activity and diversity, and hence competitors and predators as well as alternative sources of food. For example, most nematode species (especially pathogens) can be reduced significantly by the application of organic matter, which stimulates the action of several species of fungi that attack nematodes and their eggs.

An agricultural technique used in a number of tropical countries in Africa, Asia and South America to ameliorate soil conditions for crops is "ecobuage". This is a complex agricultural system that entails incinerating herbaceous vegetation piled up in mounds and buried under a layer of soil taken from the surroundings. It is a traditional system that is more evolved than the slash-and-burn technique often used in intertropical zones.

A study conducted in the region of Bouenza (Congo) showed that the use of "Maalas" (ecobuage) improved soil macrofauna communities, particularly earthworm communities. The technique supplied the soil with mineral nutrients through slashes, and increased soil pH. The improvement in soil macroinvertebrate communities improved soil structural stability, creating good conditions for plant root development. Thus, this system enabled the cultivation of plants that are demanding in terms of nutrient supply. In addition, the earthworm activity improved soil porosity (macroporosity became more important), allowing plant roots to go deeper into the soil. Improved soil structure enabled the cropping of plants with tubercules that need an aerated soil for their development (Mboukou, 1997).

Experiments at Carimagua (Colombia) suggest that the spatial and temporal array of parcels allocated to different crops may favour the conservation of locally high earthworm-population density and diversity. These spots may serve as reservoirs and refuges for the colonization of depopulated areas (Lavelle *et al*., 1999).

Direct management practices

These practices involve intervening in the production system in an attempt to alter the abundance or activity of specific groups of organisms (Hendrix *et al*., 1990). Examples of direct interventions include: (i) inoculation of seeds or roots with rhizobia, mycorrhizae, fungi and rhizobacteria for enhanced soil fertility; and (ii) inoculation of soil or the environment with biocontrol agents (pest or disease), antagonists and beneficial fauna (e.g. earthworms).

Mycorrhizal microorganisms colonize the roots of many plants through a symbiotic relationship. This relationship helps the plants to be more efficient at obtaining available nutrients, such as P and N, and water, both elements vital to plant survival. Mycorrhizae increase the surface area associated with the plant root, which allows the plant to reach nutrients and water that might not be otherwise available. The application of N-fixing rhizobia for the production of common beans in the Parana region in Brazil increased yields by almost 50 percent (FAO report, 2000). This kind of intervention might be a way of reversing the poor yields and nitrogen depletion that plague tropical areas.

In southern India, the long-term exploitation of soil under tea gardens has led to impoverishment of soil fertility and stabilization of yields despite increasing applications of external inputs such as fertilizers and pesticides. The application of high-quality organic matter and earthworms was very effective at increasing tea yields (more than by the application of fertilizers alone) owing to their favourable effects on physical and biological soil properties. Yields increased by 79.5–276 percent (Senapati *et al*., 1999).

The loss of abundance and diversity of communities under annual crops results invariably in a loss of certain important soil functions (Lavelle, 1996; Giller *et al*., 1997).

The results obtained in these studies suggest various options for conserving and stimulating the activities of soil macrofauna. For example, the negative effects of annual crops could be reduced by decreasing the intensity and frequency of perturbations such as tillage and the use of pesticides, and by increasing the quantity and quality of the energy resources used by the macroinvertebrates, e.g. the use of legume cover crops and the maintenance of crop residues. Integrated systems of short phases of crops with longer periods of pastures (3–5 years) are also an option for maintaining macroinvertebrate populations as well as bringing other benefits for soil physical and chemical parameters (Thomas *et al*., 1995).

Organic manuring helps to enrich or favour the multiplication of many soil fauna and microorganisms including those antagonistic to soil pests. In recent years, the application of greater quantities of synthetic fertilizers has been very common in contrast to the negligible use of organic manures. The eggs, larvae and pupae of soil insects are liable to be affected either by the soil-inhabiting pathogens or their toxins. However, the absence of organic manures in the soil enables the above pests to thrive owing to the depletion of the natural biotic restricting factors. The increasing use of pesticides has also upset the balance of life in soil when they have been applied directly in the soil and by drip from the foliage. Their subsequent incorporation into soil can also reduce the natural enemies of soil insects.

Certain practices such us improved pasture can result in increased populations of soil macrofauna. The similarity of the original ecosystem and the derived agro-ecosystem tends to be a major determinant of native species' survival, adaptation, resilience and stability within the boundaries of ecosystem management.

The spatial arrangement of pastures alongside cropped plots can accelerate the recovery of macrofauna populations in the cropped plots. Beneficial species, which can be more rapidly established, can also help reverse some of the degrading effects of cropping on soil structure, thereby avoiding the need to solve soil degradation problems with expensive, machinery-intensive strategies. Thus, earthworms become a resource that can be harnessed to improve ecosystem health (Jimenez and Thomas, 2001).

MANAGEMENT PRACTICES WITH NEGATIVE IMPACTS ON SOIL MACROFAUNA

Examples of mismanagement

Example 1

In Corrientes Province (northern Argentina), the use of heavy machinery to prepare soil for rice culture has caused soil compaction (Folgarait *et al*., 1998). This type of soil management has led to important changes in soil macrofauna abundance and diversity. After several years of culture, fields are left fallow. During this period, the soils are recolonized by soil fauna. However, the soil compaction makes this process difficult and the composition of the soil macrofauna is dominated by the ant species *Camponotus punctulatus*. These ants usually build their nests in soil, but soil compaction modifies their behaviour and they construct epigeic mounds. As a consequence, the soil becomes covered by ant mounds 1–2 m high, which can reach densities of more than 2 000 mounds/ha in 2–3 years (Plate 6). This action completely prevents the possibility of further agricultural uses of the land, without extensive and expensive measures to destroy the ant nests and the ant populations.

Example 2

In Manaus (Brazil), the transformation of forest zones into pastures leads to the degradation of the soil as a consequence of mismanagement, phytosanitary problems, poor soil fertility and soil structural modification (linked to fauna activity). Where the forest is converted to pasture, first the machines and then the cattle trampling the soil lead to severe soil compaction, particularly in the top 5–10 cm. However, the most important consequence is that the native soil macrofauna communities are altered radically, with most of the native taxa disappearing. These are replaced by an opportunistic invading species: the earthworm *Pontoscolex corethrurus*, which increases in biomass to represent almost 90 percent of the total soil-fauna biomass.

This species produces more than 100 tonnes/ha of casts, dramatically decreasing soil macroporosity down to a level equivalent to that produced by the action of

Plate 6

Field invasion by the ant species Camponotus punctulatus. 1) natural grassland; 2) 2–3 years rice-field fallow; and 3) 3–4 years rice field fallow.

heavy machinery on the soil (2.7 cm^3/100 g). During the rainy season, these casts plug the soil surface, saturating the soil and producing a thick muddy layer where anaerobic conditions prevail (increasing methane emission and denitrification). In the dry season, desiccation cracks the surface and the inability of roots to extract water from the soil causes the plants to wilt and die, leaving bare patches in the field (Chauvel *et al*., 1999).

However, this earthworm species can have either a positive or a negative effect in the same soil. For example, Duboisset (1995) verified in a study at Yurimaguas (Peru) that, in the absence of good quality organic additions, *P. corethrurus* causes soil compaction and an increase in dense zones at the surface. However, where crop residues and leguminous mulch are present, the activity of the earthworm translates into a decrease in soil density and a transformation of the pore size distribution with the development of an interaggregate macroporosity.

Example 3

In temperate zones (the Netherlands), some farmers contacted scientists because of an invasion by lumbricid earthworms (*Aporrectodea caliginosa* and *A. rosea*) in the soil. These earthworms species were creating massive structure (similar to that created by *P. corethrurus* in Amazonian pastures) in potato fields (Ester and van Rozen, 2000). Problem areas in the fields with cloddy, compacted structure were identified and these were always associated with high earthworm numbers. When the potatoes growing in these problem areas were harvested, large soil clods (up to 50 cm) were harvested together with the potatoes, rendering the harvesting process impossible and reducing the quantity and quality of the potatoes.