

EXERCISE 7: EFFECT OF SOIL FAUNA ON SOIL STRUCTURE (SO AFFECTING POROSITY AND WATER INFILTRATION)

Background

Under forest, the great production and cycling of foliage results in much biological activity, humus formation, and hence a dark coloured topsoil. Because of the great number of insects and worms, there are large pores, which allow water infiltration. In contrast, under annual crops, leaf production is much lower, the biomass is largely removed, the soil is tilled several times each year and becomes much drier. Consequently, less food and moisture are available for earthworms and insects, and their habitat is repeatedly disturbed or destroyed.

Goal

To recognize the effect of soil fauna in soil structure by comparing small soil blocks of forest, pastures and crops.

Time required

Two hours.

Materials

Paper, pens and a spade.

Procedure

1. Facilitator/trainer to ask participants to describe the main characteristics (in terms of soil structure, soil colour, type and quantity of vegetation, quantity and size of roots, presence of a litter layer, and presence of soil organisms) of a soil under forest, under pasture and under a cropped system. Make a list containing the characteristics for each situation.
2. A field trip is undertaken to study these systems “in situ”, e.g. forest, pasture and intensive or mixed cropping system.
3. At each site, a block of soil is picked up and broken into two parts. There are several points to emphasize to participants:
4. Is the soil easily broken? Is it crumbly?
5. Is there a soil profile from surface to deeper zones? Can you distinguish several layers with different colours?
6. How is the soil to the touch? Can you see soil aggregation? When you pull up a plant and look at its roots, is the soil attached to the roots?
7. Make a drawing of the soil and roots for each situation.
8. At each step (a–d), the trainer explains why soil has these characteristics and the consequences for soil functions. If galleries are found, it could be interesting to follow them and look at the interior. Sometimes roots have colonized earthworm galleries or there are excrements of other animals.
9. Back in the classroom, the list is checked and completed with new information.

BIOGENIC STRUCTURES CREATED BY SOIL MACROINVERTEBRATES

Biogenic structures are those structures created biologically by a living organism. They are mainly earthworm casts, termite mounds and ant heaps. The biogenic structures can be deposited on the soil surface and in the soil, and they generally have different physical and chemical properties from the surrounding soil. The colour, size, shape and general aspect of the structures produced by large soil organisms can be described for each species that produces it. The form of the biogenic structure can be likened to simple geometric forms in order to evaluate more easily the volume of soil moved through each type of structure on the soil surface.

Through these structures, the organisms that produce them can modulate the availability or accessibility of one or more resources used by other organisms. Therefore, their activities, including the building of biogenic structures, are capable of modifying the abundance and/or community structure of populations of other organisms without being involved directly in any trophic relationship (e.g. predation, parasitism, mutualism and competition) (Jones *et al.*, 1994, 1997).

There are several main groups of biogenic structures that are commonly found in agricultural systems, with different importance and consequences in agro-ecosystems.

Earthworm casts

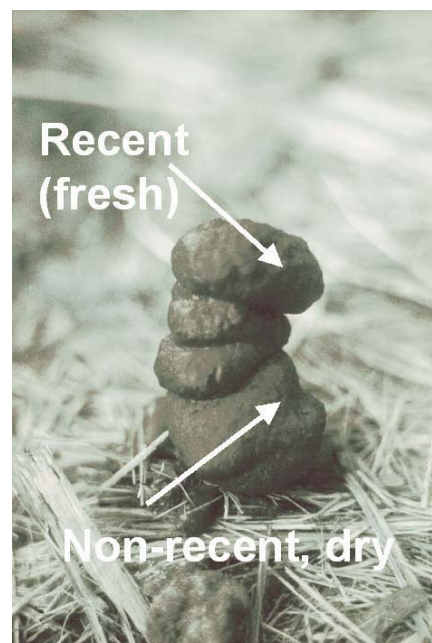
Depending on the size of the earthworms that produce them, casts may range from some millimetres to several centimetres in diameter, weighing only a few grams or more than 400 g:

- **Granular:** These casts are very small and are formed by isolated faecal pellets (Lee, 1985). These casts can be found on the soil surface or in the soil, and are generally produced by epigeic earthworms (Plate 10).
- **Globular:** These casts are larger and formed of large aggregates (Plate 11). These are normally produced by endogeic and anecic earthworms. The casts produced by anecic earthworms comprise an accumulation of somewhat isolated, round or oval-shaped pellets (of one to several millimetres in diameter) that may coalesce into “paste-like slurries” that form large structures (Lee, 1985). Hence, casts are large in size and tower-like, and made of superposed layers of different ages, the older (i.e. dry and hard) located at the base and the more recent (i.e. fresh and soft) on the top. Casts produced by anecic earthworms have a higher proportion of organic matter, especially large particles of plant material and a larger proportion of small mineral components than in the surrounding soil.

Both granular and globular casts are normally found in agro-ecosystems in sub-Saharan Africa. (Plate 10 Plate 11)



P. LAVELLE

Plate 10*Granular casts on the surface of an African soil.*

P. LAVELLE

Plate 11*Globular casts deposited by an African earthworm.*

Earthworm burrows

Earthworms construct burrows or galleries through their movement in the soil matrix. The type and size of the galleries depends on the ecological category of earthworm that is producing it. Anecic earthworms create semi-permanent subvertical galleries, whereas endogeic worms dig rather horizontal burrows. These galleries may be filled with casts that can be split into smaller aggregates by other smaller earthworms or soil organisms. The galleries are cylindrical and their walls coated with cutaneous mucus each time the worm passes through.

Soil microorganisms (bacteria) concentrate on the surface of the gallery walls and within the adjacent 2 mm of surrounding soil. This micro-environment comprises less than 3 percent of the total soil volume but contains 5–25 percent of all the soil microflora; it is where some functional groups of bacteria predominate (Lavelle and Spain, 2001).

Termite mounds

Termite mounds (termitaria) are among the most conspicuous features in sub-Saharan Africa, especially in savannah landscapes. Termite mounds (Plate 12) are of diverse types and they are the epigeal part of a termite nest that originates belowground. Therefore, the termite mounds have at least some part of their structure below the ground surface. In Africa, termites build up half of the biomass of the plains. Their nests may occur in different locations, e.g. within the wood of living or dead trees, in subterranean locations, in other nests formed by

other termite species, and by forming epigeal and arboreal nests.

Termites process large quantities of material in their building activities, thereby affecting the soil properties as compared with surrounding soils (Lee and Wood, 1971). Soil texture and structure are strongly modified in the termite mounds. In general, the soil of termite mounds exhibits a higher proportion of fine particles (clay), which termites transport from the deeper to upper soil horizons. Termites that build epigeic domes normally cement soil particles with variable quantities of salivary secretions and excrements rich in organic matter (Lee and Wood, 1971; Wood and Sands, 1978; Kooyman and Onck, 1987; Lee and Foster, 1991). The enrichment of faecal organic matter explains the differences in concentrations of both C and mineral elements observed between termite mounds and the soil (Lobry de Bruyn and Conacher, 1990; Black and Okwakol, 1997; Lopez-Hernandez *et al.*, 1993).

Ant heaps

Because of their feeding habits, ants may be of less importance than termites and earthworms in regulating soil function. The exception to this is the tropical American genus *Atta*, the leaf-cutting ant. These ants make subterranean nests and their leaf harvesting may lead to enormous incorporations of organic matter and hence nutrients into the soil (Lavelle and Spain, 2001).

Many other ants nest in the soil. In some locations, ants may be important agents of bioturbation (Levieux, 1976; Cowan *et al.*, 1985; Lockaby and Adams, 1985). A number of species also concentrate plant nutrients in their nests and the surrounding soils (Wagner, 1997). Ground-dwelling ants, particularly the mound-building ants, can be considered ecosystem engineers (Folgarait, 1998) in that they modulate the availability of resources and alter the soil and surface environments in ways that affect other organisms (Jones *et al.*, 1994).



C. ROULAND

Plate 12

Two different kinds of termite mounds.

As with termites, ants also modify soil chemical and physical properties by transporting food and soil materials during feeding and mound and gallery construction. These activities affect soil developmental processes and fertility and may modify the nature and distribution of the vegetation.

Where abundant, ants modify the physical structure of the soil through the creation of systems of galleries and chambers. This activity influences soil porosity, aeration, infiltration and drainage, and it also creates habitats for smaller soil organisms.

Ant activities can also influence the chemistry of the soil, notably by increasing the amounts of organic matter, P, K and N in the mounds (Petal, 1978; Carlson and Whitford, 1991). Many soil materials associated with ant mounds induce greater mineralization activities by decomposers (McGinley *et al.*, 1994) and heightened root and mycorrhizal growth.

Roots

Although not generally considered soil organisms, they grow mostly within the soil and have wide-ranging, lasting effects on both plant and animal populations aboveground and belowground. Therefore, they are included in soil biota.

The rhizosphere is the region of soil that is immediately adjacent to and affected by plant roots. It is a very dynamic environment where plants, soil, microorganisms, nutrients and water meet and interact. The rhizosphere differs from the bulk soil because of the activities of plant roots and their effect on soil organisms.

Roots produce exudates that can help to increase the availability of nutrients in the rhizosphere and they also provide a food source for microorganisms (bacteria). This results in a larger number of microorganisms in the rhizosphere than in the bulk soil. Their presence attracts larger soil organisms that feed upon these microorganisms. The concentration of organisms in the rhizosphere can be up to 500 times higher than in the bulk soil.

An important feature of the rhizosphere concerns the uptake of water and nutrients by plants. Plants take up water and nutrients into their roots. The soil organisms near the rhizosphere influence plant roots because:

- they alter the movement of C compounds from roots to shoots (translocation);
- earthworm galleries (burrows) provide an easy pathway for roots to take as they grow through the soil (Plate 10);
- mycorrhizal associations can increase nutrient uptake by plants;
- some of them are pathogenic and can attack plant roots, e.g. nematodes.

Growing roots also produce important soil aggregation through the production of exudates mixed with clay and other mineral particles (Plate 13). Aggregation in the rhizosphere may also result indirectly through the accumulation of faecal pellets of earthworms and other invertebrates that feed in the rhizosphere. This function is very important for preventing soil erosion.

Numerous soil macrofauna groups create biogenic structures (endogeic and epigeic structures) that influence soil processes and structure (Figure 14). Earthworms, termites and ants form the main groups of soil macrofauna recognized as “soil engineers” and the structures that they produce may serve to evaluate their impact on both the soil and other organisms living in it (Anderson and Ingram, 1993; Lavelle, 1997).



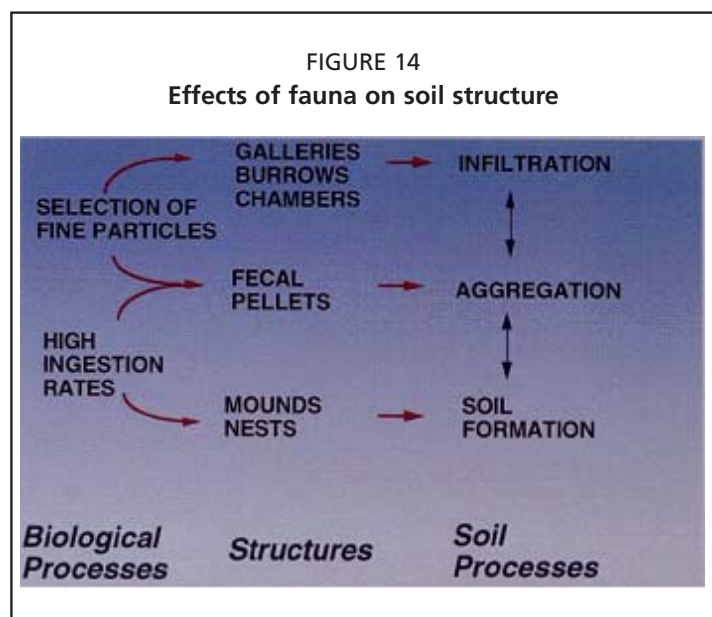
Plate 13
Aggregation effect of roots.

Depending on the type of structure considered the impact on soil will be different. The physical structures produced on the soil surface by ecological engineers can be classified into three main categories (Decaëns *et al.*, 2001) (Box 4):

1. Earthworm casts: very compacted structures, large aggregates, high organic C content and assimilable nutrients.
2. Termite mounds: low compacted structures, large aggregates, high organic C content and assimilable nutrients.
3. Termite surface channels and ant nests: slightly compact and granular aggregates, low organic C content and assimilable nutrients.

Species producing structures typical of groups 1 and 2 (termites and earthworms) accumulate organic C on the soil surface and probably influence organic matter dynamics and the rate of release of mineral elements assimilable by plants (Black and Okwakol, 1997; Lavelle *et al.*, 1998; Lobry-de-Bruyn and Conacher, 1990). These structures are characterized by their large size. In contrast, structures in group 3 (termite channels and ant nests) are much smaller.

The production of aggregates with diverse physical-chemical characteristics may result in the efficient regulation of soil structure. For example, in Côte d’Ivoire, the smaller earthworm species break up the casts produced by larger species, thus preventing excessive



Source: Lavelle (1997).




accumulation on the soil surface (Blanchart *et al.*, 1997; Rossi, 1998). In Carimagua (Colombia), a similar regulation is carried out by termites, it visibly accelerates the degradation of the large casts produced by earthworms (Decaëns, 2000).

In Amazonian pastures (Manaus, Brazil) the presence of abundant populations of the earthworm species *Pontoscolex corethrurus* leads to considerable soil compaction because these populations are not associated with species able to break their casts down into much smaller aggregates (Chauvel *et al.*, 1999).

The following exercises, Exercises 8 and 9, facilitate the observation of biogenic structures created by soil macrofauna and the estimation of quantities of soil moved and relate soil macrofauna to their ecological roles in the soil.

BOX 4

Biogenic structures on soil surface

<i>Structure</i>	<i>Properties</i>	<i>Aspect</i>
Earthworm casts	Very compacted structures Large aggregates High organic matter content High assimilable nutrient content	
Termite mounds	Low compacted structures Large aggregates High organic matter content High assimilable nutrients	
Termite channels Ant nests	Slightly compacted structures Granular aggregates Low organic matter content Low assimilable nutrients	

EXERCISE 8: IDENTIFICATION OF BIOGENIC STRUCTURES AND CALCULATION OF SOIL MOVED BY SOIL MACROFAUNA

Background

This exercise can be done during a transect or a field trip for the observation of soil structure, and also during the agro-ecosystem analysis (AESAs) that is conducted during the Farmer Field School process. Selected types of land-use management will be studied.

Goal

The goals of this exercise are: (i) to identify the main types of biogenic structures and be able to relate them to the soil organisms that produce them; (ii) to highlight the importance of biogenic structures when they are present in the soil and their effects on soil surface topography; and physical characteristics of casts depending on the type, i.e. granular or globular, etc.; and (iii) to relate some important concepts (e.g. aggregation, compaction, nutrient dynamics, and organic matter) to the presence of biogenic structures.

Time required

Two or three hours.

Materials

Pen, pencil, notepad and a ruler.

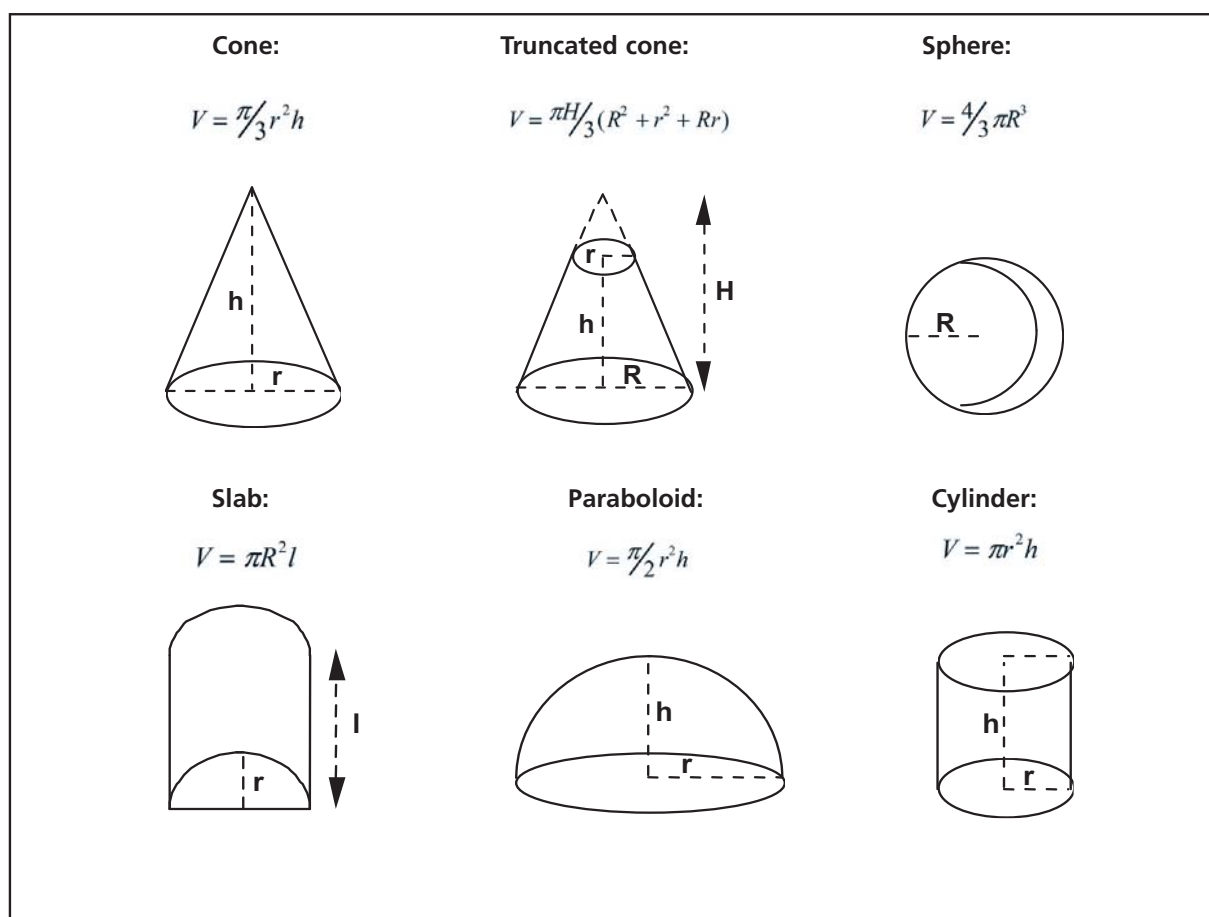
Procedure

1. Facilitator trainer to walk with participants through the field plot and identify those structures on the soil surface that are likely to have been produced by soil organisms.
2. Measure the size of the structures according to simple geometrical forms: cone, sphere, etc. (see below).
3. Examine their construction. Are they formed by a single structure or by the superposition of layers and/or small soil particles that are different from the rest of the soil?

Questions to discuss and points to emphasize

1. Are there obvious differences between plots under different land-management practices in terms of the presence of biogenic structure types? Which land-use practice shows the highest amount and diversity of structures? Which structures were compact and which not? Why?
2. How would you relate what is happening in terms of soil health? Are the presence of these structures a problem for the productivity of the crop or do you think that they are beneficial?

(If the trainees are not used to doing calculations by applying equations, then lead the discussion through the implications about the presence of these structures in the farming system). Geometrical forms to calculate the total volume of different surface biogenic structures produced by earthworms, termites and ants:



V = volume; R = radius (major); r = radius (minor); h = height; π = pi number (3.1415)
Source: Decaëns *et al.* (2001).

EXERCISE 9: THE CARD GAME**Goal**

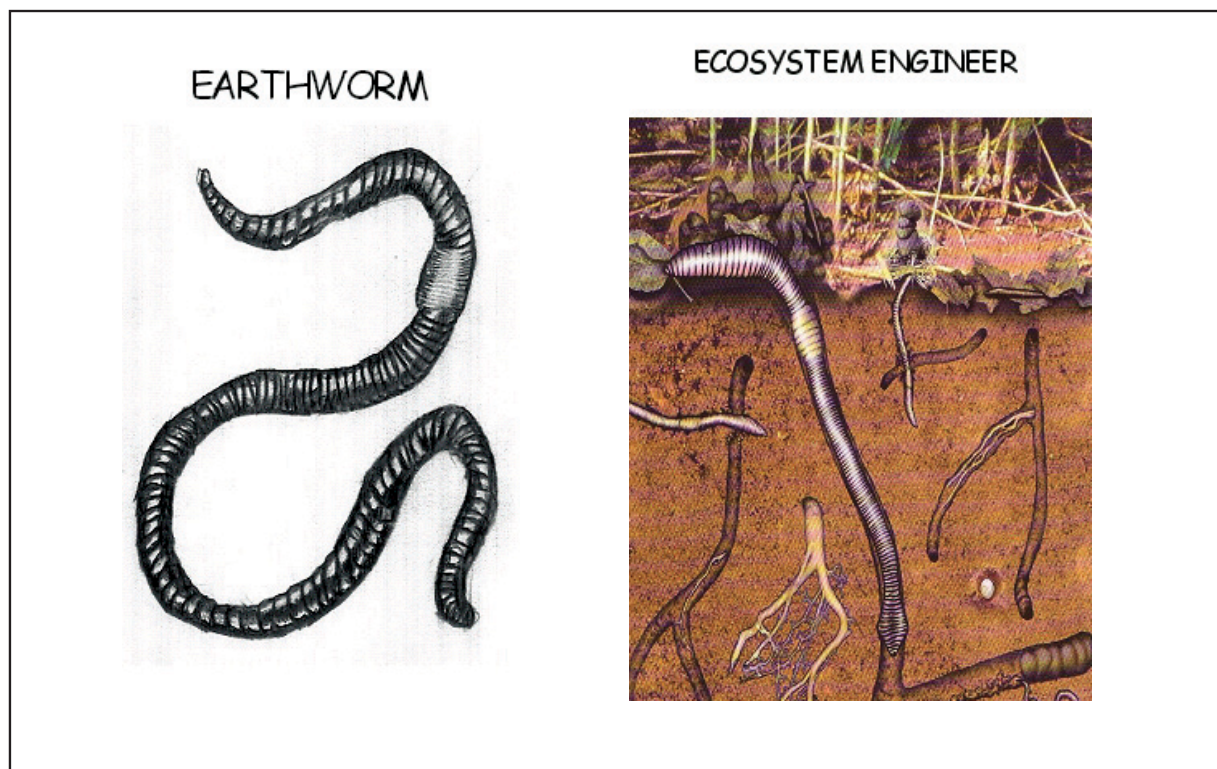
To relate the presence of soil macroinvertebrates to their ecological role in soil.

Materials

Cards (a pair of cards for each group of soil macroinvertebrates).

Procedure

There are two types of cards: one with the image or drawing of a soil macroinvertebrate, and another with the image of the effect of this group in soil, e.g. earthworms and a soil with galleries and casts on the surface. On cards showing a soil macroinvertebrate, the name of the organism will be written. Cards, each showing an image of their functional role in soil, will have the name of their ecological role (see figure below).



All the cards are distributed to the participants. Each of them should pass one card to the person on their right until someone forms a correct pair. The first person to form a pair is the winner.

RELATIONSHIPS BETWEEN KEY INDICATOR GROUPS AND OTHER SOIL ORGANISMS

Most soil organisms live in a variety of symbiotic relationships. Symbiotic relationships include: mutualism (both organisms benefit); commensalism (one organism benefits, the other does not but is not harmed); competition; parasitism (one organism benefits, the other is harmed); and predation (one organism benefits from the other by killing it). These relationships allow many diverse organisms to live in conditions that they could not live in on their own. Together they create substances and recycle materials that create the conditions necessary for life in the soil.

Thus, some key indicator groups present these kinds of relationships with other soil organisms. For example, termites are associated closely with specific microbial communities related with termite digestion. Termites also interact with other soil organisms by mutualism, symbiosis, commensalism and predation or parasitism. There is a symbiotic relationship between termites and ants, some termite species profit from the presence in their nests of ants to feed on the residues of dead individual ants (Jaffe *et al.*, 1995).

In some cases, red wood ants have been found in association with earthworms (Laakso and Setälä, 1997). It is a mutualistic relationship; the surface of the ant nest mound provides a better environment than that of the surrounding soil for earthworms (favourable temperature, moisture and pH, and an abundant food supply) and earthworms prevent the nest mounds from becoming overgrown by moulds and fungi.

Another example of the association of a key indicator group with microorganisms are the fungus-growing ants (which include the leaf-cutting ants). These ants collect various materials and feed them to a symbiotic fungus that lives in their nests. The ants then feed on special nutritional bodies produced by the fungus. This is an example of mutualism. The ants obtain food from the fungus, and the fungus has a place to live protected by the ants from predators and parasites.

Large-blue butterfly larvae spend most of their larval stage inside ant nests, either eating ant larvae or being fed by the ants as if they were the ants' own brood (like cuckoos). This is an example of parasitism. The butterflies are dependent on the ants for survival, and have evolved special mechanisms to trick the ants into looking after them.

However, there is another type of relationship between soil organisms that does not rely on trophic interactions but on the biogenic structures produced by the ecosystem engineers. Through their activities, earthworms, termites and ants produce a large variety of macropores (e.g. galleries and chambers) and organo-mineral structures (e.g. earthworm casts, termite mounds, and ant nests) that influence hydraulic properties, macroaggregation and organic matter dynamics in soil (Anderson, 1995; Lavelle, 1996; 1997).

Through their mechanical and feeding activities, ecosystem engineers modify living conditions (the physical environment and the availability of food resources) for other smaller and less mobile soil organisms, and hence influence their abundance and diversity (Lavelle, 1996).

One of the main constraints on the activity of soil organisms is the difficulty of moving in the soil. The mineral soil environment is compact and movement for most species is only possible through the network of pores, galleries and fissures created by the activity of ecosystem engineers.

Biogenic structures, particularly earthworm casts, increase macrofauna density. Some organisms prefer to live inside casts or in the underlying soil because casts have high organic matter content (Guggenberger *et al.*, 1996; Rangel *et al.*, 1999) and may represent a valuable food for smaller earthworms and humivorous termites. The biomass of roots is increased locally below casts (Decaëns *et al.*, 1999) and this may be beneficial to larvae or rhizophagous Coleoptera.

When litter is consumed by earthworms, some changes occur in its composition. These changes attract some litter-dwelling species, such as Isopoda and Diplopoda (Szlavec, 1985), that prefer to consume this litter. Small predatory species (Chilopoda and Arachnida) can find high prey densities of microfauna and mesofauna species taking advantage of earthworm-enhanced living conditions (Brown, 1995; Loranger *et al.*, 1998).

Other species may respond to changes in soil structure and to the creation of new specific microhabitats. Macropores that result from earthworm activity can be considered as habitats for some microfauna and mesofauna species (Haukka, 1991; Loranger *et al.*, 1998). Large numbers of corn-root worm eggs have been found in earthworm burrows (Kirk, 1981). Ants and termites have been observed using galleries as communication ways (Decaëns *et al.*, 1999). Where soil is totally lacking in protection for surface living organisms (i.e. without litter and herbaceous layer), earthworm structures may be used as specific refuges by litter-dwelling arthropods and could help their maintenance and/or rapid recolonization of the soil surface after perturbations.

Earthworm activities tend to depress nematode populations, especially phytoparasitic species (Boyer, 1998; Roessner, 1986). This effect is the result of changes in the soil environment (Yeates, 1981) and the activation of nematophagous fungi (Edwards and Fletcher, 1988).

Relationships between biogenic structures produced by ecosystem engineers and other organisms may be critical for the conservation and dynamics of SOM and the regulation of soil physical properties. For example, when small organisms feed on large and compact earthworm casts, they prevent their excessive accumulation on the soil surface, which otherwise may lead to a superficial soil compaction and affect plant growth negatively (Rose and Wood, 1980; Chauvel *et al.*, 1999). Moreover, they may re-activate organic matter decomposition by making organic resources available to microorganisms that were sequestered in dry casts (Lavelle, 1996).

