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Soil Fauna Diversity – Function, Soil Degradation, Biological Indices, Soil Restoration

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Additional information is available at the end of the chapter

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1. Introduction

Soil represents one of the most important reservoirs of biodiversity. It reflects ecosystem metabolism since all the bio-geo-chemical processes of the different ecosystem components are combined within it; therefore soil quality fluctuations are considered to be a suitable criterion for evaluating the long-term sustainability of ecosystems. Within the complex structure of soil, biotic and abiotic components interact closely in controlling the organic degradation of matter and the nutrient recycling processes. Soil fauna is an important reservoir of biodiversity and plays an essential role in several soil ecosystem functions; furthermore, it is often used to provide soil quality indicators. Although biodiversity was one of the focal points of the Rio conference, in the 1990s virtually no attention was paid to activities for the conservation of soil communities. However, with the new millennium, the conservation of soil biodiversity has become an important aim in international environmental policies, as highlighted in the EU Soil Thematic Strategy (2006), the Biodiversity Action Plan for Agriculture (EU 2001), the Kiev Resolution on Biodiversity (EU/ECE 2003) and afterwards in the Message from Malahide (EU 2004), that lay down the goals of the 2010 Countdown.

Human activities frequently cause a degradation of soil environmental conditions which leads to a reduction in the abundance and to a simplification of animal and plant communities, where species able to bear stress predominate and rare taxa decrease in abundance or disappear. The result of this biodiversity reduction is an artificial ecosystem that requires constant human intervention and extra running costs, whereas natural ecosystems are regulated by plant and animal communities through flows of energy and nutrients, a form of control progressively being lost with agricultural intensification. For

these reasons the identification of agricultural systems which allow the combination of production targets and environmentally friendly management practices, protecting both soil and biodiversity, is essential in order to prevent the decline of soil fauna communities in agricultural landscapes.

2. Biodiversity of soil fauna

Soil biota are thought to harbour a large part of the world's biodiversity and to govern processes that are regarded as globally important components in the recycling of organic matter, energy and nutrients. Moreover, they are also key players in several supporting and regulating ecosystem services [1]. Furthermore, they are key components of soil food webs. Rough estimates of soil biodiversity indicate several thousand invertebrate species per site, as well as the relatively unknown levels of microbial and protozoan diversity. Soil ecosystems generally contain a large variety of animals, such as nematodes, microarthropods (Figure 1) such as mites and Collembola, Symphyla, Chilopoda, Pauropoda, enchytraeids and earthworms (Figure 2). In addition, a large number of meso- and macrofauna species (mainly arthropods such as beetles, spiders, diplopods, chilopods and pseudoscorpion (Figure 3) , as well as snails) live in the uppermost soil layers, the soil surface and the litter layer.

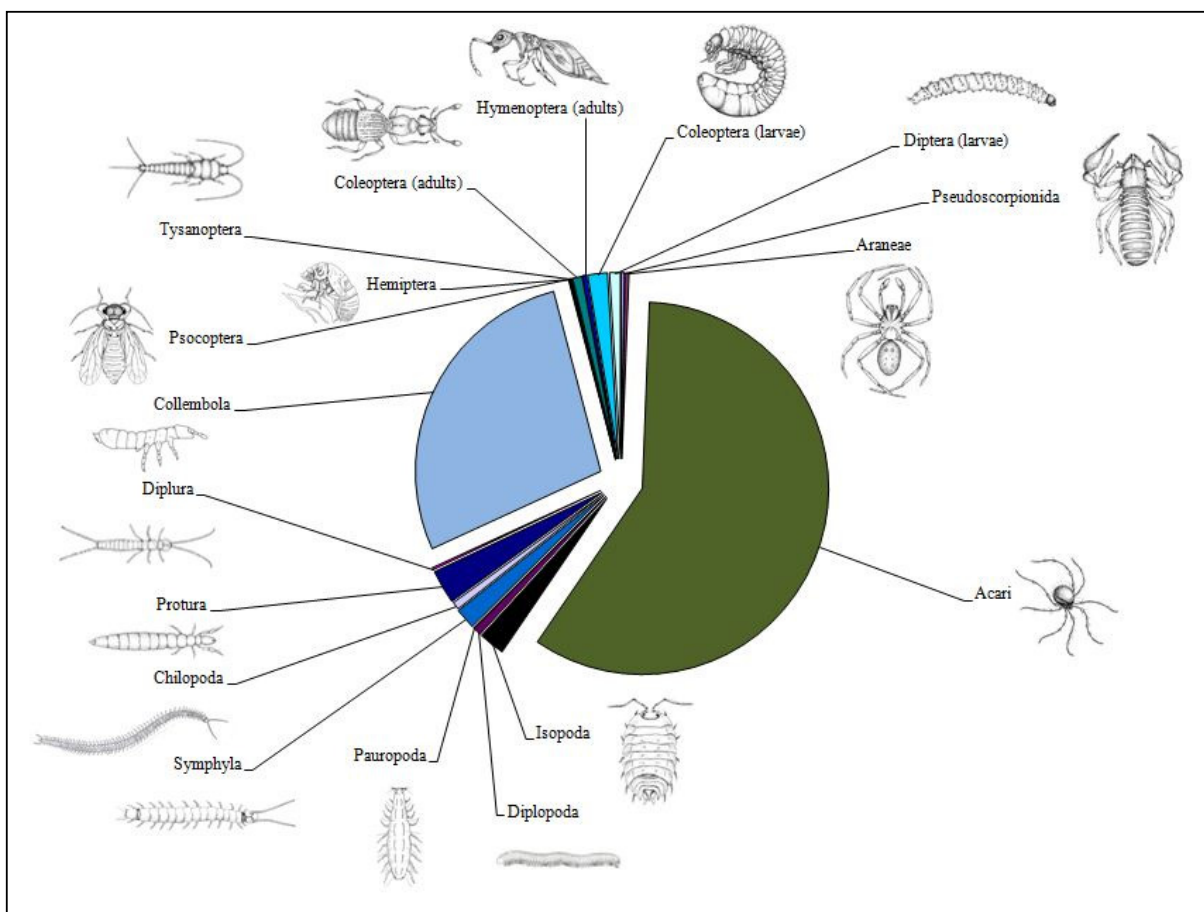


Figure 1. Soil microarthropod community in a beech forest of Northern of Italy



Figure 2. Earthworm belonging to megafauna



Figure 3. Pseudoscorpion, a typical organism that live in the wood litter

In general, soil invertebrates are classified according to their size in microfauna, mesofauna, macrofauna and megafauna [2] .

Microfauna: organisms whose body size is between 20 μm and 200 μm . Just one group, protozoa, is found wholly within this category; among the others, small mites, nematodes, rotifers, tardigrades and copepod crustaceans all fall within the upper limit.

Mesofauna: organisms whose body size is between 200 μm and 2 mm. Microarthropods such as mites and springtails, are the main representatives of this group, which also includes nematodes, rotifers, tardigrades, small araneidae, pseudoscorpions, opiliones, enchytraeids, insect larvae, small isopods and myriapods.

Macrofauna: organisms whose size is between 2 mm and 20 mm. This category includes certain earthworms, gastropods, isopods, myriapods, some araneidae and the majority of insects.

Megafauna: organisms whose size exceeds 20 mm. The members of this category include large size invertebrates (earthworms, snails, myriapods) and vertebrates (insectivores, small rodents, reptiles and amphibians).

Despite several decades of soil biological studies it is still very difficult to provide average abundance and biomass values for soil invertebrates. This is partly caused by their high variability in both time and space, as well as by differences in the sampling methods used [1]. In addition, most work has been performed in the forest soils of temperate regions, while other ecoregions such as the tropics, or other land uses such as agriculture, have been seriously neglected [1].

Soil fauna are highly variable and the majority are also highly adaptable with regard to their feeding strategies, ranging from herbivores to omnivores and including carnivores. Depending on the available food sources many soil fauna are able to change their feeding strategies to a greater or lesser extent with many carnivorous species able to feed on dead organic matter in times of low food availability. The interactions between soil fauna are numerous, complex and varied. As well as the predator / prey relationships and in some instances parasitism, commensalism also occurs.

The degree of interaction between soil organisms and the soil itself can be highly variable among taxa and dependent on the part of the life cycle that is spent in the soil [2]. In particular, in this regard, combined with the morphological adaptations and the ecological functions of organisms, it is possible to classify soil fauna into four main groups: temporarily inactive geophiles, temporarily active geophiles, periodical geophiles, and geobionts (Figure 4). It should be noted that these groupings do not have any taxonomical significance but rather are useful when studying the life strategies of soil invertebrates. Temporarily inactive geophiles are organisms that live in the soil for only certain phases of their life, such as to overwinter or to undergo metamorphosis, when protection from climatic instability is more necessary. Due to their relative inactivity, the organisms belonging to this group have a weak influence on the ecological function of soil, although they can be important as prey for other organisms. Temporarily active geophiles live in the soil in a stable manner for a large part of their life (i.e. for one or more development stages, and emerge from the soil as adults). Most of these organisms are insects, such as Neuroptera, Diptera, Coleoptera and Lepidoptera. Organisms having a "pupae" stage in their life cycle, play a minor role in the soil during these phases, while the "larvae" stage is much more important for the ecology of soil, especially when the population density is high [1,2]. Most larvae can act as both detritivores and predators. Periodical geophiles spend a part of their life cycle in the soil, generally as larvae, but throughout their lives they occasionally go back to the soil to perform various activities, such as hunting, laying of eggs or to escape dangers. Several Coleoptera groups (e.g. carabids, scarabids, cicindelids) spend their larval stage in the litter or in the upper layers of mineral soil, and when adults, use soil as a food source, a refuge and for other purposes [1,2]. Geobionts are organisms that are very well adapted to life in soil and cannot leave this environment, even temporarily, having characteristics

that prevent survival outside of the soil environment due to their lacking protection from desiccation and temperature fluctuations, as well as the sensory organs necessary to survive above ground by finding food and avoiding predators. Several species of myriapods, isopods, Acari, molluscs and the majority of Collembola, Diplura and Protura, belong to this group [1]. These different types of relationships between soil organisms and the soil environment determine a differentiated level of vulnerability among various groups, as a consequence of any possible impact on soil environment. For instance, if soil contamination occurs, any impact will be highest on geobytons (because they cannot leave the soil and must spend all their life there) and lowest on temporarily inactive geophiles.

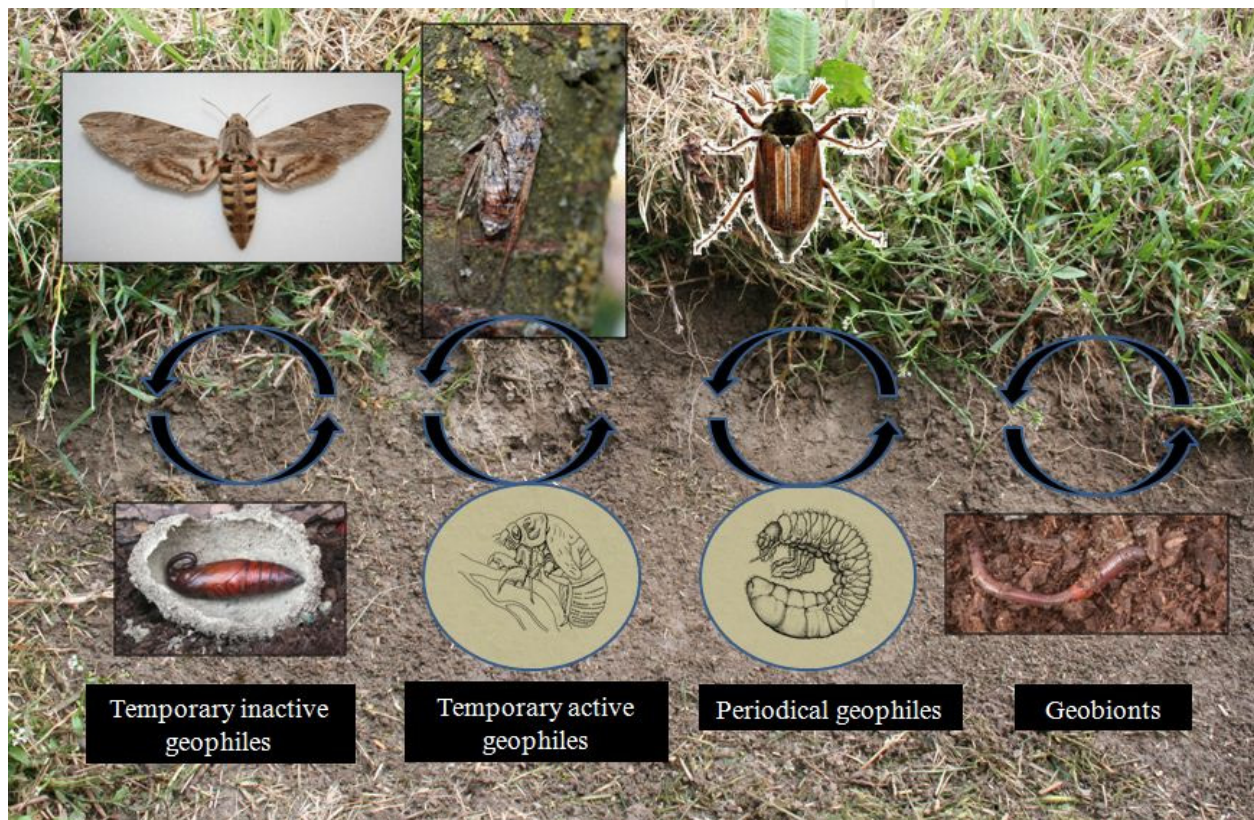


Figure 4. The main four grouping that can be individualized between soil invertebrates, depending on their life strategies and how closely they are linked with soil

There are many extremely old groups of microarthropods in soils, such as collembola and mites, dating from the Devonian period (more than 350 million years ago). In relation to the origin of soil microarthropods, it is possible to form two hypothetical groups: the first group originated in epigeal (above the soil) habitats and only subsequently adapted to soil (e.g. Coleoptera, Chilopoda (Figure 5), Diplopoda (Figures 6 and 7) and Diptera. The second group possibly originated directly in the soil. This group contains organisms such as Protura, Diplura, Symphyla, Pauropoda (Figure 8), and Palpigrada which do not have forms in epigeal, or aquatic habitats (some exceptions are found in caves, where the environmental conditions are very similar to that of soils).



Figure 5. Centipede (Chilopoda)



Figure 6. Millipede (Diplopoda)



Figure 7. Polyxena, a curious group of Diplopoda



Figure 8. Paupoda, a microarthropod well adapted to soil

Over the very long period of adjustment to life below ground, the bodies of euedaphic microarthropods became adapted with characteristics that allow them to survive within the soil habitat. During this process of adaptation, impressive levels of convergence have occurred with many of the adaptation characteristics being morphological, and easily explainable and understood. For example, the reduction of the visual apparatus, loss of pigmentation or cryptal coloration (camouflage), reduction of appendages and the acquiring of special structures essential for life below ground. Some of these characteristics, such as the reduction of body length (miniaturisation), loss of the appendages (legs, antenna, etc.) and the loss of eye functionality, which in some cases leads to the complete disappearance of eyes, are direct consequences of degenerative processes in structures which are very important in above ground habitats but useless in the soil. Conversely, soil microarthropods have developed characteristics that permit them to live in the particular conditions present in the soil, such as chemico- and hydoreceptors, often distributed not only in the oral

region, as they are for most above ground organisms, but also on other structures of the body. The confinement of these groups to soils, i.e. the groups' incapacity to leave them, is due to the relative stability of these habitats. In fact, diverse factors such as water, temperature and organic matter vary only slightly over the short- and medium-term, as compared to large variations in above ground environments. In addition, there is obviously no light in soil at depths greater than a few millimetres. As a result of all of these factors combined, euedaphic microarthropods are sensitive and unable to survive abrupt variations in environmental factors. They are particularly sensitive to soil degradation and to the disturbances caused, for example, by agricultural cultivation and trampling. Collembola (springtails) represent one of the most important groups of soil microarthropods, both because of the number of species, and the number of individuals, generally present in soils. They have some characteristics that make this group very interesting and useful for studying soil evolution convergence phenomena. Furthermore, they are very useful as indicators of soil quality as their biodiversity and density are influenced by numerous soil factors (in particular organic matter and water content but also other factors such as contamination).

3. The role of soil fauna in soil ecosystem processes

Some researchers have defined edaphic fauna as a "super organism" that assumes a crucial significance due to the chemico-physical and biological processes that are rooted in the soil. Soil biota play an essential role in soil functions as they are involved in processes such as the decomposition of organic matter, the formation of humus and the nutrient cycling of many elements (nitrogen, sulphur, carbon). Moreover, edaphic fauna affect the porosity and aeration of, as well as the infiltration and distribution of organic matter within soil horizons. The ecosystem services provided by soil fauna are one of the most powerful arguments for the conservation of edaphic biodiversity. Decomposition of organic matter by soil organisms is crucial for the functioning of an ecosystem because of its substantial role in providing ecosystem services for plant growth and primary productivity [3].

Due to the absence of light, which makes photosynthesis unfeasible, among the organisms populating the soil we find very few real phytophages, unless we extend the definition of soil animals to surface organisms, or if we consider that pests also include fungivorous microarthropods [2]. The activity of animals, among them typically protozoa, nematodes, rotifers, certain springtails and mites, which feed on microflora, consisting of bacteria, actinomycetes and fungi (both hyphae and spores) is of crucial importance both for regulating the density and for diffusing these micro-organisms. For example, through their faeces, springtails, which feed on fungi, can spread fungal spores that are still viable to areas as far as a few metres away from their point of origin.

The detritus food chain takes on an essential role within the soil, as it becomes the basis of the hypogean food web; in fact, many organisms such as isopods, certain myriapods, earthworms, springtails, many species of mites, and the larvae and adults of many insects feed on the vegetable and animal detritus that is deposited on the soil. For example in the

soil of a temperate forest, in which the contribution of litter each year can amount to 400 g/m², about 250 g/m² are ingested by earthworms and enchytraeids, 30-40 g/m² by mites and 50-60 g/m² by springtails. Soil fauna performs a mainly mechanical action, whereas chemical degradation is essentially performed by fungi and bacteria, both free and intestinal symbionts of other organisms; furthermore during digestion, organic substances are enriched by enzymes that are dispersed in the soil along with the faeces, contributing to humification.

Earthworms are among the most important organisms in many of the soils of the world. According to an ecological and functional classification [4] it is possible to identify three groups of earthworms that differ in size, burrowing capability, type of food and habitat: epigeic, endogeic and anecic. The epigeic, whose sizes ranges from 0.5 to 5 cm, have a red coloured body, are poorly adapted to burrowing and have a good tolerance to low pH values. They inhabit the superficial organic layers where they feed on litter. The endogeic, whose sizes range from 1 to 8 cm, have a non-pigmented body; exposure to soil with pH values below 5 restricts their activity. They live in the first few centimetres of mineral soil, feeding on humic compost and dead roots, they are capable burrowers and they make tunnels that extend mainly horizontally. Earthworms defined as anecic, whose sizes generally are in excess of 5 cm and have a reddish-brown body, are excellent burrowers, making vertical tunnels that can reach several metres in depth; they tend to avoid soil that is asphyxiated or lacking in moisture. They live in the mineral layer of the soil but rise to the surface, mainly at night, to feed on litter. The activity of earthworms produces a significant effect, not just on the structure, but also on the chemical composition of the soil, since a large part of the organic matter ingested by earthworms is returned to the soil in a form easily used by plants. While they are feeding, earthworms also ingest large quantities of mineral substances (minimally so in the case of the epigeic), that are then mixed with the organic matter ingested and, after having been cemented with a little mucous protein, are expelled in piles called worm casts. In addition to being rich in nitrogen and other nutritive substances such as calcium, magnesium and potassium, worm casts also contain a large quantity of non-digested bacteria which proliferate easily in this sub-stratum and contribute to the humification and mineralisation of organic matter [5]. Vermicasts have more favourable physico-chemical properties, increased microbial population, enzyme activities and nutrient mineralization that support plant growth and yield [6]. Many studies have reported increased microbial activities during the passage of food through the gut in earthworms [6,7] and higher numbers of fungi, bacteria and actinomycetes in vermicasts [7]. [6] showed enhanced microbial populations and activity in the freshly deposited pressmud vermicasts of *Lampito mauritii* and *Eudrilus eugeniae* in relation to nutrient rich substrate concentrations, multiplication of microbes after passing through the gut, optimal moisture level and large surface areas of vermicasts ideally suited for better feeding and multiplication of microbes. It is important to note that often worm casts are not released in the same layer in which the earthworm fed; in effect the components of the anecic group live at depth and release their mineral-rich faeces on the surface. In contrast the endogeic live at the surface and release their faeces, once again

rich in organic matter, at lower depths. These forms of behaviour together with the direct action due to the burrowing, ensure that the soil is mixed, thereby increasing its fertility. The burrowing of the earthworms is also essential for increasing the aeration of the soil and for improving the circulation of water since their tunnels increase the porosity of the ground by 20-30% [5], enabling those organisms that are not good burrowers to move around easily even at lower depths of the soil. Other than with their worm casts, earthworms contribute to the increase in the amount of nitrogen present in the ground through the excretion of ammonia and urea, forms that are directly useable by plants; furthermore a sizeable quantity of nitrogen is returned to the soil on the death of animals, which have a 72% protein content [8].

Within the context of edaphic fauna it is possible to identify, based on the type of locomotion, swimming organisms, capable of moving around in capillary or gravitational water, reptants that move by taking advantage of natural porosity or cavities produced by other organisms and burrowing organisms. The last-mentioned can open up cavities in the ground in various ways; for example, earthworms compress the ground outside their bodies, diplopods use their legs and backs to push the sediment upwards, the larvae of click beetles use their mandibles, while moles, scarabs and mole-crickets (Figure 9) have specialised legs for burrowing. This continual burrowing activity contributes to the creation of spaces within the soil with the resultant increase in its porosity; the increase of the pores between the particles in turn increases the aerobic bacterial activity and the consequent speed of demolition of organic substances. This bioturbation also has positive effects on water retention, percolation processes and the development of the rhizosphere. The burrowing activity also enables the soil to be mixed and organic matter from the surface layers to be incorporated into the lower layers, while mineral substances are brought towards the surface. This process is carried out in a very evident way by the anecic earthworms discussed a little earlier, which move vertically in the ground even reaching depths of several metres.



Figure 9. Mole cricket

The anthill is one of the most interesting and elaborate examples of the modification of the soil by cunicular burrowing organisms. It consists of a complex of chambers generally constructed on several levels and linked together by tunnels and corridors. Some nests can reach a depth of more than 5 metres and contain over 2,000 chambers, some of them set aside for the cultivation of fungi. The tunnels that connect the chambers contribute to the circulation of air and water within the anthill. Each chamber is inhabited by numerous individuals, some are reserved for incubating eggs, others for rearing the larvae, and yet others for the development of the nymphs which are moved to chambers where the humidity and temperature are more conducive to their development. An anthill can rise above ground level (Figure 10) and can have one or more entrances, or be completely underground and communicate with the surface through one or more exits that are constantly guarded by sentries. Special devices prevent the water that penetrates the soil from flooding the chambers and in this way ensure the survival of the eggs and the nymphs, which are incapable of leaving the nest. As far as the soil is concerned, the presence of channels and tunnels increases the porosity, assisting the penetration of air and water. In addition, a consequence of the movement of the fine material towards the surface by ants during the course of the construction and maintenance of the anthill, is the creation at the surface of a layer with a fine particle size, which is more mineral than organic in nature [9].



Figure 10. A typical anthill of *Formica rufa*

The soil fauna, in particularly molluscs (Figure 11) and earthworms, also has an effect on the soil through the secretion of cutaneous mucous, that have a cementing effect on the particles in the ground, assisting the stability and structure of the soil and making it less vulnerable to processes of erosion. The mucous secretions, the faeces (especially those of earthworms) and the bodies themselves of the animals (when they die) influence in large measure the concentration of nutrients present in the soil particularly potassium, phosphorous and nitrogen, reducing the C/N ratio of the litter and facilitating decomposition.



Figure 11. A slug (a) and a snail of the species *Helix pomatia* (b)

The presence of roots is generally associated with a greater density of micro-organisms in the nearby soil compared with soil devoid of roots; the term rhizosphere is used in a broader sense to refer to the portion of soil surrounding roots in which the micro-organisms are influenced by their presence; its extension is very variable but in general it is considered to be the cylinder of soil used by the root hairs and in which they emit exudates [10]. The rhizosphere can be distinguished from the majority of the soil on the basis of its chemical, physical and biological characteristics. Penetrating the ground, the roots act on the clay minerals and the particles of soil surrounding them; this leads to the formation of an area around them in which the water pathway, and the movement of nutrients and microflora is more heavily channelled than in the rest of the soil. For the same reasons, the organic matter released by the roots accumulates close to them. The chemical nature of the rhizosphere is

significantly different from the rest of the soil; this results in large part from the release of carbon and the selective capturing of ions in solution in the groundwater by the roots. The plants act as carbon pumps fixing what is available in the atmosphere in the root exudates that are quickly captured by bacteria; for this reason the level of carbon available around the roots is never very high. The selective absorption of ions instead, causes the depletion of some of them in the rhizosphere, while others, not absorbed by the roots, tend to accumulate. The relationship between the roots and the microflora can be very close and lead to bacteria or fungi becoming an integral part of the roots as in mycorrhizal symbiosis and in the association of bacteria and legumes. The peculiar characteristics of the rhizosphere are also reflected in a selectivity of the animal element. The interaction between soil animals and the roots of the plant can take a variety of forms that lead to benefits or repress the growth of the plant, and often involve interactions with the microbial population of the soil. The dispersion of the inocula of mycorrhizal fungi by soil animals can have beneficial effects for the plants; this dispersion is particularly favoured by burrowing organisms belonging to the mega- and mesofauna. The hyphae of mycorrhizal fungi may make up a significant proportion of the total microbial biomass in some soils and can become one of the most important sources of food for fungus grazing animals such as springtails. Numerous soil animals feed directly on the roots of plants; among them are a large number of species of springtails and myriapods. It is still not entirely clear how much of the damage inflicted on plants can be attributed to the direct action caused by the grazing of the roots or from the subsequent vulnerability of the roots to pathogens in the soil, especially fungi.

It is extremely rare for the biological relationships between soil organisms to consist of a simple and clear interaction. The actual conditions are the result of many complex interactions that typically involve multiple participants in life in the soil such as the plants, the microbes, the fungi and the animals, the last mentioned at different levels of organization. For example, examination of the faeces of earthworms reveals a mixture of fragments of plants, microorganisms, fungi, and fragments of encysted animals and protozoa capable of surviving the unfavourable conditions in the gut of the earthworm [10].

4. Diversity of soil fauna in different ecosystems and soil managements

A rapid survey of invertebrate and vertebrate groups reveals that at least $\frac{1}{4}$ of described living species are strictly soil or litter dwelling. The greatest diversity is observed in systems where equilibrium exists between the productivity level and the perturbation rate, whereas local species extinctions may occur through lack of demographic recuperation when perturbations increase or through competitive exclusion when productivity increases. Land use changes and the intensification of agriculture also generate severe habitat degradation or destruction of soil biota. The environment of soil organisms in managed ecosystems can be influenced by any combination of land use factors, such as tillage, pesticide and fertilizer application, soil compaction during harvest, and removal of plant biomass.

The profile of a mature and undisturbed soil can be divided into a number of spheres, whose chemico-physical properties are determined by vegetation cover, by geographical location and by climate; this stratification is reflected in the edaphic population and as a result in its vertical distribution. Usually two groups of organisms are recognised in the soil: the euèdaphons, which include organisms that live in the strip of mineral soil, and the hemiedaphons, found in the strip of organic soil; to these can be added the epiedaphons (or epigeons), consisting of organisms that live in the surface of the soil, and hyperedaphons that extend to the herbaceous layer. The moisture content and the pH of the soil have the greatest influence on the distribution of the hemi- and euedaphon fauna, even if the characteristics of the litter, the porosity of the soil and numerous other factors are also important in determining the vertical distributions of edaphons. Humidity has often been used to establish further subdivisions within the hemiedaphons; one example is the classification in which hemiedaphon springtails were subdivided into three categories: hydrophilic (living on the surface of free water), mesophilic (living in damp organic litter) and xerophilic (living in more exposed dry areas, such as in lichens, mosses and tree bark). In reality this type of stratigraphical classification is difficult to apply since soil organisms migrate on both a daily and a seasonal basis; in fact, many species, for example mites, springtails and isopods, can move towards the surface over distances ranging from a few millimetres to a few centimetres. An interesting case is that of sinfili that can go down as much as 40-50 cm. Nematodes are usually most abundant in the first 10 cm of soil, but their distribution can vary greatly depending on the type of vegetation cover and conditions of dampness. For example, in soil with abundant vegetation cover and a high presence of roots, these organisms concentrate in the upper part of the ground which, being rich in exudates and decomposing organic matter, maintain a numerous population of their potential prey. In soils with sparse vegetation cover, the high frequency of dry conditions on the surface cause nematodes to be more common at a depth of 5-10 cm whereas, in cultivated land a uniform distribution of the population can be observed down to a depth of about 20 cm, attributable to the mixing effects caused by ploughing. The density of these organisms is particularly high in grasslands, where they can be present with a density in the order of 20 million/m², whereas in moorland the density varies greatly and usually is less than one million/m², even though in some cases it can exceed 5 milioni/m².

The abundance, diversity, composition and activity of species of the soil community can be affected by plant species, plant diversity and composition, as well as by animal grazing [3]. The two factors that most likely influence the soil community are the nutrient resources available, and the diversity of microhabitats [3]. Resource type is determined by the tissue chemistry of plant species and the nutrient content of excreted wastes from grazing by consumers [3]. The microhabitat is directly affected by the physical and chemical properties of the system as well as the amount of nutrient input [11].

Various studies have described the structure of soil invertebrate communities in relation to forest diversity, dynamics and management [12-18]. In central Italy silvicultural practices and the composition of deciduous forests do not seem to have any important effect on the structure of microarthropod communities [19]. The absence of a change in soil community

structure could be linked to the litter layer that in these hardwood stands is thick enough to maintain a high level of organic matter and a favourable microclimate in every season. Soil mesofauna seem to recover quickly after disturbances such as tree cutting [12] indicating a good level of ecosystem integrity (community resilience). The same aspect also emerged in conventional tillage conditions where soil arthropod abundance was significantly higher in autumn compared with summer [20]. The authors suggested that, given sufficient time without soil disturbance, soil arthropods are able to recover within the growing season. These results agree with previous studies conducted on a temperate cool rain forest in west Canada where there were no significant differences in the population density of arthropods between undisturbed forests on harvested plots and those on unharvested patches [21]. Additionally, in another recent study involving a beech forest, the hypothesis of [22], which predicts community changes during forest rotations, was refuted from a functional view point [14]. However several studies considering the effects of silvicultural practices on soil fauna found important impacts on soil forest fertility/productivity and in the terrestrial food chain [23]. It is generally accepted that the removal of trees by clear-cutting, or other methods, has a significant effect on the invertebrate fauna of the forest floor [24,25]. The effects on arthropod communities are complex and difficult to analyze since various taxonomic groups are affected and they react to impacts differently [12,26-29].

A study that compared the soil community in different grasslands with a semi-natural woodland area and an arable land site showed that microarthropod communities of the three land use typologies differed in terms of both observed groups and their abundance [30]. Typical steady soil taxa characterised woodland and grassland soils, whereas their abundances were significantly higher in the former. The mean highest abundances of Acari and Collembola were observed in grassland, confirming the suitable trophic conditions of this habitat, whose taxa diversity and soil biological quality did not significantly differ from woodland samples. On the contrary in the arable land, the microarthropod community showed a reduction both in taxa number and soil biological quality compared with the other sites. Besides, mite and springtail abundances were significantly lower than in grassland. The authors concluded that soil biological quality and edaphic community composition highlighted the importance of grassland habitat in the protection of soil biodiversity, especially because it combines fauna conservation with the production of resources for human needs.

5. Principal factors affecting the loss of soil fauna diversity

Around the world there are numerous soils that have lost their fertility or their capacity to carry out their function due to the impact of man. The causes are mainly related to processes that are accelerated or triggered directly by human activities and that often act in synergy with each other, amplifying the effect. Among them, the most widespread at a worldwide level are erosion, the loss of fertility and a decline in organic matter, compaction, salinisation, phenomena of flooding and landslides, contamination and the reduction in biodiversity. Reduction of soil biodiversity as a result of urbanization can be even more severe. The

urbanization process leads to the conversion of indigenous habitat to various forms of anthropogenic land use, the fragmentation and isolation of areas of indigenous habitat, and an increase in local human population density. The urbanization process has been identified as one of the leading causes of declines in arthropod diversity and abundance.

Soil properties determine ecosystem function and vegetation composition/structure, serve as a medium for root development, and provide moisture and nutrients for plant growth [31]. Disturbances linked to natural forces and to human activities can alter physical, chemical and biological properties of soils, which can, in turn, impact long-term productivity [32,33]. Humans have extensively altered the global environment and caused a reduction of biodiversity. These change in biodiversity alter ecosystem processes and change the resilience of ecosystems to environmental change. It is estimated that human activities increased the rates of extinction 100-1000 times [34]. In the absence of major changes in policy and human behaviour our effect on the environment will continue to alter biodiversity. Land use change is projected to have the largest impact on biodiversity by the year 2100 [35]. Within agricultural land use, that covers 10.6 % of land surface, the intensity of agronomic practices and crop management can also affect biodiversity (Figure 12). Land use is considered to be the main element of global change for the near future. In a review on changing biodiversity [35] consider that land use will be the main cause of change in biodiversity for tropical, mediterranean and grassland ecosystems. Forests, tropical or temperate, generally represent the biomes with the largest soil biodiversity. Consequently any land use change resulting in the removal of perennial tree vegetation will produce a reduction of soil biodiversity. In some cases forests are succeeded by pasture or perennial grasslands, while in others arable land replaces formerly wooded areas. The change in soil biodiversity will therefore be influenced by the subsequent use of land following the forest.



Figure 12. Image of Val D'Adige (Italy) where it's possible to note the intense agricultural utilization

The abundance, biomass and diversity of soil and litter animals are influenced by a wide range of management practices which are used in agriculture. These management practices include variations in tillage, treatment of pasture and crop residues, crop rotation, applications of pesticides, fertilisers, manure, sewage and ameliorants such as clay and lime, drainage and irrigation, and vehicle traffic [36]. Furthermore differences in agricultural production systems, such as integrated, organic or conventional systems, have been demonstrated to affect soil fauna in terms of numbers and composition [37,38]. The impact of soil tillage operations on soil organisms is highly variable, depending on the tillage system adopted and on soil characteristics. Conventional tillage by ploughing inverts and breaks up the soil (Figure 13), destroys soil structure and buries crop residues [39] determining the highest impact on soil fauna; the intensity of these impacts is generally correlated to soil tillage depth. Minimum tillage systems can be characterized by a reduced tillage area (i.e. strip tillage) and/or reduced depth (i.e. rotary tiller, harrow, hoe); crop residues are generally incorporated into the soil instead of being buried. The negative impact of these conservation practices on soil fauna is reduced compared with conventional tillage. Under no-tillage crop production, the soil remains relatively undisturbed and plant litter decomposes at the soil surface, much like in natural soil ecosystems. The influence on soil organism populations is expected to be most evident when conservation practices such as no-till are implemented on previously conventionally tilled areas because the relocation of crop residues to the surface in no-till systems will affect the soil decomposer communities [40]. No-till [41] and minimum tillage generally determine an increase in microarthropod numbers.



Figure 13. Conventional tillage by ploughing inverts and breaks up the soil, destroy soil structure and buries crop residues

A multidisciplinary study was carried out over four years in Northern Italy on a silt loam under continuous maize [42] to evaluate two factors: the soil management system (conventional tillage and no-tillage) and N fertilisation. This study showed that total

microarthropod abundances were higher in NT compared with CT (+29%). Acari showed higher sensitivity to tillage compared with collembola. Moreover, N fertilisation with 300 kg N ha⁻¹ had a negative effect on the total microarthropod abundance. [43] also observed that higher values of mite density were associated with a decrease in tillage impact. [38] similarly reported that the mite community, in particular oribatid, was more abundant in no-tillage compared with conventional tillage, but the differences were found only in some periods of the year. Conventional tillage caused a reduction of microarthropod numbers as a result of exposure to desiccation, destruction of habitat and disruption of access to food sources [44]. The influence of these impacts on the abundance of soil organisms will be either moderated or intensified depending on their spatial location; that is, in-row where plants are growing, near the row where residues accumulate or between rows being subjected to possible compaction from mechanized traffic [45].

Observations on the impacts of different forms of agricultural management on communities of microarthropods showed that the high input of intensively managed systems tends to promote low diversity while lower input systems conserve diversity [11,46]. It is also evident that high input systems favour bacterial-pathways of decomposition, dominated by labile substrates and opportunistic, bacterial-feeding fauna. In contrast, low input systems favour fungal pathways with a more heterogeneous habitat and resource leading to domination by more persistent fungal feeding fauna [11].

The effects of fertilizers on soil invertebrates are a consequence of their effects on the vegetation and, directly on the organisms. Increases in quantity and quality of food supplied by vegetation are frequently reflected in greater fecundity, faster development and increased production and turnover of invertebrate herbivores [47]. The effects of organic and inorganic fertilizers in terms of nutrient enrichment may be comparable, but these two types of fertilizers differ in that organic forms provide additional food material for the decomposer community. [48] concluded that the total soil microbial biomass and the biomass of many specific groups of soil organisms will reflect the level of soil organic matter inputs. Hence, organic or traditional farming practices, that include regular inputs of organic matter in their rotation, determine larger soil communities than conventional farming practices [48]. Also [49] reported that the soil microbial and faunal feeding activity responded to the application of compost with higher activity rates than with mineral fertilization. Generally the responses of soil fauna to organic manure will depend on the manure characteristics, and the rates and frequency of application. Herbivore dung, a rich source of energy and nutrients, is exploited initially by a few species of coprophagous dung flies and beetles and, later, by an increasingly complex community comprising many general litter-dwelling species [47].

A study related to sewage sludge application on agricultural soils showed an increase in the abundance of Collembola [50], Carabidae [51], Oligochaeta [52], soil nematodes [53] and Arachnida [53]. In some cases, the application of sewage sludge to agricultural land can bring toxic substances that, accumulating in the soil, reach potentially toxic levels for soil fauna [53]. Field studies have suggested that metals contained in sewage sludge don't

reduce the abundance of euedaphic [50] and epigeic collembola [54] but may alter their population structure. [53] reported negative effects on collembola communities in soil treated with sewage sludge and this effect may be attributed to anaerobic conditions and high ammoniacal level. In effect, the knowledge gained in relation to the effects of sewage sludges showed that species more sensitive to the toxic substances contained in sewage sludge can disappear, while others which are more tollerant, can dramatically increase.

Organic wastes are usually stored in dump areas with associated high management costs and problems of environmental impact. On the other hand organic wastes could become an easily available and cheap source of organic matter after composting processes. The use of compost obtained by organic waste in agricultural activity enables the converting of waste materials into a useful resource. Therefore, the national authorities have over recent years stimulated both the use of compost to reduce the soil fertility loss and research aimed at assessing its effects on both agricultural production and soil environment [55-57]. But negative effects on soil fauna could be related to the use of organic waste, such as the accumulation of trace metals in soil. In fact many trace elements contained in organic wastes can reduce the abundance and diversity of soil microarthropod communities, or can influence the survival potential and the rate of growth of more sensitive species [58]. [59] concluded that negative effects of compost use on soil fauna abundance or biodiversity were not observed in two Italian sites studied that were treated with compost, supporting the use of this product derived from waste in order to add organic matter into the soil.

Pesticide application to the soil can affect the soil fauna influencing the performance of individuals and modifyng ecological interactions between species. When one or more ecosystem component is impacted by a pesticides, this will affect the microarthropod communities in terms of number and composition. Pesticide toxicity on soil fauna is determined by different factors, such as the pesticide's chemical and physical characteristics, the species' sensitivity and the soil type. In fact among soil microarthropods, different taxa showed a variety of responses. The physical and chemical characteristics of the soil, such as its texture, structure, pH, organic matter content and quality, and nature of clay minerals, are important factors determining the toxic effects of pesticides or other xenobiotics. A study carried out by [60] showed reduced toxic effects, as a function of soil type, in the following order: sand>sandy-loam>clay>organic soil. Often, the toxicity of pesticides can be related directly to soil organic matter content [61]. However pesticide application does not always cause negative impacts on the entire soil microarthropod community. For example for certain types of soil there is evidence that some taxa can obtain a competitive advantage from the application of some specific pesticides.

6. Use of soil invertebrates in soil biodiversity assessment and as soil biological quality indices

As previously illustrated, the increasing anthropic pressure on the environment is leading, in most parts of the world, to a rapid change in land use and an intensification of agricultural activities. These processes often result in soil degradation and consequently loss

of soil quality. Soil quality could be defined as the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, to maintain or enhance water and air quality, and to support human health and habitation [62,63]. A common criterion for evaluating the long-term sustainability of ecosystems is to assess the fluctuations of soil quality [64]. Soil reflects ecosystem metabolism; within soils, all bio-geo-chemical processes of the different ecosystem components are combined [65]. Monitoring ecosystem components plays a key role in acquiring basic data to assess the impact of land management systems and to plan resource conservation. Maintaining soil quality is of the utmost importance to preserving biodiversity and to the sustainable management of renewable resources.

Soil quality can be evaluated through its chemical-physical properties and biological indicators and indices. The importance of some of these parameters is generally accepted. Soil organic matter among the chemical indicators, bulk density [66-69,42] and aggregate stability [70,71] among the physical indicators, were the most often used but there were few examples of biological indicators of soil quality [72,66,68]. However, biological monitoring is required to correctly assess soil degradation and correlated risks [73,74]. Indicators of soil health or quality should fulfil the following criteria [75]: 1) sensitivity to variations of soil management; 2) good correlation with the beneficial soil functions; 3) helpfulness in revealing ecosystem processes; 4) comprehensibility and utility for land managers; 5) cheap and easy to measure. The growing interest in the use of living organisms for the evaluation of soil conditions is justified by the great potential of these techniques, that allow the measurement of factors difficult to detect with physical-chemical methods and give more easily interpretable information [76]. Biotic indices, based on invertebrate community studies, were recently developed as a promising tool in soil quality monitoring. These organisms are highly sensitive to natural and human disturbances and are increasingly being recognized as a useful tool for assessing soil quality. The complex relationships of soil fauna with their ecological niches in the soil, their limited mobility and their lack of capacity to leave the soil environment, make some taxa (e.g. Collembola, Protura, Pauropoda) particularly vulnerable to soil impact [77]. For these reasons soil fauna communities represent an excellent candidate for soil bioindication and for evaluating soil impact. The basic idea of bio-indications is that the relationship between soil factors and soil communities can be tight [76]. When soil factors influence community structure, the structure of a community must contain information on the soil factor [78]. To retrieve information about soil quality, different properties of community structures, such as the richness and diversity of species, the distribution of numbers over species, the distribution of body-size over species, the classification of species according to life-history attributes or ecophysiological preferences and the structure of the food-web can be used [78]. The number of bio-indicator systems using soil invertebrates is relatively high; some approaches use Nematode, Enchytraeid, mites, Collembola, Diptera, Coleoptera or all microarthropod communities [79,78,77,80,81]. Moreover the use of bioindicators makes it possible to highlight the interactions among the different pollutants and between them and the soil. Often, bio-monitoring techniques are not very specific in identifying the pollutant or environmental variable that creates stress in the organisms. For this reason bio-monitoring

must not be considered a substitute for physical-chemical analysis, but a complementary methodology which allows a broader outlook on the case study.

Most edaphic animals have life cycles that are highly dependent on their immediate environment, interacting with soil in several different ways. To be able to evaluate their role and function, it is important to use methodologies that highlight either the number of species present or the processes and roles that they play in the soil environment. In particular mesofauna groups are a key component of soil biota. They are very abundant, their role in soil formation and transformation is well-recognized, the area covered during their life cycle is representative of the site under examination, their life histories permit insights into soil ecological conditions and, several species have already been recognized as useful biological indicators of soil quality. In general, soil invertebrate-based indices consider the consistency and richness of populations [82]. Some species in a single taxon may be specified as indicators of soil quality or as test organisms and used in toxicology tests. In the collembolan taxon, *Folsomia candida* (Figure 14) is the most frequently used species in both sub-lethal and lethal testing [83-86]. *Onychiurus armatus* [87,58], *Orchesella cincta* [88-90], *Isotoma notabilis* [58], *Tetradontophora bielanensis* [91] and other collembolan species [92] have been used in laboratory tests but have not reached the same level of routine use as has *F. candida*. Because of the species-specific differences in responses to contaminants, the tests conducted on *F. candida* provide partial indications as to the effects provoked by these substances on the collembolans; this information has also been useful in calibrating experiments on other species. Some collembolan species like *Folsomia quadrioculata*, *Folsomia fimetariodes*, *Isotoma minor* and others species have been used to evaluate the effects of chemicals on collembola in the field [85].



Figure 14. *Folsomia candida*, a collembola used in toxicology tests

The Maturity Index (MI) [93] is a bio-indicative method based on the soil nematological community composition (Figures 15 and 16) that sorts the families into five categories according to the reproductive characteristics which define them as colonizer or persistent organisms. Each family is assigned a score ranging between 1 and 5 passing from the

colonizer to persistent forms. These values, called c-p (v), are then multiplied by the organisms' frequency (f) and finally inserted in a summation.

$$MI = \sum_{i=1}^n v(i)f(i)$$

Index values close to 1 indicate the predominance of colonizer forms and therefore an environmental situation that presents no great stability. On the other hand, values ranging between 2 and 4 highlight the presence of a situation with persistent forms and more stable conditions.



Figure 15. A nematode belonging to Mononchidae family

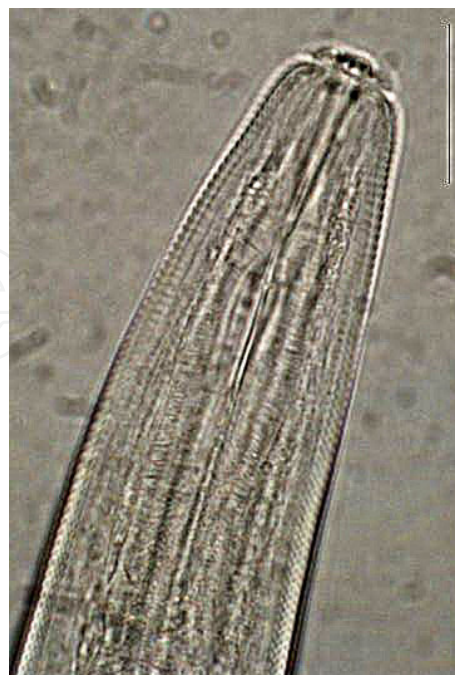


Figure 16. A nematode belonging to Plectidae family (*Chiloplectus andrassyi*). In the picture is showed a particular of the head

Moreover, soil biological quality could be expressed using an Acari/Collembola ratio (A/C) and the QBS-ar index. The first indicator is based on the densities of Acari and Collembola communities where in natural conditions the ratio of the number of mites to the number of collembola is greater than one. On the other hand, in the case of soil degradation, that ratio shifts towards collembola and its value diminishes [94]. The QBS-ar index [77] is based on the following concept: the higher the soil quality is, the higher the number of microarthropod groups morphologically well adapted to soil habitat will be. Soil organisms are separated into biological forms according to their morphological adaptation to the soil environment; each of these forms is associated with a score named EMI (eco-morphological index), which ranges from 1 to 20 in proportion to the degree of adaptation. The QBS-ar index value is obtained by summing the EMI of all the collected groups. If biological forms with different EMI scores are present in a group, the higher value (more adapted to soil form) is selected to represent the group in the QBS-ar calculation. QBS-ar was applied in several agricultural ecosystems, grasslands, urban soil and woods at different levels of naturalness and anthropic impact [95,42,30,96,19]. This index reached higher values in grassland and woods and lower values in agricultural ecosystems [30]. Moreover, [96] demonstrated that QBS-ar was highest in the soil with the lowest metal content and the highest density and taxa richness of the invertebrate community. The authors suggested that this index seems to be appropriate in defining the quality of the investigated soils. In Figure 17 are showed some QBS-ar values detected in different soils.

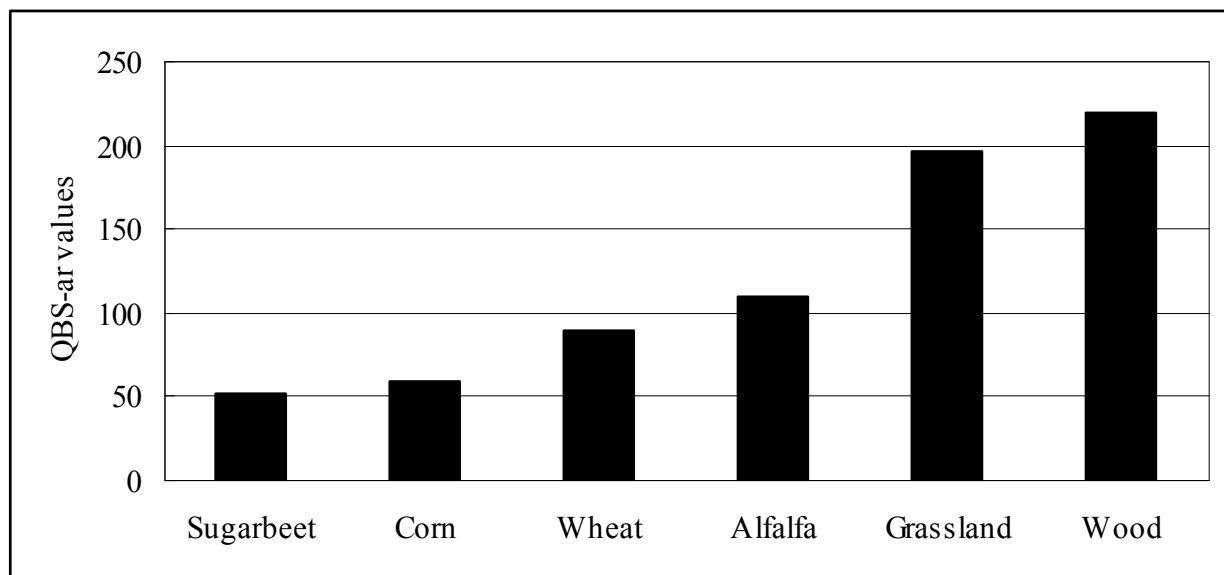


Figure 17. QBS-ar values detected in different soils

[19] concluded that in forest ecosystem management, QBS-ar could be an efficient index for evaluating the impacts on soil of forest harvesting (i.e. soil compaction due to logging) and so for determining the sustainable use of renewable resources. At the same time, QBS-ar can be a valuable tool in ecosystem restoration programmes for monitoring the development of soil functions and biodiversity and for preventing the negative effects of soil compaction when mechanization is used (e.g. in Europe many LIFE projects include mechanized

operations). Furthermore this index could be implemented in environmental management programmes of urban forestry and protected areas in relation to recreational use to prevent the negative effects of trampling.

Another index that could be applied to soil fauna communities is the V index [97], which expresses the magnitude of the response to tillage.

The V index was calculated as:

$$V = \frac{2M_{CT}}{M_{CT} + M_{NT}} - 1$$

where M_{CT} and M_{NT} could be the abundance of taxa under conventional tillage and no-tillage, respectively.

Six magnitude categories were provided for the V index [97]:

Extreme inhibition by tillage (or treatment): $V < -0.67$

Moderate inhibition by tillage (or treatment): $-0.33 > V > -0.67$

Mild inhibition by tillage (or treatment): $0 > V > -0.33$

Mild stimulation by tillage (or treatment): $0 < V < 0.33$

Moderate stimulation by tillage (or treatment): $0.33 < V < 0.67$

Extreme stimulation by tillage (or treatment): $V > 0.67$

Wardle V index proved to be a good indicator of the response to tillage [42].

7. Effect of actions for restoration and conservation of soil fauna diversity

The realisation that degradation of the soil is an environmental problem of global significance, with immediate consequences at an economic and social level, and the recognition of the importance of protecting it, have led to an increase in international initiatives. The Convention on Biological Diversity is the first global agreement aimed at conservation and the sustainable use of biological diversity (Secretariat of the Convention on Biological Diversity 2000). The CBD lies at the heart of biodiversity conservation initiatives. It offers opportunities to address global issues at a national level through locally grown solutions and measures. One important requirement is the development of National Biodiversity Strategies and Action Plans mainstreaming them into relevant sectors and programmes, a principal means for implementation of the Convention at the national level (United Nations 1992). The recent Conference of the Parties of the Convention on Biological Diversity (May 2008, Bonn) demonstrated that the need for action to protect biodiversity is unanimously acknowledged. Biodiversity conservation is essential both for ethical reasons and especially for the ecosystem services that the complex of living organisms provides for current and future generations. These ecosystem services are essential for the functioning of our planet. A necessary starting point for achieving the objective of preserving soil

biodiversity is to reach an adequate level of knowledge on its extent and on its spatial and temporal distribution. Among the most important tasks that man should set himself for safeguarding the assets of the soil is to rectify the damage caused to ecosystems, where it is still possible, through works of environmental recovery. There are a number of actions that could reduce the risk of damage to ecosystems, ecological receptors and to humans, that include land reclamation, environmental restoration and halting the exposure to sources of pollution (either by physical means or through communication such as information and education) [98]. These initiatives are often problematical and carry a heavy price tag. It is well known that the reclamation of waste disposal sites is usually characterized by soil quality problems; soil used to cover the dump is generally affected by physical, biological and sometimes chemical degradation. These conditions affect both the plant and the animal communities and, more generally, the effectiveness of the restoration processes. In this habitat the soil fauna can be inherited or can have established itself on the reclaimed waste disposal site; generally the more structured the soil is the more complex is the soil fauna community. Management of waste disposal is an extremely emotive issue and the level of acceptance of this kind of facility by the local community is often dependent on the mitigation of its impact and on a good restoration of the interested sites. Beyond the well-known hygienic-health risks and its strong impact on the landscape, the construction of a dump requires the removal of a large quantity of soil that cannot be considered an unlimited resource. In order to prevent the risks of groundwater contamination, the bottom of waste disposal sites is sealed using layers of waterproof materials and the top of the dump is sealed to prevent rain seepage and the leakage of biogas produced by decomposition. The surface layer of a dump is usually covered by filling soil that is suited to being re-colonized by plants and animals, even though this soil does not represent the same physical, chemical and biological characteristics of the removed soil. Thinking about the complexity of the issues relating to dumps, it is important to obtain exhaustive and multi-disciplinary information on the environment and it is necessary to support traditional physical-chemical analyses with bio-monitoring techniques. As previously stated, the growing interest in the employment of living organisms for the evaluation of soil conditions is justified by the great potential of these techniques, that allow the measurement of factors difficult to detect with physical-chemical methods and that give more easily interpretable information [76]. The great differences in abundance and maturity shown by nematode communities (Maturity Index MI 2.76) in the top soil of a reclaimed waste disposal site compared with permanent grassland and wood could have been caused by many factors [99]. In this study disturbance in the soil from a dump is reflected by the lower maturity [93] due to the absence of omnivorous nematodes like Thorneinematidae [100]. The greater abundance and maturity in the nematode communities from woods and grasslands may be due to the fact that the soil is less disturbed. The differences in soil litter composition and in root distribution had probably affected the predominance of plant feeding nematodes in grasslands and the predominance of dorylaimids (Qudsianematidae, Leptonchidae) in the woods [101]. [102], in a study related to nematode communities in ash dumps covered with turf and reclaimed from different times reported MI values ranging from 2.0 and 2.3. [102] reported that in the

ash dump reclaimed over a longer period the total abundance of nematodes was higher than those reclaimed over a shorter time and in some samples it was similar to the lowest abundances observed in grasslands in Poland. The author suggested that the species with high ability to colonize new habitats had the best chance of survival in these conditions. Probably, lack of soil structure, high salt content and low organic matter content may be responsible for low MI values and the low density observed in the dump that was the subject of the [99] study. Moreover, the poor and little structured covering of vegetation in the dump, that consequently did not create homogeneity in soil structure and organic matter content, may be a very important reason also limiting the microarthropod community. [103] showed the vulnerability of springtails and pauropods. The authors observed that the reduction of collembolan and pauropod densities in high-input management systems is largely explained by the mechanical and chemical perturbations produced by conventional agricultural management practices and by particular abiotic soil conditions present in the intensively managed sites that are unfavourable for these organisms. The authors reported that symphylans were more abundant in the mixed management site. Extraction activities have a significant impact on the community, affecting both vegetation and soil microbes and animals. The studies related soil community changes during ecological succession in degraded soils are still scarce. After the extraction, the ecosystem would be able to recover spontaneously if the mineral substratum and the environmental conditions were right, but in many cases the physical, chemical and biological conditions of the soil are too disturbed (e.g. unbalanced particle sizes, low organic matter content, inadequate biological component of the soil) or the start of a secondary succession is impeded due to isolation from the colonisation resources [104]. In the process of open-cast mining, the vegetation is completely removed and this causes major changes in the physical, chemical and microbiological properties of the soil [105]. Topsoil is an essential component in abandoned quarries for the growth of vegetation and must be preserved for the restoration of the ground once the extraction work has been completed [106]. Generally a significant period of time passes between the initial removal of the topsoil and the final distribution of the same over the restored area. Because of this, the properties of the stored soil can deteriorate and it can become biologically sterile. In [108] it was demonstrated that the microbial population in the accumulated stockpile falls dramatically in comparison with a control sample of soil that had not been removed. In the same study results were compared of samples taken in the quarry and those taken from a control area, and the particle sizes of the mineral components were analysed. It was found that the proportion of sand particles in the quarry site had risen, while the particles of lime and clay had fallen in comparison with the control soil, phenomena probably due to the process of erosion. This is a consequence of a low stability of the aggregates and, consequently, a high rate of infiltration [107]. In the accumulated stockpile instead, it was observed that there was an increase in density and a reduction of porosity, caused by compaction by machinery during the excavation. These changes make the diffusion of gases more difficult and they restrict the growth of the deep roots of the plants, thus representing one of the reasons why in the shrub stage they cease to grow. To this must be added a change in the pH of the stockpile, with an increase in its acidity due to

the separation of the base cations and the scarcity of nutrients, probably caused by the reduction of soil microbes induced by the accumulation of the soil stockpile. If it is not possible to deposit the stored soil in the quarry site within the maximum period for preserving its fertility, it becomes necessary to initiate a biological restoration in order to preserve the topsoil, but it must still be carried out within the conservation period, that is before the cessation of microbiological activity and the breakdown of the nutrient cycle, in order to prevent the soil from becoming completely unproductive [108]. The motor for the succession is the interaction between the trophic levels of the ecosystem. Given that plants are at the bottom of the food chain and that they play an important role in the formation of the physical structure of the soil, the changes in the vegetation during the succession are crucial to the successional development of the other organisms, including soil animals. At the same time, the succession of plants depends on the abiotic conditions of the site, on the pool of species and the intra-species competition, but it is also influenced by other trophic levels, among them the herbivores and the soil invertebrates. The latter can influence the successional changes of the plants through soil phytophagous, the effects on the availability of nutrients, and by influencing the formation and the modification of the soil as a habitat for plants. Soil communities are important in the processes of soil formation because they influence the distribution of the organic matter and as a consequence, the rate of decomposition [109]. The study by [109] on the restoration of an extraction site demonstrated that there are strict timing synchronisations between the changes in the vegetation, the soil and its being populated. This indicated that the interaction between all these components can play an important role in successional changes in the ecosystem. The study of these components of fauna are therefore important for monitoring environmental recovery processes, given the links between edaphic fauna, soil and vegetation. As with vegetation, the post-restoration recovery of the invertebrate community is slow and not less than 15 years [110,111], with 80-102 years estimated for the recovery of springtail communities in forests [112]. The maximum density of the mesofauna is generally reached during the 2-3 years of the “pioneering” phase, which is followed by a drastic reduction in the density to levels of less than 20% within the following 10 years [113]. Successive changes in the taxonomical composition and relative abundance may be correlated to successional changes in factors such as vegetation cover, the pH of the soil and the content of organic matter, etc. [114]. The richness of the animal taxa is indicative of the maturity of the community of vegetation in the recovered area. After recovery of the soil, the process of secondary succession involves an increase in the diversity of the structure and in the available ecosystem energy, that facilitate the development of high trophic levels. A study conducted in northern Italy in an open-cast quarry after the restoration phase showed mature microarthropod communities and higher abundances in the sites where the extraction activity had finished earlier. The presence of edaphic organisms generally associated with stable soil conditions, such as pauropods, symphylans, proturans and diplurans, was found only in these sites (personal data unpublished). Succession to a naturalized grassland from former agricultural land and pasture is accompanied by changes in plant biodiversity and in the soil community [3]. These change are the result of a reduction or elimination of management, fertilizer applications and of grazing by large herbivores. The response of the soil faunal

community and diversity might not be in-step with plant succession. Species of soil biota found in early successional stages persist in later stages, although with changes in dominance and species frequency [3]. Species replacement is either less pronounced or it occurs on a different time scale. In a study of grassland succession from 7 to 29 years into restoration, the changes in soil faunal species in Isopoda, Chilopoda and Diplopoda did not correspond with plant successional changes, although the macro-invertebrate diversity and density increased with field age, but decreased in the oldest field [115]. Environmental changes during succession increased the amount of basal resources that provided various micro-habitat and nutrient resources for macro-invertebrates that could lead to the establishment of a diverse community [3]. An increase in the amount of habitable space created by increasing pore surface area would increase the abundance of the macro-invertebrates [115]. It is still not clear to what extent different groups of organisms, such as nematodes, microarthropods or bacteria, respond separately or as an integrated food web community to plant succession. Mechanisms of feedback interactions of soil organisms among themselves and with roots are complex, and not well understood at a molecular level [3].

8. Conclusion

Too rarely do we pause to reflect on the fact that soil is the foundation upon which society is sustained and evolves, that it is a vital component of ecological processes and cycles, as well as the basis on which our infrastructure rests. Often not enough importance is given to the fact that soil quality and its protection contribute significantly to preserving the quality of life, and that the nutrition and health of humans and animals cannot be separated from the quality of the soil. Growing pressures from an ever increasing global population, as well as threats such as climate change and soil erosion, are placing increasing stresses on the ability of soil to sustain its important role in the planet's survival. Evidence suggests that while increased use of mono-cultures and intensive agriculture has led to a decline in soil biodiversity in some areas, the precise consequences of this loss are not always clear [1]. Soil is one of the fundamental components for supporting life on Earth. It is the processes that occur within soil, most of which are driven by the life that is found there, which drive ecosystem and global functions and thus help maintain life above ground. Soil performs numerous ecosystem functions and services, ranging from providing the food that we eat to filtering and cleaning the water that we drink. It is used as a platform for building and provides vital products such as antibiotics, as well as containing an archive of our cultural heritage in the form of archeological sites. Life within the soil is hidden and so often suffers from being 'out of sight and out of mind' [1]. A more complete knowledge of soil fauna is needed for biodiversity conservation.

Only by knowing soil in all its complexity, while maintaining its functionality and quality through actions aimed at protecting its properties, and acknowledging the importance it assumes in the quality of life worldwide, can we embark on a truly sustainable use of soil perceived as a resource and build a proper Man / Soil relationship to be left to future generations.

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