Microbial Amendments and Microbe-friendly Additives

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Introduction

Before we can understand the role of amendments and additives to the soil and their part in a healthy soil, we need to understand what is in the soil and role of some of the organisms in the soil. By knowing something about soil biology we can get a greater appreciation of the constraints and challenges presented by the use of amendments and additives to the soil. This article is not meant to be prescriptive or a definitive assessment of soil biological activity, but is a general overview and discussion on soil biology and biological activities in the soil.

What is in soil?

Soil is made up of four broad categories: minerals (~45%), air (~25%), water (~25%) and organic matter (~5%). The proportion of these elements is variable between soils, but it is the organic fraction that is the most variable between soil management systems. The organic matter component of the soil makes it a vital living system. The organic component of the soil is composed of the residues of dead plants and animals and living organisms that consume organic matter and other soil organisms. Most of the biological activity in the soil occurs in the top 10 cm where there is continual exchange of air and plant residues. We often do not realise the amount of life and what type of organisms exist in soil, because we do not see their activities. We also do not understand the diversity of organisms present in the soil and their function. A popularised experiment in Norway describes how two scientists took a gram of soil from outside their laboratory and found between four and five thousand separate species of bacteria. They then drove a few kilometres to the coast and took another gram of soil and found 5,000 different species of bacteria. The author questioned “if two pinches of soil in Norway contained over 9,000 separate species of bacteria, how many different species of bacteria may exist in soil?” (Bryson 2003).

To begin to understand the function of soil organisms it is sometimes easier to divide them into groups and try and understand the functions of some of the organisms in the group before looking at the whole soil biological ecosystem. Soil organisms are typically classified according to size—divided into microflora, microfauna, mesofauna and macrofauna (Figure 1, Table 1).

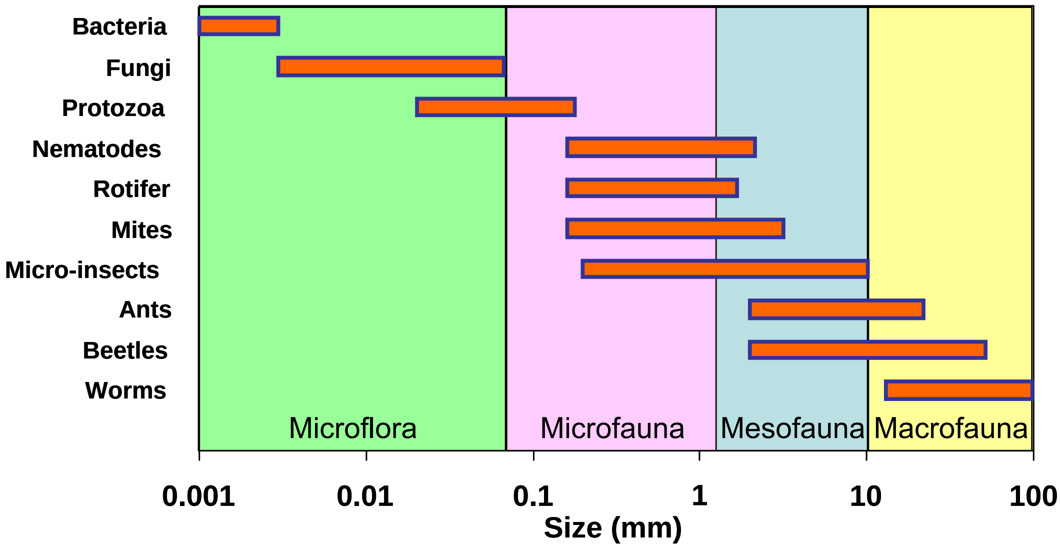
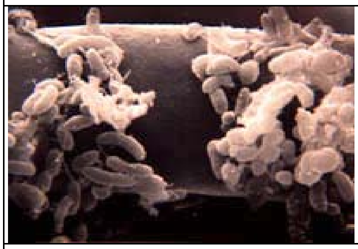
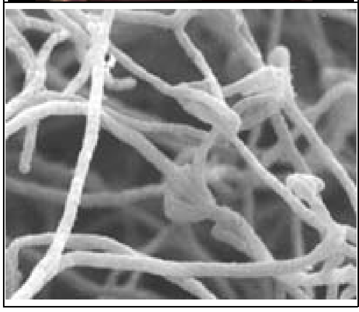
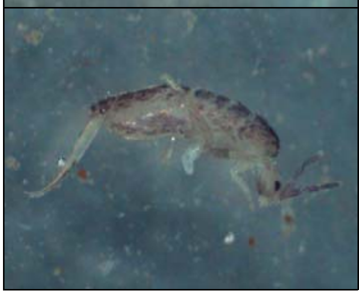


Figure 1: Size classification of some example organisms found in the soil.

Table 1: Examples of some soil organisms and their roles in the soil.

Microflora	Soil microflora is made up of the microscopic component of soil life. These a organisms are primarily responsible for breaking down organic matter in the soil
	**Bacteria** Bacteria are less than 5 µm in size and can only be seen using a microscope. There are as many as 1 to 100 million bacteria per gram of soil. They have a wide range of functions in the soil and are the main agents for breaking down organic material and recycling nutrients in the soil.
	**Fungi and filamentous bacteria** Fungi and filamentous bacteria are usually slower growing than bacteria and not quite as numerous with usually less than 1 million colony forming units per gram of soil. However, there may be as much as 6 metre of filament per gram of soil. This group of organisms decompose organic matter more resistant to decomposition by bacteria and can withstand a greater range of environmental conditions.

Microfauna	Microfauna are primarily involved in the recycling of nutrients and the release of nutrients for further biological transformations in the soil.
	**Protozoa** Protozoa feed by engulfing other organisms in the soil such as bacteria and fungi. Their numbers in the soil range from 10 to 1 million per gram. Protozoa have a high turnover and their feeding on soil microflora helps to refresh the microflora population.
	**Nematodes** Nematodes have been described as the "vacuum cleaners of the soil". Their numbers in the soil range from 2 to 200 per gram of soil. Nematodes can feed on bacteria, fungi, roots or are predators of other nematodes and protozoa. Nematodes are very important in recycling nutrients within the soil.
	**Other microfauna** Other microfauna exist such as rotifers (pictured) and tartigrades. Their role is similar to nematodes and protozoa—feeding on the soil microflora and recycling nutrients. However, these organisms are not quite as numerous in the soil.
Mesofauna	Mesofauna are primarily responsible for regulating and distributing microorganisms in the soil. They may also fragment organic matter in the soil, making it easier for microorgansims to decompose.
	**Mites** Mites in the soil can feed on fungi, decomposing organic matter or they may be predatory on smaller microorganisms. Mites vary in size from less than 1 mm to 6 mm. There may be as many as 15 mites in 1 gram of soil.
	**Insects** There is a wide range of small insects, such as collembolan (pictured). Their size varies from 1-10 mm and numbers are typically around 5 per gram of soil. Small soil insects can feed directly on decaying organic matter, soil microflora (bacteria and fungi) or on soil microfauna.

Macrofauna	These are the larger animals in the soil and easily seen with the naked eye. Not all macrofauna are permanent residents in the soil, but may complete only part of their life cycle below ground. The macrofauna are described as “soil engineers” as they are able to move soil particles.
	**Ants** There is a large range of ants that live in the soil. The larger animals that live in the soil have the capacity to rearrange soil particles creating channels in the soil. Ants can range in size from 1-25 mm.
	**Beetles** There can be a range of beetles and their larvae that live in the soil. They typically live on plant material or may be predatory on other soil animals. They range in size from 0.5 to 10 mm.
	**Earthworms** Earthworms feed on organic matter in the soil and are important in moving organic matter to lower soil depths. Earthworms range in size from 5-25 cm and their numbers vary in soils from 30-300 per m^2. The tunnelling and worm castings due to worm activity are important in maintaining soil structure.

Role of microorganisms in the soil

Nutrient recycling

There are a lot of nutrients contained with organic matter. However, much of these are unavailable to plants until they under go transformation mostly by soil microbes. This process is known as *mineralisation*. Without the activities of microorganisms on organic matter the surface of the world would be covered to the depth of several meters in undecomposed organic matter. However, very few organisms possess the ability to entirely decompose organic matter by themselves. Instead there are a chain of events as the organic matter passes between organisms in the soil that lead to the decomposition of the organic matter. For example larger organisms can shred organic matter into smaller pieces, increasing the surface area that bacteria and fungi are able colonise to start microbial decomposition. This connectivity of organisms and flow of nutrients between organisms is known as the *soil food web*.

Soil management has a big impact on the flow of nutrients and the turnover of organic matter in the soil. The management of inputs into the soil will influence the biology and availability of nutrients to soil organisms. Long term changes in soil biology take place when management practices occur over a long time or dramatic disturbances occur to the soil environment.

Maintaining soil structure

The formation and maintenance of good soil structure has a strong dependence on soil biological activities. The mucus covering of the organisms in the soil mix with soil particles, sticking them together to form soil aggregates. Fungi in the soil not only produce mucus which sticks the soil together, but the hyphae act like a net, helping to bind soil particles.

The formation of soil aggregates helps the movement of air and water into the soil, which not only supports better plant growth but a more diverse range of soil organisms. Soils with better binding of the particles, or *aggregate stability,* are more stable when exposed to water and tillage.

Suppression of plant diseases

Disease suppression is a natural condition which can be disrupted by agricultural activities, which often allow soil pathogens and pests to become dominant. Some soils with high amounts of organic matter and biological diversity are able to suppress pests and diseases. That is, the pests and diseases may be present in the soil but they rarely become problematic. Suppressive soils are thought to be the result of *predator-prey* relationships occurring as part of the interactions between organisms in the soil food web.

Soil detoxification

The organisms in the soil act as *biofilters*, decomposing many of the pollutants and pesticides added to the soil. The organisms in the soil are able to use some pesticides applied to the soil as a food substrate. This is referred to as *biodegradation*. Other organisms are able to tie up pollutants such as heavy metals, stopping them from being recycled in the soil ecosystem and ending up in the food chain.

Measuring soil biological activity

There are three broad categories that we are interested in when we want to measure the biology of soils:

1. Size or biological activity,
2. Diversity and
3. Function.

Biological activity

Biological activity only gives an estimation of the size of the biological component in the soil. It cannot tell us how many different types of organisms are present or what their functions are. Soil biological activity can be measured either directly or indirectly. The direct measurements of biological activity can look at the organisms still in the soil or may use various methods of trying to extract them from the soil.

Direct investigations of organisms in the soil is difficult due to the opaque properties of soil. The extraction of organisms from the soil does not always remove all the organisms and some methods are biased towards certain groups. It is estimated that only 1% of soil microflora can be cultured on nutrient media. However, new techniques are being developed that overcome some of these problems, but they are experimental and tend to be expensive.

Indirect measurements of biological activity rely on measuring chemical substrates produced by organisms in the soil. The respiration of living organisms produces carbon dioxide (CO_2). The production of CO_2 can be used as one measure of biological activity (Figure 2). Similarly, the amount of carbon contained in the bodies of microorganisms (biomass C) is another method of measuring the size of the biological component of soils (Figure 2). A study by Shi *et al.* (2006) found greater microbial activity (up to 3 times greater) in older turf grasses compared to younger turf grasses or neighbouring forest (Figure 2).

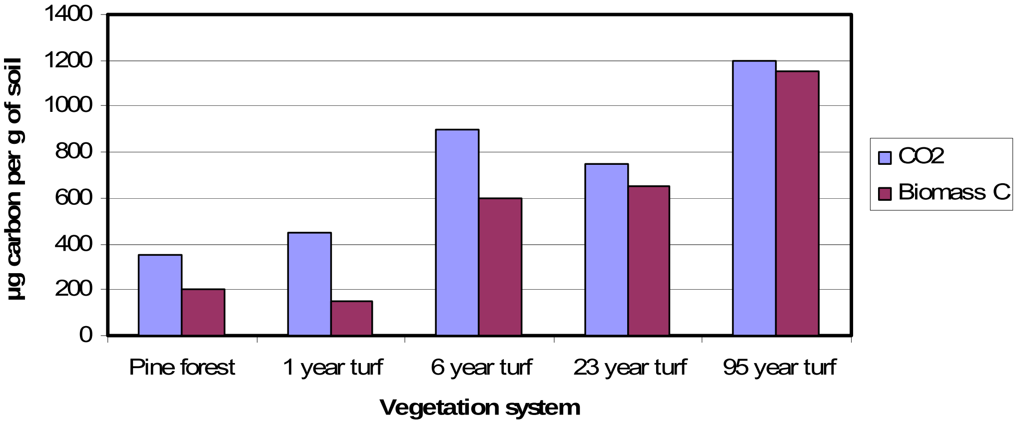


Figure 2: Microbial activity measured by respiration and biomass carbon in four turf grasses of different ages compared to neighbouring forest (Shi *et al.* 2006).

The activity of organisms in the soil requires enzymes to break down organic matter. The amount or activity of the enzymes in soil can give an estimation of the biological activity. The enzymes in the soil can be measured directly or a substrate added to the soil and its decomposition gives an indication of biological activity.

Biological diversity

Biological diversity is the number of different types of organisms present in the soil. The soil is a diverse environment and we can only estimate the true extent. It is estimated that less than 5% of the species in the soil have been described (Bardgett *et al* 2005). It is recognised that different organisms have different roles in the soil or perform a similar function slightly differently. Therefore, a soil that has greater biological diversity has greater resilience to stress and changes, which could be termed as *biological buffering*. A diverse soil ecosystem has a wider range of functions with more interactions among soil organisms. This means there are more organisms in the soil that perform various processes and are able to take over roles of other organisms if a particular group is inhibited by stress. Soil management decisions have the ability to change growth factors, substrate quality or substrate concentration in the soil, which can change the organisms that dominate the biological soil community.

Biological function

The function that different organisms in the soil perform is much more difficult to determine. Some estimates of functions can be made by soil ecological studies. Estimates of the diversity of functions in the soil can be made by the addition of different carbon sources to the soil and measuring their decomposition. In soils with greater functional diversity, the carbon sources will decompose at a similar rate and relatively quickly. However, in soils that have little functional diversity, one or two carbon sources may decompose much quicker than others.

Indicator groups of organisms can be used as *surrogate* indicators of soil functions. For example, soil nematodes are being used more widely as ecological indicators because they feed on a diverse range of substrates and perform different roles in the soil food web (Figure 3).

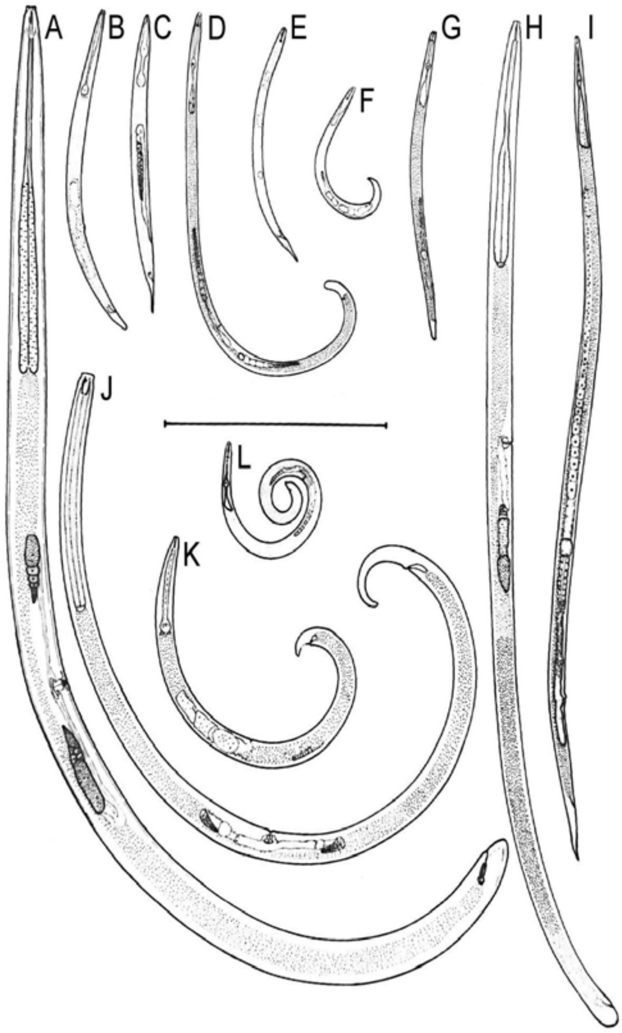


Figure 3: Diversity of size in 12 genera of nematodes recovered from soil. Drawings are at uniform magnification; **A**: *Aporcelaimus* (Dorylaimida; omnivorous), **B**: *Cephalobus* (Rhabditida; bacterial-feeding), **C**: *Rhabditis* (Rhabditida; bacterial-feeding), **D**: *Tylenchorhynchus* (Tylenchida; plant-feeding), **E**: *Heterodera* second stage (Tylenchida; plant-feeding), **F**: *Paratylenchus* (Tylenchida; plant-feeding), **G**: *Pratylenchus* (Tylenchida; plant-feeding), **H**: *Pungentus* (Dorylainida; plant-associated), **I**: *Ditylenchus* (Tylenchida; species variously plant-feeding or fungal-feeding), **J**: *Mononchus* (Mononchida; typically predacious but some have been cultured on bacteria), **K**: *Anaplectus* (Chromadorida; bacterial-feeding), **L**: *Helicotylenchus* (Tylenchida; plant-feeding). Scale line 500 µm = 0.5 mm.(Yeates and Pattison 2006).

Application of microbial inoculants to soil

Discussion so far has highlighted that the soil environment is diverse, well buffered and difficult to modify. Short term changes may be induced by the addition of amendments to the soil. However, microbial organisms applied as inoculants are more likely to be affected by the soil environment than any other agricultural practice. Each microbial agent has specific temperature, moisture and pH requirements for growth and colonisation of the soil. It is very difficult to generalise about the requirements that favour the proliferation of microbial agents. There are few studies that track the survival of microbial inoculants. However, one study investigated the addition of bacteria to the soil and found a 10 fold reduction in the population of that bacteria in the soil after 4 days, 100 000 fold reduction after 50 days and after 90 days the bacteria was undetectable in the soil (Esnard *et al*, 1998) (Figure 4).

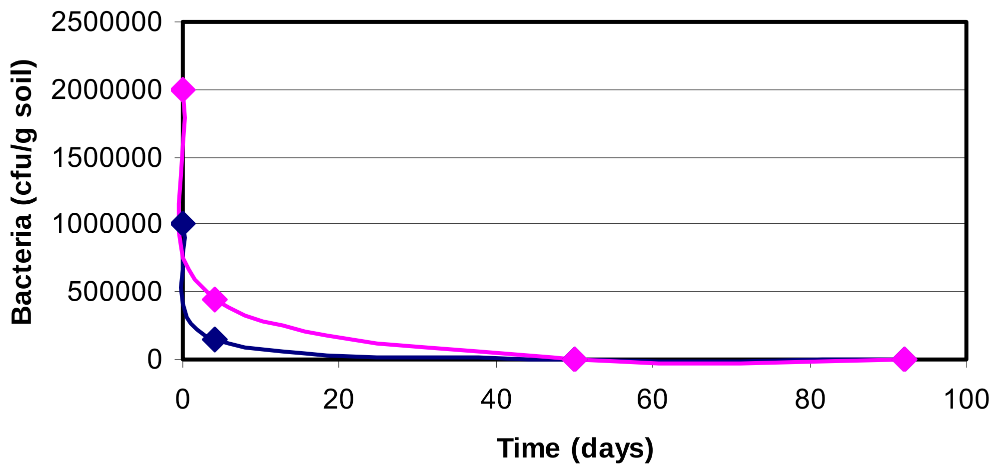


Figure 4: Recovery of bacteria added to soil at two rates over 92 days. (Esnard *et al*, 1998).

There are three general methods that have been used to change the microbial status of the soil. These are:

1. *Inundation* or *microbial pesticide* application—the microbial agent is introduced in large numbers, but fails to persist in the soil so frequent applications are needed (Figure 4).
2. *Introduction* or *mass release*—the microbial agent is normally absent, but it can spread and establish itself in soil to provide long term control.
3. *Natural control*—microbial agents have increased in the soil and their manipulation is confined to preserving or enhancing the conditions that favour their activity.

Introduced microbial agents must compete with the indigenous microflora for scarce energy resources. When adding microbial inoculants to the soil it is important to understand what is trying to be achieved. The addition of microbial inoculants often makes the soil manager feel good, without producing the desired outcome(s). Therefore, some criteria for determining the success of the microbial inoculant need to be set before the inoculant is applied. This will allow an objective comparison with untreated areas (see page 65, Growing the Soil Biology).

Successful introduction of microbial inoculants often depends on the addition of organic matter to enable the microbe to overcome competition. The organic amendment is added to the soil as an energy source to aid the establishment of microbial agents added simultaneously. It then becomes difficult to determine if the microbial agent or the organic matter added has the greatest impact on soil properties. The energy source considered essential for the successful introduction of microbial agents will have marked effects on the soil biology and these effects vary with the soil amendments.

Large amounts of organic matter can be added to the soil to enhance indigenous soil organisms. However, soil biology can be slow to respond and is dependent upon the distribution of the organic matter through the soil. The addition of amendments have many side effects that cannot be attributed solely to changes in soil biology. Soil amendments may result in changes in soil structure and plant nutrition. However, changes in the soil biology from the addition of amendments to promote indigenous organisms tend to have longer lasting effects than the addition of foreign microbial inoculants.

Application of organic amendments

The application of organic amendments has a greater potential of altering soil properties than the addition of microbial inoculants. Organic amendments may not only alter the biological characteristics of the soil, but change the physical and chemical properties in the soil. However, large quantities of material are needed to change soil properties (Figure 4). The application of between 10-25 tonnes per ha of compost were needed to significantly increase the yields of potatoes (Figure 5, Stephen Harper, DPI&F unpublished data). However, the application of more than 30 tonnes per ha of compost began to reduce potato yields (Figure 5).

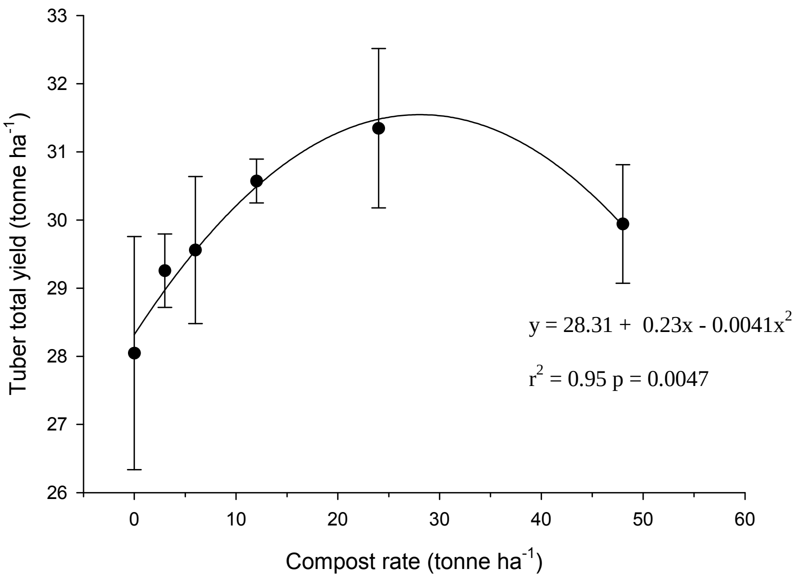


Figure 5: Response curve of potato yields to increasing compost applications (Stephen Harper, DPI&F unpublished data).

Not all organic matter decomposes at the same speed. The rate of the decomposition is reliant on:

- The chemical properties of the organic matter—the C/N ratio and the type of carbon contained within the organic matter,
- The activity of microorgainsms—the number and types of organisms present,
- Temperature and
- Moisture.

The more complex the organic amendment, the more organisms are required to decompose it and release nutrients (Figure 6). Valenzuela-Solano and Crohn (2006) found that grass clippings had nearly completely decomposed after one year, whereas redwood shreddings had only lost 20% of their biomass in the same time (Figure 6).

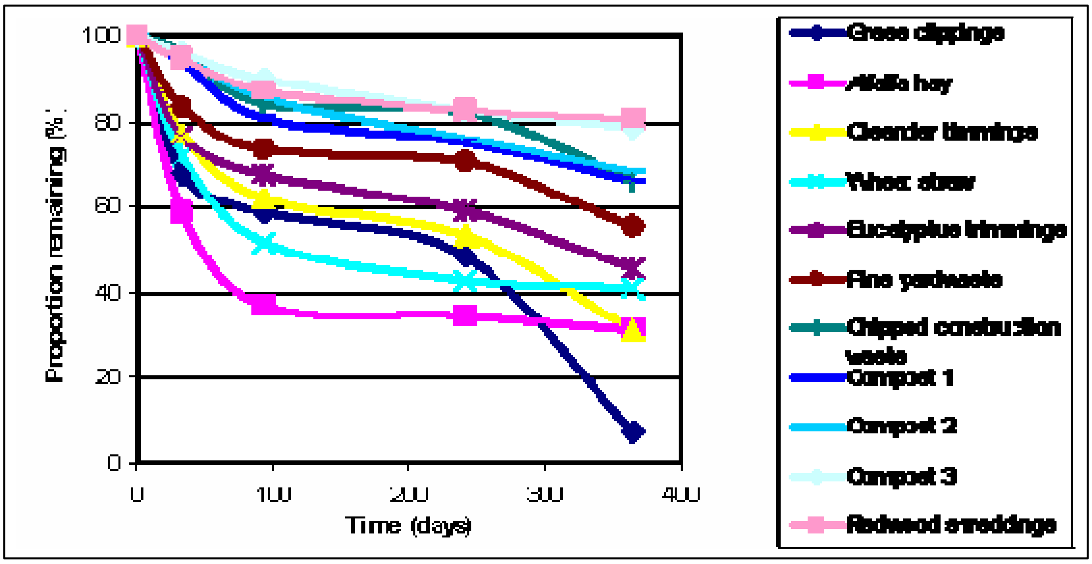


Figure 6: Proportion of mulch remaining applied to the soil surface in a one year experiment.

Complex or resistant organic matter requires more time to decompose and to release nutrients, and will require different groups of microorganisms compared to less complex, nutrient-rich organic matter. The decomposition of organic matter, especially mixtures such as composts, and their effects on soil biology are largely dependent on the supply source used. Similarly, the placement of the amendment will also have a big impact on the rate of decomposition and soil biology. Amendments incorporated into the soil tend to decompose faster and stimulate bacterial activity, whereas those left on the soil surface decompose slower and tend to stimulate fungal activity in the soil.

Different amendments have different impacts on the biology in the soil. In banana soil which had different amendments applied, there was a dramatic variability in the proportion of different feeding groups of nematodes. There were less plant parasitic nematodes and more omnivorous and bacterial-feeding nematodes in soils amended with grass hay or banana trash (Figure 7). The application of biosolids and alfalfa to the soil increased the proportion of bacterial-feeding nematodes (Figure 7).

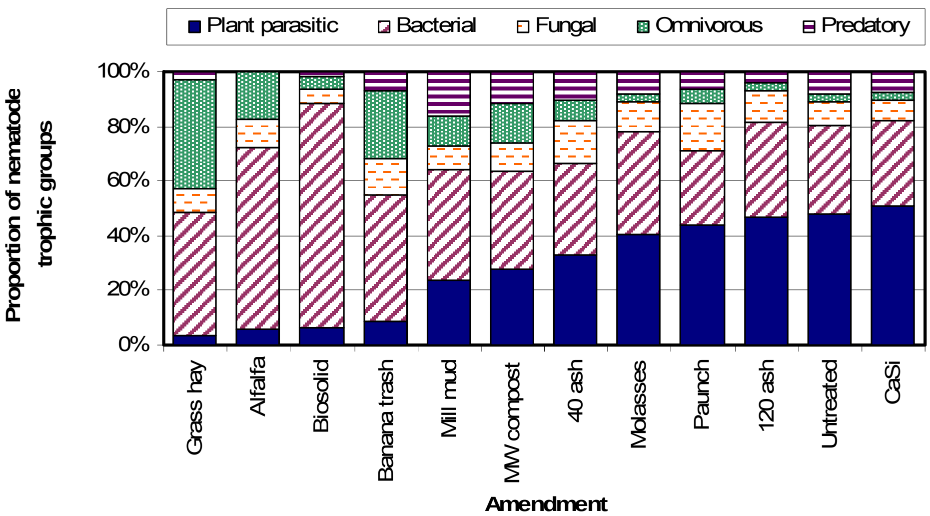


Figure 7: Effects of soil amendments on nematode feeding (trophic) groups in soil.

Influence of plants on soil biology

The influence of plants growing on the soil surface exerts a very strong influence on the organisms in the soil. There is a phenomenon is known as *above-ground-below-ground feedback*. This occurs because atmospheric carbon (CO_2) fixed by plants is decomposed by a select group of organisms in the soil which regulate the availability and supply of nutrients required for plant growth. The growth of *monocultures* (single species) is selecting organisms in the soil that are suited to surviving around the roots and decomposing residues associated with that plant species. A mixture of plant species requires a more diverse soil biological community to deal with the roots and residues of the different plants growing on the soil surface. This was highlighted in a survey comparing banana monocultures to neighbouring mixed plant communities, either forest or pastures. The monoculture had a greater proportion of plant-parasites (75%) in the soil, whereas the mixed plant species had a more even distribution of the different feeding types of nematodes (Figure 8).

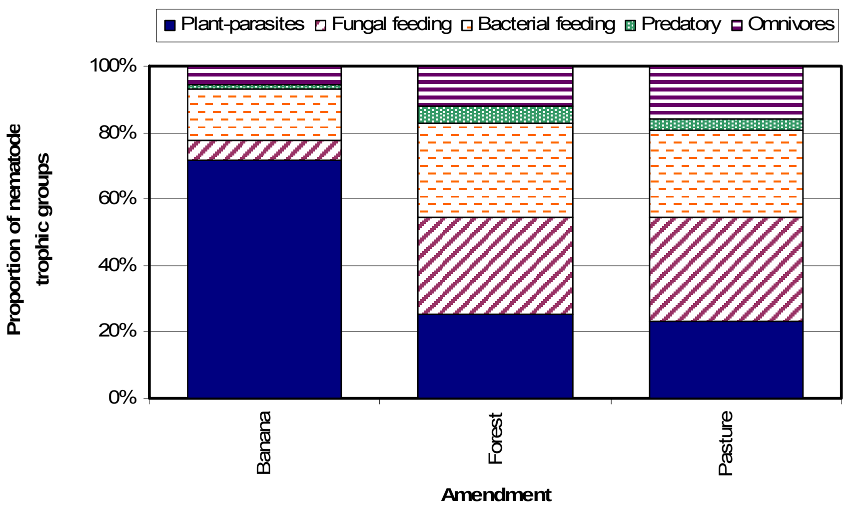


Figure 8: Effects of different plant communities on the proportion of nematode feeding (trophic) groups.

Growing the soil biology

With a greater understanding of the types of organisms in the soil and the roles they perform, we can start to develop strategies to make the most of the soil biology. However, before any type of biological farming can take place, there needs to be clear objectives about what is trying to be achieved. Some of the important questions that need to be answered include:

1. What do I want to achieve by changing the soil biology?—greater productivity, increased sustainability, disease suppression etc.
2. What organisms should I try to promote in the soil?—fungi, bacteria, earthworms etc.
3. What amendments would best help me achieve the objective and how much do I need? For example: amendments high in carbon applied to the soil surface stimulate fungal decomposition, whereas amendments high in nitrogen incorporated into the soil stimulate bacterial decomposition.

4. How do I know if the amendments are working and achieving the desired effect? There needs to be an established method of assessment and comparison with untreated areas.

The measurement of soil biology is difficult, but the plants growing on the soil surface can act as *bioindicators* of the function of soil health. Because plants integrate the biological, chemical and physical aspects of soil they are often the easiest determinant of changes occurring below the ground. However, it is then difficult to establish *what* has caused the change. This is why it is important to keep areas untreated, as a reference point to see differences.

Degradation of the soil takes place over a long time. Similarly, the restoration of a soil environment is a slow process and large quantities of material are required to bring about changes. Continual monitoring of the soil may help to find trends in soil indicators that can help to prevent soil degradation. An improvement in soil biology is only the start to a healthy soil—it is not the solution to unhealthy soils.

Conclusion

Life in the soil is a small but very important component of the soil system. The biology in soils is responsible for recycling nutrients, maintaining soil structure, suppressing diseases and removing toxins from the environment. For the biology of the soil to function properly and sustain healthy plant growth, organisms in the soil are dependent on one another to form a soil food web. There is an large number of organisms and diversity of different organisms existing in the soil—ranging from microscopic microflora to macrofauna the size of earthworms.

The composition of the soil biological community is well buffered against changes in the absence of large disturbances. Practices that bring about long term changes in the biological composition of the soil are large scale management changes—such as changes in plant community composition or the addition of large amounts of amendments. The effects on soil biology resulting from the addition of amendments are dependent on the source of the amendment and the quantity applied. To understand what effects amendments have on soil biology requires a structured process of assessing and comparing changes in soil and plant properties. A holistic view of how soils function to sustain plant growth is required to make the most of the life existing in soils.

Acknowledgements

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Further reading

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