Chapter 5
Understanding & Managing Soil Biology

CONTENTS

5 Understanding and Managing Soil Biology

5.1 Introduction

This chapter aims to provide an overview of soil biology including; what it is, what it does, why it is important, what affects it, and how to manage this resource to support profitable and sustainable dairying.

5.2 Soil Organic Matter

Soil Organic Matter (SOM) is the common feedstock that supports soil biology.

It is derived from plants and animals, with the primary source coming from plant residues. Soil organic matter includes all the organic substances in or on the soil (Figure 5.1).

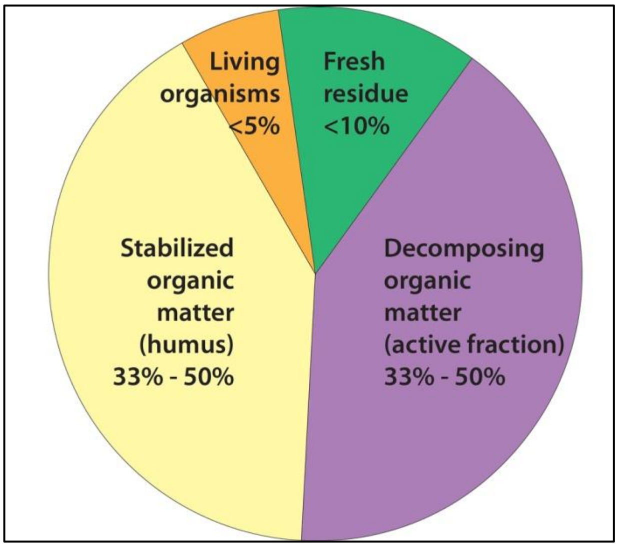


Figure 5.1 Make up of soil organic matter (NRCS, 2013a)

SOM has a number of significant functions (Lal, 2004). These are:

- substrate for energy for soil biota;
- source and sink of principal plant nutrients (e.g. N, P, S, etc.);
- promoter of improved nutrient and water use efficiency;
- significant contributor to cation exchange capacity;
- absorbent of water at low moisture potentials leading to increase in plant available water;
- promoter of water infiltration and reducing losses to runoff;
- promoter of soil aggregation improving soil structure;
- source of strength for soil aggregates, reducing susceptibility to erosion;
- buffer against fluctuations in soil pH;
- moderator of soil temperature through its effect on soil colour.

The most important part of SOM is its carbon component. Soil organic carbon (SOC) is equivalent to about 58% of the SOM.

SOC is made up of four pools, defined chemically as:

- dissolved organic carbon,
- particulate organic carbon,
- humus, and
- recalcitrant organic carbon.

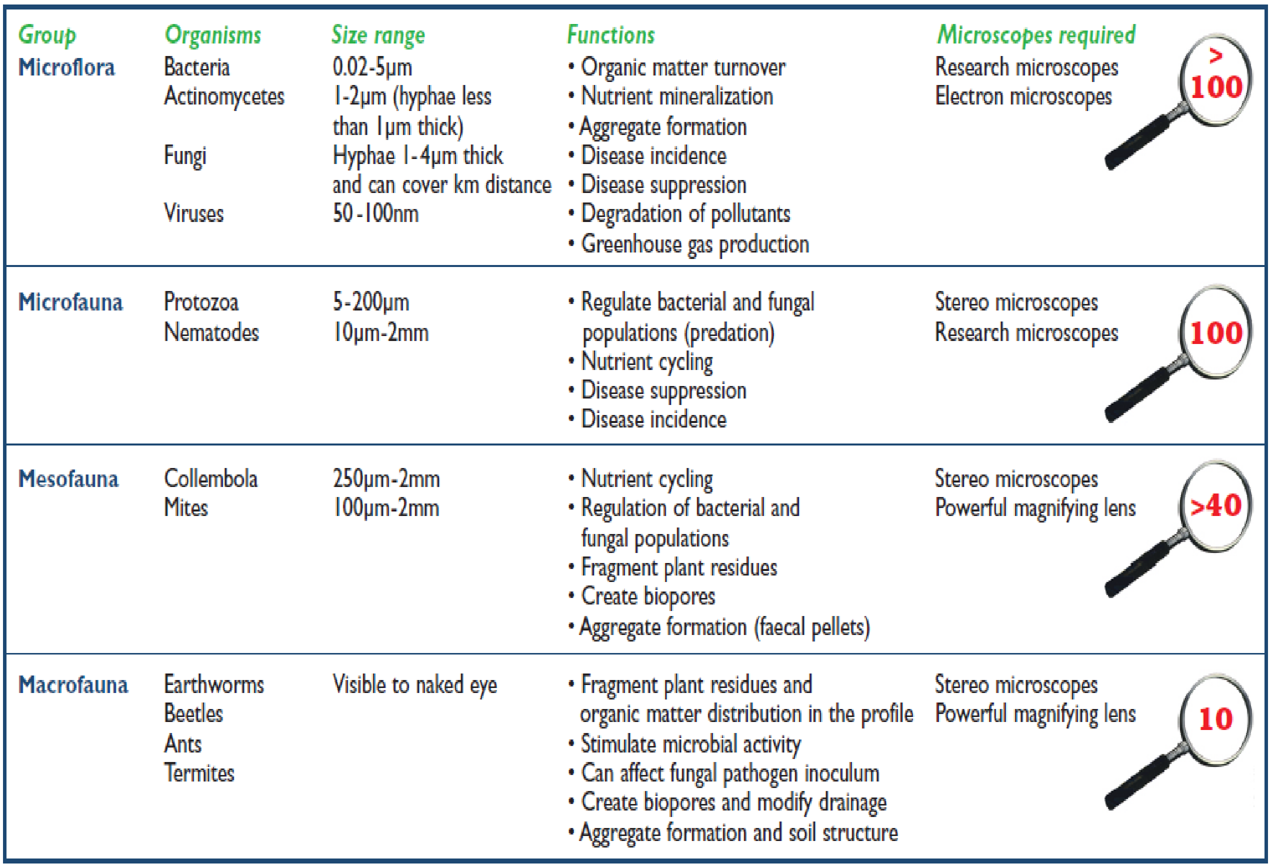
The living organisms usually make up 5% of the soil carbon pool and are responsible for transforming all SOC pools and releasing nutrients for plant uptake. *Dissolved organic carbon* is found in the soil solution and represents a small fraction of SOC. *Particulate carbon* includes recently added plant or animal debris which usually still has a recognisable cellular structure. *Humus* comprises both organic molecules like proteins and cellulose, and molecules with no identifiable structure (humic and fulvic acids and humin) but which have reactive regions which allow the molecule to bond with other mineral and organic soil components. Humus is usually the largest SOC pool, except in pasture systems where humus and particulate carbon can be found in roughly equal quantities. In Australian soils, *recalcitrant carbon* is mainly comprised of charcoal due to the history of fire.

In simple terms, particulate carbon typically lasts for weeks to a year or more in the soil; humus lasts for decades to centuries while recalcitrant carbon can persist for thousands of years. However, current understanding suggests that persistence of organic carbon in soil has more to do with ecosystem properties than molecular properties. This means that the persistence of soil carbon is closely associated with the capacity of the soil to protect the carbon from microbial degradation (Schmidt et al, 2011). This highlights the benefits of perennial systems where soil disturbance is minimised.

SOC's contribution to biological processes is governed by how available the energy in the carbon is to microbes. Dissolved and particulate carbon are most readily available. Although humus is also important as a biological energy source, it can be more resistant to break down and therefore nutrients are released more slowly. However, as a source of plant nutrients, humus is the main storehouse in the soil. Recalcitrant carbon, like humus, is dark in colour and influences the soil's thermal properties.

5.3 Components of the soil biological community

Soil biology may be described by size, taxonomic group and the functions they perform (Figure 5.2). The smallest – the microflora and microfauna – are microscopic in size, that is, they can only be seen using high powered magnification. The meso- and macrofauna may be seen with lower level magnification, a hand lens, or the naked eye.



Group	Organisms	Size range	Functions	Microscopes required
Microflora	Bacteria Actinomycetes Fungi Viruses	0.02-5µm 1-2µm (hyphae less than 1µm thick) Hyphae 1-4µm thick and can cover km distance 50-100nm	• Organic matter turnover • Nutrient mineralization • Aggregate formation • Disease incidence • Disease suppression • Degradation of pollutants • Greenhouse gas production	Research microscopes Electron microscopes >100
Microfauna	Protozoa Nematodes	5-200µm 10µm-2mm	• Regulate bacterial and fungal populations (predation) • Nutrient cycling • Disease suppression • Disease incidence	Stereo microscopes Research microscopes 100
Mesofauna	Collembola Mites	250µm-2mm 100µm-2mm	• Nutrient cycling • Regulation of bacterial and fungal populations • Fragment plant residues • Create biopores • Aggregate formation (faecal pellets)	Stereo microscopes Powerful magnifying lens >40
Macrofauna	Earthworms Beetles Ants Termites	Visible to naked eye	• Fragment plant residues and organic matter distribution in the profile • Stimulate microbial activity • Can affect fungal pathogen inoculum • Create biopores and modify drainage • Aggregate formation and soil structure	Stereo microscopes Powerful magnifying lens 10

Figure 5.2 Elements and functions of soil biological communities (from *Source:* Gupta http://www.csiro.au/Outcomes/Food-and-Agriculture/SoilOrganismsPoster.aspx

5.3.1 Functions of biota in natural soil processes

There are three levels of participation by biota in ***natural*** soil processes (Figure 5.3):

- Ecosystem engineers (e.g. earthworms, termites & ants);
- Litter transformers (e.g. microarthropods); and
- Micro-food webs (e.g. microbes and microfaunal predators)

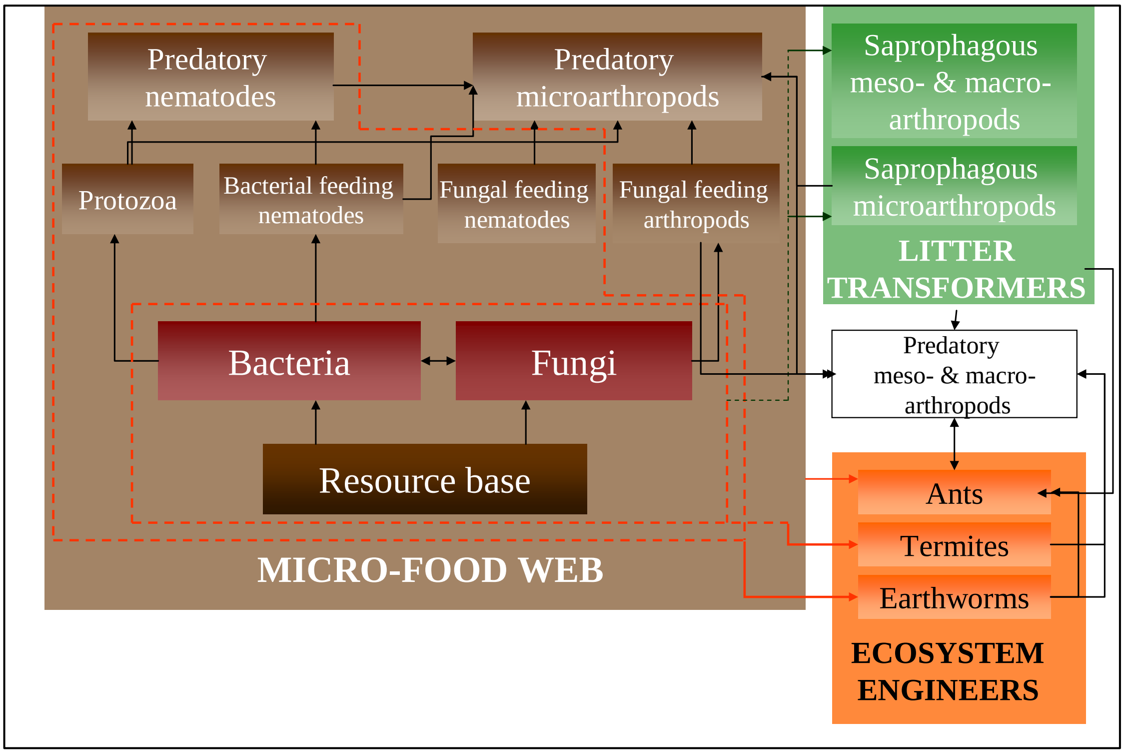


Figure 5.3 Roles and relationships; soil micro-, meso- and macro-organisms (redrawn from Wardle, 2002)

5.3.1.1 Ecosystem engineers

Ecosystem engineers alter the physical structure of soil by the action of earthworms, beetles and ants physically rearranging and pushing soil particles together. They also move organic materials from the surface of soils below ground. In addition, the movement of macrofauna up and down the soil profile creates semi-permanent channels through which air, water and roots can penetrate deeply. Improved aeration and infiltration, together with the deposition of organic materials below ground, create additional sites for soil microbes to chemically break down organic compounds, thereby releasing nutrients for plant uptake – a process known as mineralisation. In this way, the ‘ecosystem engineers’ have a strong influence over rates of nutrient cycling and energy flow in soils.

5.3.1.2 Litter transformers

Litter transformers are those organisms which are capable of shredding and ‘pre-digesting’ organic materials. Collembola (springtails) and oribatid mites are potentially numerous in productive agricultural soils. Through the action of their chewing mouthparts, plant litter is fragmented and its surface area expanded to improve availability of nutrients to microbes (Franzluebbers, 2004).

5.3.1.3 Micro-food webs.

In contrast to the larger organisms, bacteria, archaea and fungi decompose plant litter through enzyme action. Enzymes are released outside the cell and break down litter and any other suitable substrate, thereby releasing nutrients for uptake by other microbes, and plant roots. In their turn, bacteria, archaea and fungi provide a food source for predatory protozoa, nematodes and many of the arthropods such as collembola and mites (Franzluebbers, 2004). Predatory organisms regulate soil populations maintaining stability within a community. They may also control numbers of disease causing organisms; a phenomenon referred to as ‘disease suppression’. Suppressive soils are identified has having potentially damaging levels of pests or disease, yet the pest or disease is either expressed at a sub-economic level, or not at all, due to the presence of certain beneficial organisms.

5.3.2 Where are soil organisms located in soils?

Soil organisms are not uniformly distributed. The factors that influence their distribution are principally access to suitable substrate, air and moisture. Typically, larger populations of soil organisms are found around decomposing residue and in the rhizosphere (root zone) of plants where readily available food sources are located (Schmidt et al, 2011).

Soil organisms may be more evenly distributed in cultivated soils that are thoroughly mixed, particularly with successive cultivations. In dairy soils, which can remain undisturbed for many years, populations can be discontinuous and centred around food resources such as pasture roots. However, given the high earthworm populations commonly found in many dairy soils, the degree of bioturbation (the mixing of soils through the action of the 'ecosystem engineers') in the topsoil can result in a higher degree of soil mixing than might otherwise be found, thereby increasing the distribution of soil organisms throughout the topsoil.

5.4 Why is soil biology important to dairy farmers?

Soil biology mediate critical soil functions by:

- nutrient cycling
    - regulating plant nutrient supply and loss (e.g. N, P, K, Mn etc.),
    - capturing and releasing greenhouse gases such as carbon dioxide, methane and nitrous oxide.
- decomposing plant residues,
- improving soil structure (aggregate stability),
- degrading pesticides and herbicides, and
- regulating water quality (e.g. nutrient filter).

5.4.1 Nutrient cycling

Given that dairy farms have a high nutrient requirement and that all nutrient transformations in soils are biologically-mediated, diverse biological populations are required to support optimum nutrient cycling from both organic and inorganic sources.

5.4.1.1 The Carbon Cycle

The breaking down of organic materials and the release of bound nutrients for plant uptake are important parts of the carbon cycle (Figure 5.4).

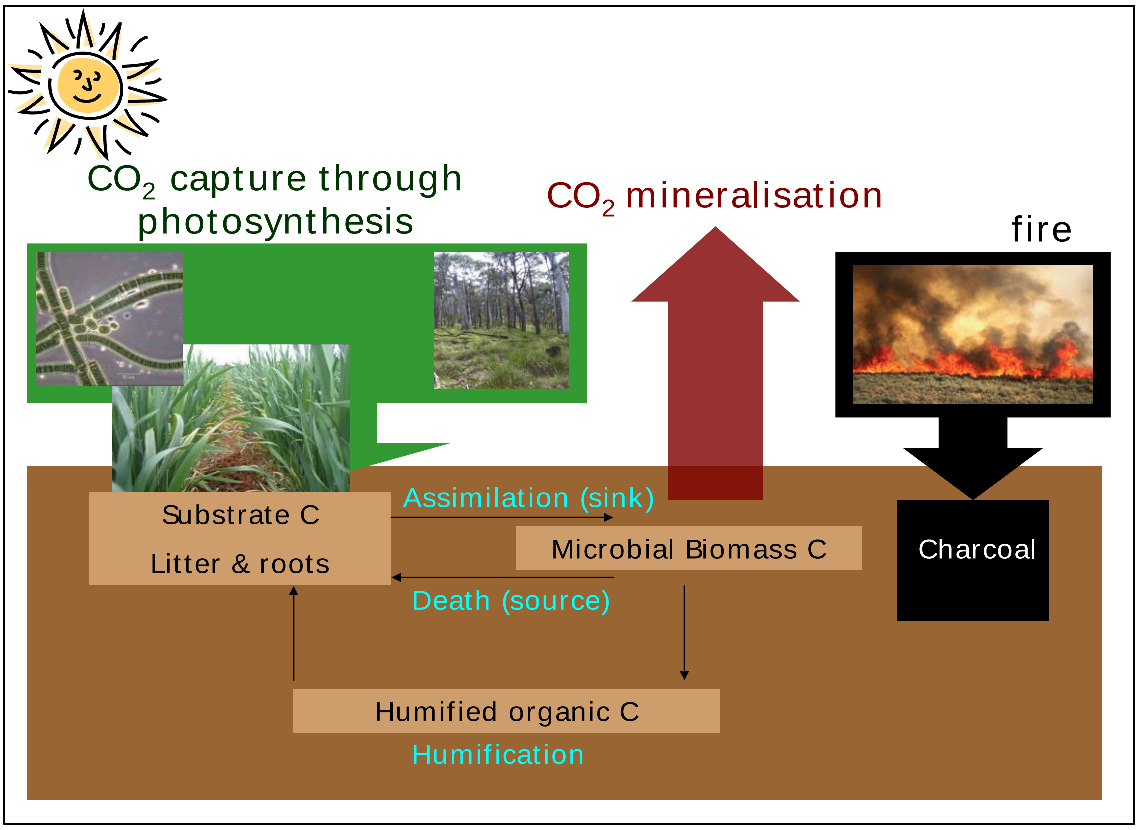


Figure 5.4 The Carbon Cycle (Mele, from www.dpi.vic.gov.au/vro/soil)

In photosynthesis, sunlight drives a biochemical process in plants that splits atoms of carbon dioxide and water and re-combines them as carbohydrates to form the basic units of the terrestrial (land-dwelling) food chain. A large proportion of these carbohydrates are then available to the carbon decomposing soil biota as plant litter or in the form of root exudates. Some of this carbon cycles quickly through the soil (*particulate or labile carbon*) while a usually larger component becomes *sequestered* as microbial biomass carbon, or *humified* carbon and will have a longer residence time. Charcoal can be a significant component of soil carbon if the land had a previous history of fire. This form of carbon can have very long residence times in soils, but ultimately all organic carbon will become mineralised and will be returned to the atmosphere as carbon dioxide.

One aspect of the carbon cycle that is of current concern involves the large return of carbon dioxide (CO_2) to the atmosphere. CO_2 is a potent greenhouse gas and is produced through cellular respiration - the metabolic process that takes place within cells through which organisms obtain energy from organic molecules.

5.4.1.2 The Nitrogen Cycle

Another important cycle is significant in dairy systems, not only because it drives production, but because it is also implicated in the production of greenhouse gases. This is the nitrogen cycle (Figure 5.5).

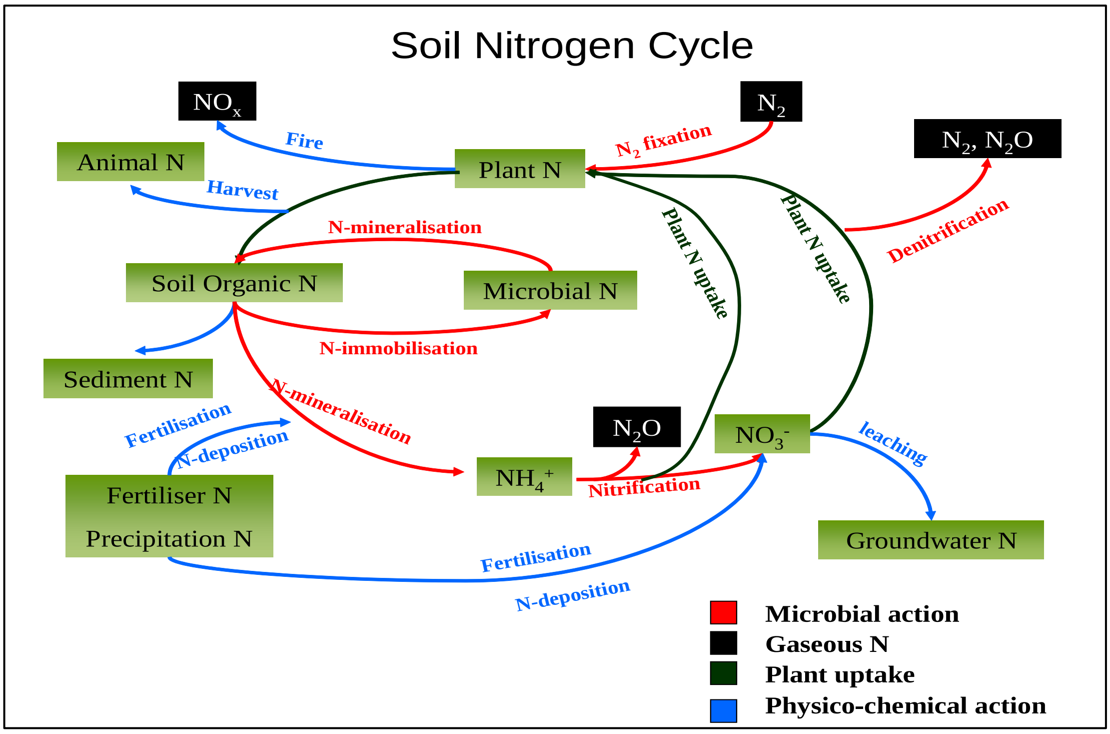


Figure 5.5 The Soil Nitrogen Cycle (Adapted by Mele in www.dpi.vic.gopv.au/vro from E.Paul, 2007)

Depending on the phase of the nitrogen cycle, nitrogen can exist in the atmospheric dinitrogen (N_2) form, the ammonia (NH_3) form, the ammonium (NH_4) form, as nitrite (NO_2^-), as nitrate (NO_3^-), or as nitrous oxide (N_2O). It can also exist as mono-nitrogen oxides (NO_x) produced from the reaction of nitrogen and oxygen gases in the air during fires.

As the different forms of nitrogen move from one phase to the next, their conversion is mediated by biological processes either in the body of a plant or animal, or via microbial action in the nitrogen fixing, mineralising, immobilising, nitrifying or de-nitrifying stages in the soil (red arrows in Figure 5.5). Plants can only take up N as inorganic N forms (nitrate or ammonium), so organic forms of N need to be mineralised by soil microbes before they can be taken up by pasture. Conversely, ammonium and nitrate can also be *immobilised* back to the organic form when decaying plant material breaks down. The relative speed of the nitrogen cycle in the soil is dependent on temperature and moisture. This means that warm, moist conditions favour the release of nitrous oxide (a potent greenhouse gas) from soil so care is required with regard to the form of nitrogen fertiliser used and its application rate – Refer Chapter 12.1.2.

Pasture legumes, such as subterranean clover, provide high quality feed for grazing animals and can contribute substantial quantities of nitrogen to dairy systems. This nitrogen is essentially provided at no cost. Atmospheric nitrogen is biologically ‘fixed’ by **rhizobia bacteria** living in association with legume roots so that the legume may have no further need of soil/fertiliser nitrogen – See Chapter 3.4.1.3. Rhizobia cannot form survival structures (‘resting bodies’) like spores and this makes all rhizobia very sensitive to environmental stresses. They can easily be killed by exposure to stresses such as heat, extreme pH, and chemicals such as high rates of some fertilisers or fungicides (Drew *et al*, 2012). Rhizobia are aerobic organisms and need oxygen for respiration, moderate temperatures, moisture and food (Table 5.1).

Table 5.1 Rhizobia needs for growth and survival (from Drew *et al*, 2012)

REQUIREMENT	COMMENT
Food and energy	Usually carbohydrates (sugars such as glucose)
Mineral nutrients	Essential macro and micro nutrients
Water	Rhizobia can only grow in moist conditions
Temperature	Preferred range is 15 to 30°C
pH	Preferred range is pH 6.0 to 7.5
Air	Rhizobia are aerobes and need oxygen for respiration

Popular legume varieties for dairying in southern Australia include lucerne, red clover and white clover. All require soils with good fertility, and for lucerne in particular, good drainage. A 2012 review found that annual N_2 fixation rates in Australian dairy pastures are generally low – usually less than 50kg/ha. This is due to low pasture legume content with typical legume contents of grazed pastures less than 30% of total pasture biomass production – See Chapter 12.2.1. Other factors that could positively influence N_2 fixation input (i.e. nutrition, acidity or moisture) were found to have little impact until the proportion of legume in the pasture increased. Potential (maximum) N_2 fixation is governed by legume total dry matter production which is dependent on mineral N availability, soil fertility, and the quality and quantity of the rhizobia (Unkovich, 2012).

Over application of inorganic nitrogen fertiliser can reduce the contribution of organic nitrogen from legumes to a low level, representing a potentially unnecessary cost to the farmer (Unkovich, 2012). At low soil nitrate levels (below 50kg N/ha.) legume reliance on N fixation is high. As soil nitrate levels increase, biological N_2 fixation becomes more suppressed to a point above 200kg N/ha when nodulation and nitrogen fixation will be close to zero (Drew *et al*, 2012). Maintaining legume in mixed pasture swards requires a combination of appropriate grazing management, and applying moderate amounts of N per year (100-150 kg N/ha) – See Chapter 12.6.3 for more information.

Free-living nitrogen fixing bacteria can contribute additional nitrogen per hectare per year. These bacteria, typically species of the *Azospirillum* and *Azotobacter* genera, are found in many Australian soils. Their proliferation is dependent on availability of soil C and relatively low nitrogen levels (Gupta *et al*., 2011; Gupta & Paterson, 2006). Their contribution to dairy soil nutrient budgets is therefore not likely to be large in dairy systems.

5.4.1.3 Phosphorus cycle

Like the nitrogen cycle, the P cycle is very complex, involving many interactions and chemical reactions in the soil. The rate by which organic phosphorus becomes inorganic and plant available in the soil solution will depend on the *mineralisation* process driven by soil microorganisms and their enzymes. As with nitrogen, whilst in the soil solution in this soluble form, phosphorus is also subject to being *immobilised* by soil microorganisms back into an organic form.

Plants and soil organisms have co-evolved symbiotic associations whereby plants can signal a range of needs (e.g. nutrients, plant defence) through the form of plant root exudates produced (Rasmann & Agrawal, 2008).

Soil organisms such as **mycorrhizal fungi** have developed a symbiotic relationship with plants such as phosphorus solubilisation and transport, thereby making P more available to plants.

High rate application of inorganic sources of fertilisers can interrupt this process and reduce biological nutrient cycling. Conversely, a reduction in phosphorus application rates on high P soils has not resulted in loss of production suggesting a resumption of P solubilising functions.

5.4.2 Improving soil structure

Soil biology has a particularly important role in promoting and maintaining soil structure and aggregate stability. Soil structure is influenced by the amount of clay and organic carbon in soils, and the amount and proportion of cations (particularly calcium and magnesium) – See Chapter 4. The cations help flocculate soils into microaggregates and also build bridges between the mineral fraction of the soil and the organic fraction. However, this flocculation alone is not sufficient in most cases to ensure good aggregate stability and good structure. A Cornell University soil scientist, Richard Bradfield, recognised back in 1950 that ‘aggregation is flocculation – plus!’ The ‘plus’ refers to what he called ‘cementation’ – the physical enmeshment of soil aggregates by plant roots and fungal hyphae, and the ‘gluing’ of soil particles by bacterial and fungal exudates (Hillel, 1998). An example of this is the secretions of glomalin from arbuscular mycorrhizal fungi.

5.4.3 Degrading pesticides and herbicides

Soil organisms have the capacity to degrade applied biocides including pesticides, fungicides and herbicides. The concern over the persistence of organochlorines (e.g. DDT, dieldrin, chlordane) in agricultural and horticultural soils relates to their toxic effect on microorganisms (Lal & Saxena, 1982). Modern biocides are, in general, of lower persistence in soils due to the ability of organisms to degrade the chemicals into harmless compounds (UWA, 2013). Without this soil function, the repeated application of herbicides and pesticides would result in these compounds accumulating in soils to levels that would threaten the health of terrestrial and aquatic ecosystems.

5.4.4 Regulating water quality

Another important function of soil biology is the filtering of excess nutrients (within the limits of a given system) thereby contributing to improved groundwater quality before its passage into surface creeks and rivers.

5.5 What regulates Soil Biology?

There is growing awareness of the importance of soil biology to efficient soil function. It is therefore helpful to understand what regulates soil biological populations so that favourable management practices can be used to promote biological function.

There are two levels of regulation of soil biology. The primary regulators are environmental and include air, water, temperature, and soil type. In the context of a habitat all of these features are related such that the texture and porosity of a soil determines the water and air available for growth. The secondary regulators relate to organic matter quality and quantity, the amount and frequency of soil disturbance, and the inputs used to manage production (fertilisers, herbicides, lime etc.).

5.5.1 Primary Regulators

5.5.1.1 Soil air

The movement of air into and out of the soil is critical to the survival of aerobic organisms, and the functions they perform. There exists therefore, a strong relationship between soil structure and soil biological functions.

Given that most nutrient cycles are biologically-dependent, meeting the needs of microorganisms for air, water and food through management practices that support good structure, and avoid damaging compaction, will promote efficient nutrient cycling.

5.5.1.2 Soil water

Aerobic microbial activity responds to soil water potential assuming soil temperature is not limiting. Figure 5.6 shows that microbial biomass is closely aligned with soil moisture content with populations rising with available moisture when food and temperature are not limiting. Above field capacity, the loss of soil oxygen due to inundation would see a reduction in microbial biomass.

Of the microorganisms, fungi are generally more tolerant of lower soil moisture than bacteria as bacteria are less mobile and rely on diffusion to obtain nutrients (NRCS, 2013b). Earthworms are generally numerous on dairy farms but populations fall off below 500-600mm annual rainfall with relatively few individuals remaining below 300mm (Mele & Carter, 1999).

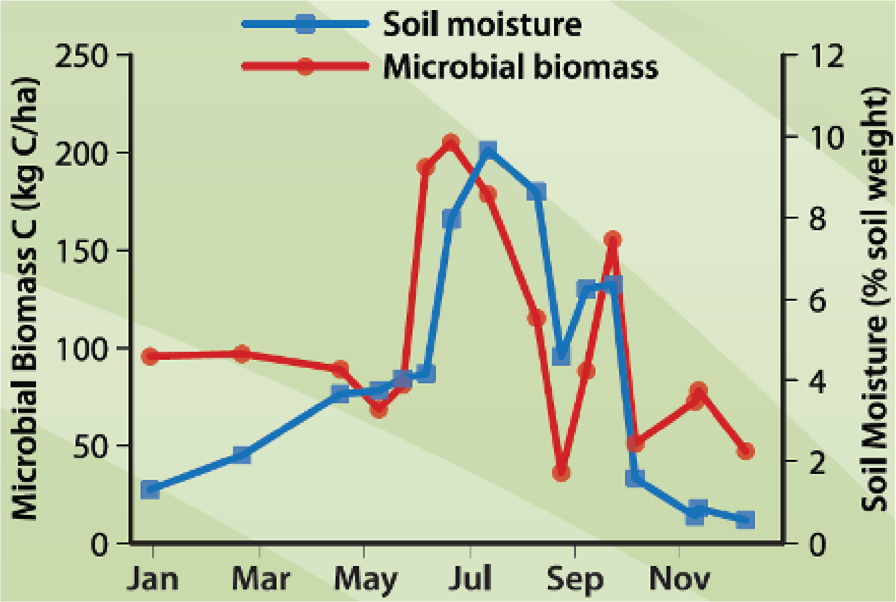


Figure 5.6 Microbial biomass activity as influenced by the level of soil moisture (http://soilquality.org.au/factsheets/microbial-biomass)

5.5.1.3 Soil temperature

Plants as well as soil organisms require certain minimum temperatures in order to grow and carry out their activities. Biological activity and associated growth and development occurs more quickly at higher temperatures, as evidenced by growth rates of pastures speeding up in spring and slowing as winter approaches.

In the soil, biological functions, such as breaking down of organic matter or cycling of nutrients, are similarly affected by temperature. This is why it is generally not a good idea to soil test for nitrogen in spring because the increase in biological activity releases nitrogen from stores of organic matter resulting in an inflated account of the true quantity of N in dairy soils.

5.5.1.4 Soil type

Soil type strongly influences microbial populations for a number of reasons. Clay soils have the potential to hold more water and for longer than a sandy soil. For this reason, they generally hold more organic carbon than sandy soils. Well-structured clay soils will have a higher number of micro- and macro-aggregates, thereby providing more potential habitat for soil organisms of varying sizes. A diversity of habitat will ensure maximum protection for soil organisms against predation.

Note that while clay soils have potential to support higher microbial biomass, this potential will only be realised if other regulators (primary and secondary) are not limiting. Most obviously this means that if the clay soil is poorly structured, its carbon capture potential, air-filled porosity, drainage, and numbers of micro-aggregates will be sub-optimal and production in such a soil is also likely to be below potential. So, even though clay soils have potential to support high microbial biomass, a heavy clay soil that has been used for cropping, or that was poorly managed in wet conditions may not be well structured and may have lower microbial biomass than a lighter loamy soil. Figure 5.7 shows two different soil types under two different land uses. Higher clay, and less disturbance results in higher microbial biomass. Actual microbial biomass on individual farms will be strongly influenced by management practices.

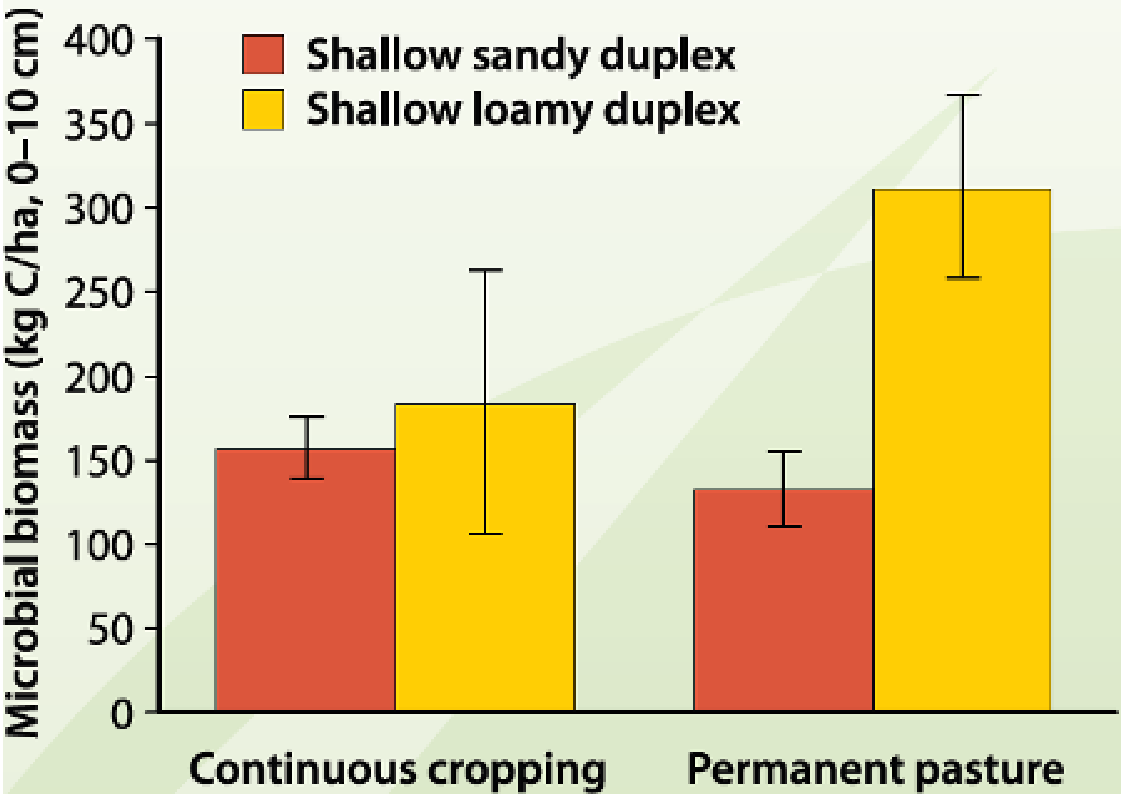


Figure 5.7 Microbial biomass carbon in soils with differing clay contents and management practices (http://soilquality.org.au/factsheets/microbial-biomass).

5.5.1.5 Survival strategies

Bacteria are simple organisms consisting of a single prokaryotic (no cell nucleus) cell. They are extremely responsive to changes in their environment either rapidly dying back or reproducing at a very high rate depending on conditions. Under favourable conditions bacteria may divide every 20 minutes. This could result in exponential growth where one bacterium could produce 10 million in just 10 hours (Agrios, 1988). However, this is unlikely to occur to this degree in soils due to reduction in food supply or accumulation of metabolic wastes. When conditions change to be less favourable, most bacteria can quickly develop a range of ‘resting bodies’ which can survive extended periods until such time as conditions again favour growth and development.

Fungi usually have plant-like vegetative bodies called mycelia (singular mycelium). The mycelium consists of elongated, branched, microscopic filaments termed *hyphae*. They are higher order eukaryotic (possessing a membrane-bound nucleus) organisms, the vast majority of which are saprophytic, that is they live on dead organic matter. Fungi reproduce primarily by means of spores. Fungi are not as responsive to environmental changes as bacteria due to their larger physical size allowing access to a wider range of soil resources. However spores may be produced as resting bodies when unfavourable conditions persist. Fungi may regrow from severed hyphae resulting from tillage but their recovery is slower than that of bacteria – food, water, air and nutrition notwithstanding.

This generally results in higher populations of bacteria in annual systems and equal or higher proportions of fungi in long-term perennial systems.

5.5.2 Secondary Regulators

5.5.2.1 Organic matter quality and quantity

Organic amendments:

The carbon to nitrogen ratio (C:N) is a good measure of likely mineralisation (release of N by microbes) or immobilisation (tie-up of N in microbial biomass) in soil. A soil's C:N should be in the order of 12:1. If the C:N is greater than 25:1, immobilisation of nutrients is likely. If the C:N is less than 25:1, mineralisation is likely. This means that if microbes (mainly bacteria and archaea) are in a high nitrogen environment (low C:N) they can use that nitrogen to breakdown organic matter in soils to access nutrients, including carbon, as a food resource, and their population will likely increase thereby turning over N for plant access. However, in low C:N soils, soil carbon is at risk of declining if sufficient carbon is not re-introduced into the system by growth (e.g. plant roots), or application (e.g. manures or compost). In low C:N soils, microbes will use available nitrogen to degrade soil carbon which is released as CO_2.

Conversely, in a high C:N soil, bacteria will access all available nitrogen to breakdown excess C and as they are superior competitors for soil N compared to plant roots (Owen & Jones, 2001), the plant will be deprived of nitrogen because it is immobilised in the bodies of bacteria and other soil microorganisms. This is termed 'nitrogen draw down'. It is usually a temporary phenomenon and is overcome when bacteria die off due to resource depletion, or another nitrogen source is introduced.

The C:N concept is important when adding organic amendments to soil. Table 5.2 shows average C:N ratios of common organic materials. As mentioned above, if an amendment has a C:N of less than 25:1 it will progressively release nutrients and should have a fertiliser effect. If the material has a C:N ratio of more than 25:1, it is likely that nitrogen will be immobilised and nitrogen draw down will occur.

Table 5.2 C:N ratios of common organic amendments (Charlesworth, 1997).

MATERIAL	C:N
Urine	2:1
Dried blood	4:1
Pig manure	5:1
Poultry manure	10:1
Farmyard manure	14:1
Seaweed	19:1
Horse manure	25:1
Weeds	30:1
Straw	80:1
Sawdust	500:1

Microbial diversity:

Microbial diversity refers to the number and variety of soil microorganisms. As a general rule, the more diverse the above-ground crop or pasture mix, the more diverse will be the micro-biological communities in the soil. Wilhelm (1973) cites the 'Elton Principle' which holds that the greater the complexity of a microbiological community in terms of total number and species of organisms, the greater the stability of the community. As shown in Table 5.2, organic amendments can vary considerably and their application to the soil will have different effects on the soil biological community. In the same way, crop and pasture mixes will also influence microbial composition and activity.

Plants vary in the size and structure of their root systems, in the quantity and quality of root exudates, and in the degradability of crop or pasture residues. This results in differences in microbial density and diversity in the plant rhizosphere (root zone) and near crop and pasture residues. Some plants possess chemicals that inhibit the growth of other plants, or have negative effects on soil organisms. Likewise, some microbes possess strategies that enhance their competitive advantage. This has particular relevance when we consider suppressive soils. The term 'suppressive soil' has been used to describe soils in which a pathogen is present but is not causing economic damage. Suppression of a pest or disease is the mechanism by which one or several organisms are antagonistic to a pathogen through the antibiotics they produce, competition for food, or through direct parasitising of the pathogen (Agrios, 1988). As an example, the production of isothiocyanates in canola has a suppressing effect on soil microorganisms. Isothiocyanates possess fungicidal, bacteriocidal, nematocidal and allelopathic properties (Fahey, 2001).

5.5.2.2 Tillage

Organic matter persists in soils to the degree that it is protected from microbial attack (Schmidt *et al.* 2001) or because prevailing moisture and temperature conditions are unfavourable for microbial decomposition. Tillage of any kind impacts on these protective mechanisms and renders the organic matter vulnerable to degradation by soil organisms. Tillage mixes the soil bringing microbes into more intimate contact with organic matter. It also improves (however temporarily) air and water movement into the soil – elements important for the growth and development of soil biology. Tillage can also be used to incorporate and distribute plant residue into the soil profile, again bringing food resources into close contact with soil organisms.

Tillage favours bacteria in view of their superior ability to respond quickly to changes in the environment. Fungal populations tend to be negatively impacted in view of the damage to the hyphal networks – See Section 5.5.1.5.

The incorporation of large quantities of organic material into soil can be a positive undertaking provided follow up actions maximise the use and sequestration potential of incorporated organic matter. For example, discing in crop residues will help to capture much of the carbon turned into the soil and will benefit the establishment and growth of perennial pasture.

The development of minimum- or no-till systems recognises the value of minimising soil disturbance. Stubble retention or surface applied organic materials will support slower decomposition and nutrient mineralisation, favour fungal growth to aerobically degrade lignocellulose compounds, promote better aggregation and soil structure, and improve the potential for SOM accumulation (Scott *et al*., 2010; de Boer *et al*., 2004)

5.5.2.3 Chemical impacts on soil biology

The large number of chemicals registered for use on farms makes it difficult to discriminate between those that are benign and those that are harmful to soil biology. While some have little effect, others do negatively impact on soil biology. Bunemann *et al*. (2006) reviewed the impact of agricultural impacts on soil organisms and found that:

- fertilisers generally enhanced soil biological activity due to increases in production;
- the acidifying effects that can occur with the use of certain nitrogenous fertilisers resulted in negative impacts on soil biological activity;

- organic amendments generally enhanced soil biological activity;
- microbial inoculation, with the exception of nitrogen fixing microbes, appears to have little long-term effect;
- the negative effects of pesticides and fungicides were more commonly reported;
- negative effects of herbicides were less commonly reported.

Roget & Gupta (2004) found that the negative impact on soil biological activity of many herbicides is reversible i.e. given sufficient time, the soil biology bounces back. However, with some chemicals, repeated applications delays or removes that reversibility. They recommended that:

- The short-term impacts of most of the herbicides tested are reversible, so it may be possible to develop management options to reduce non-target negative impacts;
- An appropriate recovery period for soil biota should be allowed between herbicide applications;
- Soils with a healthy biota could recover from short-term negative effects of herbicide application. Appropriate use of herbicides could be less destructive to soil biota if management practices that improve biological activity are promoted.

Grains Research and Development Council (GRDC) funded research from South Australia found specific effects of herbicides on soil N fixing bacteria with reductions in nodulation that resulted in reduced N benefit to the system (Drew *et al*, 2006).

Lime application and the associated increase in soil pH are strongly correlated with changes in microbial communities (Nelson & Mele, 2006). Lime has also been shown to influence functioning of the nitrogen cycle. Molecular techniques were used to target a section of the N-fixing gene in a wheat rhizosphere soil. The results suggest an increase in abundance of N-fixing rhizobacteria from which an increase in N fixation could be inferred. Research undertaken on acid soils in North-East Victoria showed an increase in ammonium N oxidisers following the application of lime.

Lime also impacts on soil structure by increasing aggregation of soil particles and the creation of a greater diversity of macro and micro pore spaces for improved habitat. Air and water movement through soil is also enhanced. In addition, biological access to food resources can be improved (Chan & Heenan, 1999).

5.6 Measurement of soil biology

Currently there are relatively limited options for commercial testing for soil biology.

Some tests assess microbial populations using direct observation via microscopy while, more recently, tests employing phospholipid fatty acid assays have become commercially available. While these tests provide some insight into soil biological populations, understanding of how to use this information is currently limited.

More sophisticated analytical tools using the science of genomics to target microbial genes to determine the functions that are active, or are potentially active in a soil, are being used to address R&D hypotheses. Testing for genes involved in the nitrogen cycle provides an insight into the potential nitrogen mineralisation or immobilisation that might occur in a given soil (Hayden *et al*, 2010). These tests can also show the presence or absence of genes involved in disease expression or control.

The future of soil biological testing is likely to focus on short term information relating to the potential for a soil to support efficient nutrient cycling for the coming season, or to the risk associated with pest or disease pressure. Longer term monitoring will reveal patterns in microbial community structure and function, the management of which will be aligned with recommended management practices. For example, biological testing may provide specific information on the effects of tillage, crop rotation, residue management, nutrient availability, or the use of a particular biocide. Such information will require calibration for different soil types and different climatic zones, but will be important for management and investment decisions.

5.7 Managing soils to improve biology

Opportunities to improve microbial biomass and biological function require management – in so far as possible – of the primary and secondary regulators.

5.7.1 Managing primary regulators

Primary regulators such as air and habitat can be managed through protection and enhancement of soil structure. Habitat will be protected if soils remain as undisturbed as possible, if air and water movement into and out of soils is optimised, and if the soil environment is free from toxicities such as salt from primary salinity or application of high salt-index fertilisers. Other primary regulators such as soil type, water and temperature may be more difficult to influence although access to irrigation may provide some flexibility.

Management practices that support habitat protection (good soil structure) include good wet weather management to avoid pugging by livestock in grazing operations, and no-till, stubble retention and direct drilling under cropping. Some work from New Zealand reported low abundances of earthworms, collembola (springtails), and oribatid mites on dairy farms possibly due to both direct and indirect effects on the decomposer community of livestock treading. The loss of decomposer habitat is proposed as a primary factor limiting the incorporation of organic matter from the soil surface into the profile to sustain soil carbon (Schon *et al.,* 2011).

5.7.2 Managing secondary regulators

Improved management practices can influence the secondary regulators of soil biology including organic matter quality and quantity, the amount and frequency of soil disturbance, and the inputs used to manage production (fertilisers, herbicides, lime etc.). For example, heavy metals in biosolids or build-up of harmful chemical residues from repeated use of biocides should be avoided.

5.7.2.1 Managing soil organic matter

Organic matter in the form of plant residues (roots or surface litter), animal manures or composts is the substrate that provides energy to soil organisms. A diversity of inputs from diverse pastures and animal manures will promote below-ground diversity and support a range of soil functions. Diversity of plant species or rotations will also reduce pest and disease pressure through improved stability of the biological community. It is important to note that organic matter input must be maintained so that soil biology have regular and continued access to food stocks. A one-off application of animal manures will see a response from soil biology and a short term increase in soil carbon, but failure to follow up with repeat applications will see the system quickly return to previous levels of soil carbon and biological activity.

5.7.2.2 Managing chemical inputs

Although more data on the impact of fertilisers, pesticides or herbicides on soil organisms is required, available data shows that repeated use of the same biocide is likely to impact on different organisms by reducing their ability to 'bounce back' from the impact. Minimising the use of pesticides and herbicides is recommended through strategic spraying and promotion of improved soil condition and grazing management.

5.8 Microbial inoculants and biological amendments

The interest in soil biology has encouraged market responses in the form of organic amendments, biological inoculants and microbial stimulants. Organic amendments in the form of manures and composts have been in use for millennia with the current challenge being integration of these inputs into conventional fertility management planning.

Many of the newer inoculants and stimulants have not been the subject of rigorous, replicated trials in a variety of soil types or climatic zones. As a result, it is difficult for farmers to know if the product is likely to return a financial benefit – even in the long term – or if the product is a waste of money.

If farmers are persuaded by anecdotal claims of product effectiveness and wish to conduct a trial on their farm, there are a few steps to follow to determine if the product delivers on its promise and the investment is worthwhile.

Firstly, there should be a clear understanding of what the product is claimed to do and how its effectiveness should be measured. In establishing a trial, a paddock which is not the best and not the worst performing should be selected. An area for the trial should be designated and its boundaries clearly marked with a GPS or physical markers that will not be impacted by grazing animals. The trial should have an area to test the product and a similar sized adjacent area on the same soil type not treated by the product, as a control.

Soil tests / pasture tests should be taken before any other action is carried out. Most importantly, only that product to be tested should be used on the trial. If additional inputs are used – e.g. lime – it will not be possible to determine if a response is due to the product being tested, the lime, or a combination of the two. Detailed records of the trial including dates, application rates, weather, pasture responses and other observations will be necessary.

Some biological inoculants have been subject to rigorous trials with, for example, rhizobia – the bacteria responsible for nitrogen fixation in legumes – having a fifty year history of research and development, and quality assurance. Similarly, much work has been done on biocontrol agents such *Trichoderma* spp., a fungus which has demonstrated control of root rots in onions, and work is continuing on new strains of *Bacillus* spp. for biocontrol of common root diseases.

5.9 Summary

Dairy systems are generally high input and bearing in mind that all nutrient transformations – be they organic manures or inorganic fertilisers – are mediated by soil biology, any negative impact on soil biology may reduce the efficiency of nutrient and carbon cycles. Being aware of the needs of soil organisms will allow the farmer to make more informed decisions with regard to protecting and enhancing soil condition.

Soil life principally needs energy resources, together with the basics of existence – air, water and habitat – to thrive. The ages-old practice of applying organic material to soils is being recognised as vital to improving and maintaining soil condition. The issue for modern dairy farming is to integrate the twin challenges of maintaining production through judicious fertiliser application, *and* feeding the soil with regular organic inputs.

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