Soils Alive!

Understanding and Managing Soil Biology on Tasmanian Farms

Sustainable Land Use
Department of Primary Industries, Parks, Water and Environment

Tasmania
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Contents

Soil organisms contribute a wide range of essential services to the sustainable function of all ecosystems by: acting as the primary driving agents of nutrient cycling; regulating the dynamics of soil organic matter; soil carbon sequestration and greenhouse gas emission; modifying soil physical structure and water regimes; enhancing the amount and efficiency of nutrient acquisition by the vegetation; and enhancing plant health. These services are not only essential to the functioning of natural ecosystems but constitute an important resource for the sustainable management of agricultural systems.

(United Nations Environment Program, 2001)

1 Introduction

There is growing interest in soil health. A number of research projects have sought to explore this concept as awareness of the importance of soil biology to the functioning of soils as ecosystems has grown. The Tasmanian project *Soil Ecosystem Health Measures: An Interpretive Guide for Land Managers* was developed in response to a need to understand the biological make-up of our soils, to establish some benchmarking data with regard to optimum populations of various micro- and macro-organisms, and to provide landholders with practical advice to better manage this resource. This book is the principal output from this project.

Carried out over 10 months in 2009, the project sampled a small range of land uses on the rich red soils of northern Tasmania. The project aimed to provide landholders with a useful guide to:

- understand the importance of soil biology to sustainable agriculture;
- improve awareness of the range and number of soil organisms on farms;
- help identify the range of soil organisms on individual farms; and
- provide guidance with regard to management practices that support healthy soil ecosystem function.

This book therefore attempts to provide a context for soil health by looking at soil ecosystems and how they function, providing simple descriptions of soil organisms likely to be found, guiding understanding of what may be good or bad populations of organisms, and outlining a range of management practices likely to impact both positively and negatively on soil ecosystem function.

It is very important to note that, to date, there has been very little research into soil ecosystems and soil biology – particularly in contrast to research into soil physics and soil chemistry. This is particularly so in Tasmania. However, rather than wait for years for research to provide answers to many questions about soil biology, this book aims to meet what the authors believe is a strong latent demand for improved information on sustainable soil management. It provides up-to-date information and recommendations on improving the management of the biological realm based on best available science *and* feedback from farmers. Farmers must however, exercise appropriate caution when trialling various approaches, and be guided by the caveats provided in the sections on management practices. It is hoped that this project and similar work will help scientific research to catch up with the notable groundswell of interest in this important area. A list of recommended reading is provided at the end of this book.

2 Soil health

So what part of the soil do we assess when we talk about health? The health of a soil is a product of its biological, physical and chemical components but can really only be assessed against its living component, the biology of the soil. If the physical and chemical components are optimally balanced, but practices impair the development of biological processes, it is unlikely that soil could maintain a healthy status.

Research has shown the critical importance of soil organic carbon to soil health. Soil organic carbon is the principal component of soil organic matter, which itself is the broken-down remains of plant and animal life. So what is the connection between soil carbon, soil health and soil biology? Organic matter can not break down by itself! Its decomposition is mediated by a vast army of shredders, fungal feeders, predators and herbivores that devour plant and animal matter whole, dissolve it with acids and enzymes, grind it to a paste, and suck its juices!

This work is constantly being carried out on or beneath the surface of the soil by legions of creatures that can number billions of organisms per gram of healthy soil. One teaspoon of soil can contain up to 1 billion bacteria. That equals a mass of over two tonnes of livestock per hectare! No wonder some people talk of 'micro herds'.

The challenge for modern farming is to understand the functions of the 'micro herds' and how to capture the hard work of these creatures to improve the health and sustainability of our farms.

Imagine a farm where most of the required nutrients are provided free, where workers manage pests and diseases at no cost, and where weeds no longer require the unrelenting program of expensive spraying. Right now that might sound impractical, but solid scientific research is showing that with proper management of the biological component of our soils, these objectives don't sound so crazy.

Science has long known and understood the nature of suppressive soils – those soils that resist diseases such as *Phytophthora* (dieback) and *Gaeumannomyces graminis var. Tritici* (take-all of wheat); research is showing that we can grow massive biomass crops with 10-20% of current nitrogen inputs; farmers are discovering a reduction in weed pressures when the underlying causes of the weeds are understood.

These findings have a common explanation – *soil biology.*

It's not the soil that's suppressive, the plants aren't growing on fresh air and the weeds are not taking a holiday. These benefits are coming from bacteria, fungi and other micro organisms that are controlling pathogens, fixing free nitrogen from the air, and maintaining nutritionally balanced soils.

Proper management of soil biology is central to sustainable agriculture. These skills have to be learned and applied across the full range of agricultural landscapes. This book represents one step on a journey into a new way of thinking about agricultural sustainability. It provides growers with practical help to start thinking about soils as ecosystems. What is a good bug and what is bad? How many is enough, too much or too little? What do these bugs tell me? And how can I adapt my management practices so that I am not working *against* the billions of organisms in my soil that can work *for* me?

There is an old saying that the best fertiliser is the farmer's footprints – i.e. there is nothing as valuable as having a good close look at what is happening at ground level in the paddock. Central to discovering soil biology is development of the ancient art of observation. Although most farmers feel there is not enough time in the day, it is hoped that a focus on soil biology will encourage growers to climb down from the tractor, take out a 10x lens and take a really good look at what is going on down where it matters, in the soil. What changes are happening seasonally? How has a particular activity impacted on bug numbers? What can I do to boost their numbers? What benefits can I observe from looking after the micro herds?

A healthy soil with healthy biological function will produce healthy food and healthy livestock. It may not produce greater *quantities* of food or livestock, but it can produce comparable *quantity* with greater *quality*. The pressure from declining terms of trade has promoted a *quantity* mindset with *quality* in second place. That pressure threatens to push farms beyond their productive capacity with resulting declines in productivity, rises in pest and disease pressure, and a range of off-site environmental impacts such as sediment or nutrient export to waterways. Managing for *quality* as well as *quantity* depends on improved understanding of the soil as an ecosystem. Such knowledge will support landholders' aspirations to farm sustainably and leave the land in as good or better condition than when they took over.

3 What is a soil ecosystem?

Most people are familiar with the concept of ecosystems. An ecosystem is a natural unit consisting of all plants, animals and micro-organisms in an area functioning together with all of the physical and chemical factors of the environment. Ecosystems usually form a number of food webs which show the interdependence of the organisms within the ecosystem.

Clearly, the concept of an ecosystem can equally apply to soils. But what do soil ecosystems look like, why are they important and what relevance do they have to agriculture?

It may be easiest to visualise an ecosystem by thinking of a tropical rainforest. Typically such systems are teeming with life. Everywhere you look, something is happening, from a bird flying through the tree tops to spectacular toadstools growing out of a fallen log. Different animals have their place (niche) in the system. For example, some plants occupy the middle canopy whilst others occupy dark corners between buttress roots of huge trees. All these organisms share an interdependent existence, that is, they provide food, shelter, protection and habitat to each other.

Now turn that picture upside down to help visualise a soil ecosystem. The plants and trees of the rainforest become the root systems that spread out under the ground. Some root systems are shallow, while some have deep tap roots (similar to the trunk of the tree) that penetrate the soil to considerable depth. Those branching roots are similar to the above ground branches in that the very extremity of the root / branch is a site of great biological and physiological activity. Above ground, the leaf is an amazing organ that captures light and uses that energy to manufacture sugars for the plant. Below ground, the root tip is equally amazing for its capacity to forage through the soil matrix, selectively take up the nutrition the plant needs for growth and exchange sugars in return for biologically-mediated nutrient delivery. In a healthy ecosystem, every surface, above or below ground has the potential to support diverse life-forms from leaf- or root-dwelling bacteria and fungi, to caterpillars, mites, springtails or nematodes.

Let us now take a more simplified picture of a soil ecosystem. Visualise a tall apartment block such as we might see in any modern city in the world. If we could look into every window of every apartment we would see people going about the business of their daily lives. The apartments provide shelter from the elements, personal safety, a place to eat, a place to sleep etc. Inhabitants go out to work, make money and use that money to maintain their lives and the lives of others through functioning economies.

When we apply this idea to a soil ecosystem, the apartment block represents a well-structured soil. There is an infinite number of individual apartments / flats (soil pores) of different shapes and sizes all interconnected by passageways through which flow air for ventilation, water for life, and nutrients to sustain the need for growth and development. Outside of the ‘apartments’, roads, highways, rivers, lakes and floodways service all parts of the soil matrix, and there are soil organisms adapted to these permanent or temporary features.

There is, in nature, a finite amount of energy (nutrients) in what are called climax communities, that is, communities of plants and animals that have reached a stable, steady state. Organisms can only survive if nutrients cycle between all parts of the system. Leaves fall, trees die, animals excrete waste and new life takes up this energy in the never-ending cycle of renewal. Soil organic matter is the storehouse for energy and nutrients used by plants and soil organisms with the most important component of organic matter being carbon.

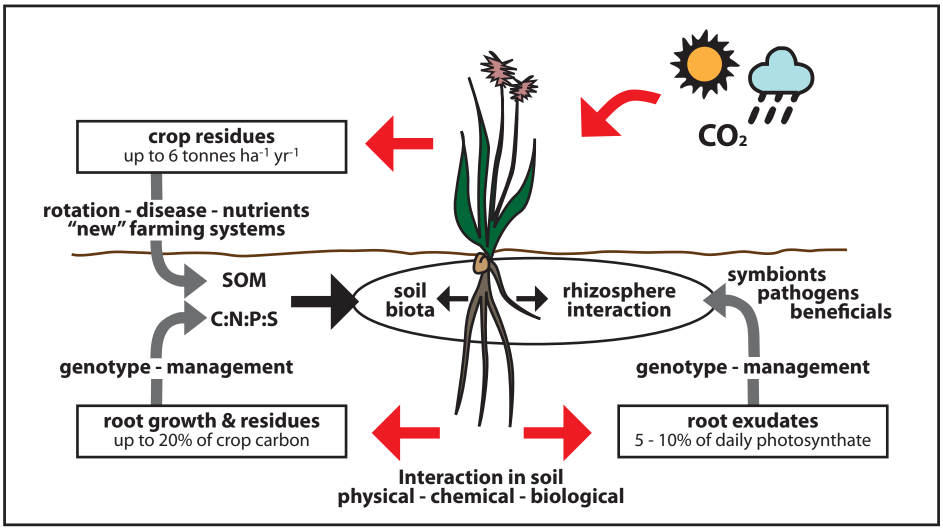


Figure 1.
Plant carbon as a driver of biological interactions in soil (SOM = soil organic matter.)

In the same way that money is a form of energy that cycles between and within human economies, carbon is the currency of natural ecosystems. Cash can be compared to labile (rapidly turning over) soil carbon, while humus (a nutritionally complex form of carbon) is the gold that spends most of its time in the bank and provides the system with resilience to survive downturns. Ecosystems tend to develop a relatively stable structure over time so that a set of species develop a certain fit with one another and with their physical and chemical environment. So long as there is no disruption in the cycling of energy or flow of air and water into the system, there is usually little change in the set of species found in an area. However, if a major disturbance such as a cyclone knocks over a section of the above-ground ecosystem, suddenly everything changes. Different organisms which are adapted to disturbance take an early lead and prosper, perhaps for a few years until the former order is restored. Or perhaps the system may change forever.

When we take this analogy and apply it to farming systems, we can immediately recognise that what we are doing when we farm is constantly 'disturbing' the system. Traditionally the first things we do as farmers is turn the block of flats upside down (plough the soil). We then set out to rebuild it (till for tilth). This work usually resulted in parts of the apartment being collapsed (compacted) by hoof or wheel. Significant amounts of new energy (fertilisers) are imported from outside the system. We then have to manage the impacts of disturbance which include a rise in weed, pest and disease pressures.

In recognition of the unsustainability of these practices, progressive growers are looking for solutions to these problems. We now recognise the importance of re-investing in our soils (building stocks of soil carbon), maintaining well structured accommodation for plant roots and soil organisms (minimum tillage) and reducing our use of chemicals that may be harmful to biological processes (crop monitoring; Integrated Pest Management). The next step is to understand how to maximise the health of the inhabitants of the system so their normal functions of nutrient cycling and ecosystem maintenance is enhanced for the betterment of the farm.

4 Why are soil ecosystems important?

The concept of 'ecosystem services' is relatively new. It came out of an understanding that there is a range of benefits to human societies from natural ecosystems. The simplest example is the role of bees as pollinators. In 1998, the Australian Beekeeping Industry estimated the value of pollination as an ecosystem service to be in the order of $1.2 billion nationally.

Soil ecosystems provide a wide range of 'services'. These include water purification, flood regulation, source of pharmaceuticals and biological chemicals, modification of soil structure, carbon sequestration/regulation of greenhouse gases, nitrogen fixation, nutrient cycling, enhancing the efficiency of nutrient uptake by plants, soil contaminant reduction/elimination, and of course, soil ecosystems form the basis of all other terrestrial ecosystems. So obvious are many of these 'services' that we have long taken them completely for granted. With the global soil resource under ever-growing threats due to population expansion, loss of prime agricultural land to development and climate change, it is clearly time to consider more consciously the services we need from soils in the long term.

Since the birth of agriculture, farmers have been managing the fertility of their soil. Pliny the Elder, in *The Natural History of Pliny* reports that even in the time of the ancient Greeks 2000 years ago, the use of manure is '*... of very ancient date. In the times of Homer even, the aged king is represented as thus enriching the land by the labour of his own hands*'. He goes on to rate the virtues of manures in the following order: thrushes, pigeons, swine, goats, sheep, oxen, and 'beasts of burden'.

It was understood that the addition of manures, ash and lime was necessary to maintain the productive capacity of the land. But we now understand that it is not the manure, ash or lime that maintains the productive capacity of the land. Rather, it is the transformed products of those inputs that have sustained agriculture for millennia. Many farmers would recall seeing recognisable plant remains when land is inverted by ploughing. This happens when there is an absence of suitable organisms or suitable conditions for organisms in the soil to breakdown plant remains. This shows that addition of organic materials alone is not sufficient to guarantee the productive capacity of land. For organic materials to be transformed into plant useable forms, a highly diverse suite of soil organisms must go to work in a physically and chemically balanced environment.

> It is not the manure, ash or lime that maintains the productive capacity of the land... it is the transformed products of those inputs that have sustained agriculture for millennia.

Organic materials are made up of a very wide range of compounds from simple sugars to polysaccharides, proteins, lignins, polyphenols and others. Each compound has particular requirements for its degradation and a healthy, diverse soil ecosystem will possess a range of organisms with highly specific enzymes to breakdown even the most resistant. For example, annual plants are mostly simple sugars, pectin and some cellulose while woody plants contain cellulose, hemicellulose, lignin and xylan. Pathogens that degrade annual plants are mostly rapid producers of pectinase. Simple sugars are readily degraded but degradation of pectin and cellulose requires extracellular enzymes. Fungi are particularly important in the decomposition process due to the range of enzymes they produce. Through the decomposition process, all nutrients eventually become available to the soil food web and for direct or indirect uptake by plants.

Importation of manures can promote rapid development of the soil food web. Suddenly everything is being consumed – the manure, the bacteria and fungi eating the manure, the protozoa and nematodes eating the bacteria and fungi, the worms eating the bacteria, fungi, protozoa and nematodes, and on it goes. With each meal, nutrients are mobilised. Some end up in the bodies of soil animals, some become available to plants. This is how nutrients cycle in natural systems.

This is how nutrients cycle in natural systems.

Importation of artificial fertilisers impacts the system in a different way. Fertilisers promote the growth of plants – both above and below ground. Vigorous plant growth and the exudates from plant roots promote increased biological activity in the root zone (rhizosphere).

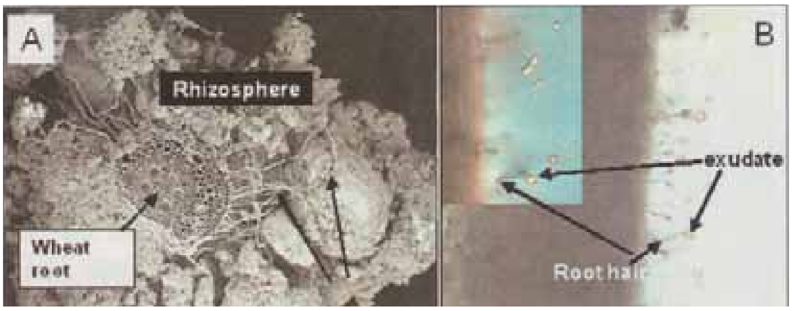


Figure 2.
A: Rhizosphere surrounding a wheat root stuck to root hairs. The rhizosphere has many compounds released by the root (exudates) that feed and signal to millions of specific soil organisms.
B: Example of a root exudate on sorghurn root hairs. Inset shows a higher magnification of the hairs and drops of exudate.

However, additions of high levels of fertilisers and other chemical inputs over time reduce biological diversity and biological activity in soils in contrast to those soils where fresh additions of carbon in the form of manures or composts are maintained. Of particular concern is the impact of high nitrogen inputs which can, in different situations, have a fumigating effect on soil biota or a stimulating effect which degrades organic carbon at an accelerated rate.

The experience of farmers is showing that there are significant benefits to understanding soil ecosystem function and that properly managed soil ecosystems can help to improve crop responses to fertilisers. In seeking to explain falling responses to fertiliser inputs, researchers have found that plant nutrient uptake is more efficient in soils with functioning biology. Soils that have been aggressively tilled and that have had high chemical inputs often have reduced biological function (see sections 7&8). However, application of artificial fertilisers does not automatically mean that biological activity will be adversely affected. Fertilisers may be regarded as good or bad depending not only on their capacity to promote plant growth, but on their capacity to influence soil ecosystem health. Although much research needs to be done into the impact of different fertilisers on soil health, strong agreement is emerging with regard to which fertilisers promote or degrade soil health. This will be discussed further in section 7.

5 What does a soil ecosystem look like?

As discussed above, healthy soil ecosystems are made up of a wide variety of organisms. The microorganisms are mainly comprised of fungi, bacteria, protozoa and nematodes. As the term 'micro' suggests, they can only be studied with the aid of a microscope. Most of the larger organisms are collectively referred to as arthropods i.e. those animals having a segmented body, jointed limbs, and usually a rigid body covering that undergoes moulting. Most of the arthropods can be observed with a 10x or 20x magnifying glass and all can be seen with the aid of more powerful magnification of about 100x. This group includes insects, spiders and mites, crustaceans, centipedes and millipedes. Earthworms are in a separate group called annelids.

This section firstly provides an overview of the main elements of a soil ecosystem – microorganisms, arthropods and soil organic matter. It then provides more detail on the individual Orders together with information on the role each plays and how to identify them.

5.1 Microorganisms

As mentioned above the microorganisms are principally made up of bacteria, fungi, nematodes and protozoa. Soils can be very different in the diversity of organisms present, but in general fungi dominate the soil biomass while bacteria are most abundant in numbers. Although each group of microorganisms is made up of hundreds or thousands of species, our project did not allow such detailed testing. Instead biomass was calculated for bacteria and fungi while counts were provided for protozoa and nematodes.

It should be noted that in each group the species mix includes beneficial and pathogenic (disease-causing) organisms. For example, many farmers have heard of root-knot nematodes in view of the wide range of host plants including capsicums, beans, lettuce, tomatoes, carrots and strawberries. However, there are very many more beneficial nematodes that control the populations of grubs, cutworms, bacteria and fungi.

Prior to this investigation of soil ecosystems in Tasmania, there was little benchmark data on what constitutes good populations of microorganisms or arthropods.

5.2 Arthropods

As in all ecosystems, animals are represented based on their capacity to compete for food and other resources. The profile of arthropods in a Queensland tropical forest soil ecosystem is shown in Figure 3.

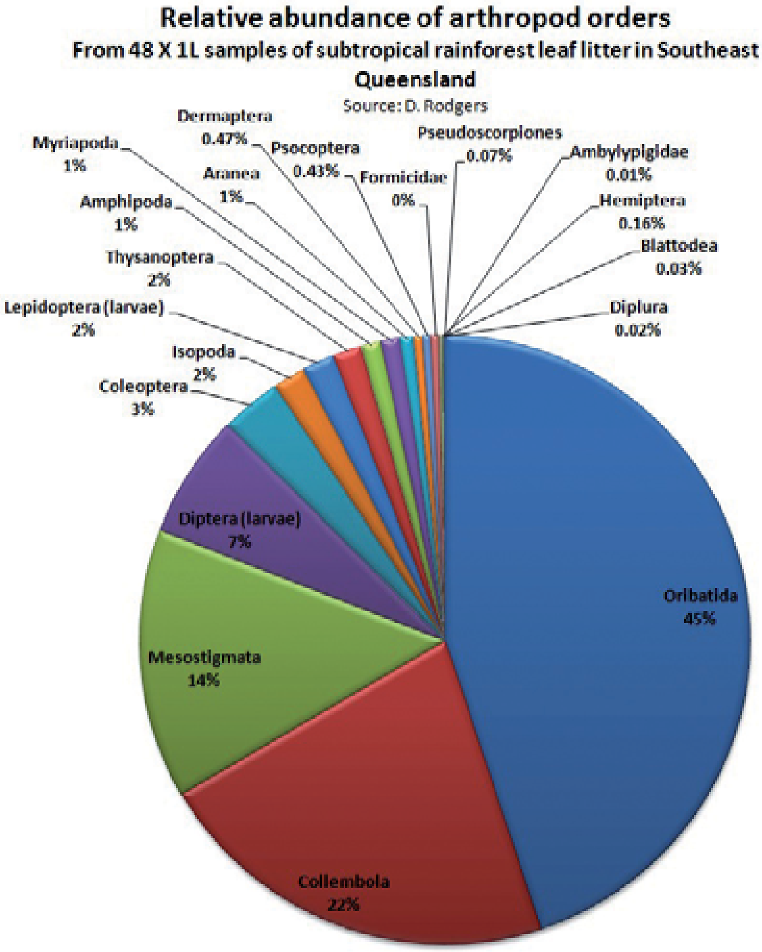


Figure 3. Arthropod component of Queensland soil ecosystem

It can be seen that almost 80% of the numbers are comprised of only three groups of arthropods: Oribatid mites, Collembola and Mesostigmatid mites. The remaining 20% is made up of 20 other Orders. This data is shown purely to note the similarity between the arthropod profile of a Queensland soil ecosystem and a Tasmanian soil ecosystem. Even though the species mix is different, the profile of arthropod Orders in northern Tasmanian Ferrosols as shown in Figure 4 is strikingly similar.

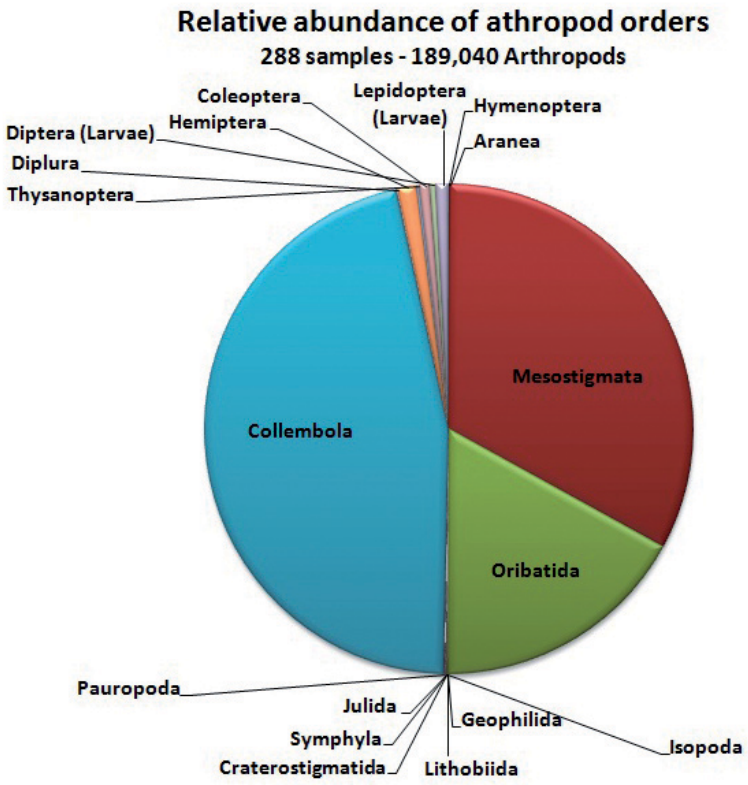


Figure 4. Relative abundance of arthropod Orders in northern Tasmanian Ferrosols

In the Tasmanian example 95% of all organisms are made up of Collembola, Mesostigmatid mites and Oribatid mites. The remaining proportion is made up of 15 other Orders.

These data suggest that Collembola, and Mesostigmatid and Oribatid mites have key roles in soil ecosystems. These are discussed in more detail below.

5.3 Soil Organic Matter

Soil Organic Matter (SOM) is a key soil component because it influences soil biological, physical, and chemical properties. It includes all the organic components of the soil and is directly derived from plants and animals. Through its breakdown and interaction with other soil constituents, it is largely responsible for chemical and physical fertility.

SOM has a number of significant functions. These are:

- substrate for energy for soil biota;
- source and sink of principal plant nutrients (e.g. N, P, S, etc.);
- promoter of high 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 effect on soil colour.

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

Typically, SOC is made up of four pools: dissolved organic carbon, particulate organic carbon, humus and recalcitrant organic carbon. Dissolved organic carbon means organic materials in the soil solution. Particulate carbon includes any organic fragments with a recognizable plant tissue / cellular structure. Humus is composed of well decomposed materials and is usually complexed with soil mineral particles. 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.

Particulate carbon typically lasts for weeks to years in the soil; humus lasts for decades to centuries while recalcitrant carbon can last thousands of years in the soil.

The different forms of carbon have different functions in the soil and these are shown in Figure 5. Cation exchange capacity (CEC) refers to the size of the nutrient storage capacity of a soil. The improvement in soil structure associated with increased organic carbon is due to carbon's ability to complex with the mineral (mainly clay) component of the soil and to increase soil strength. 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 is much harder to break down and therefore gives up its nutrients 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.

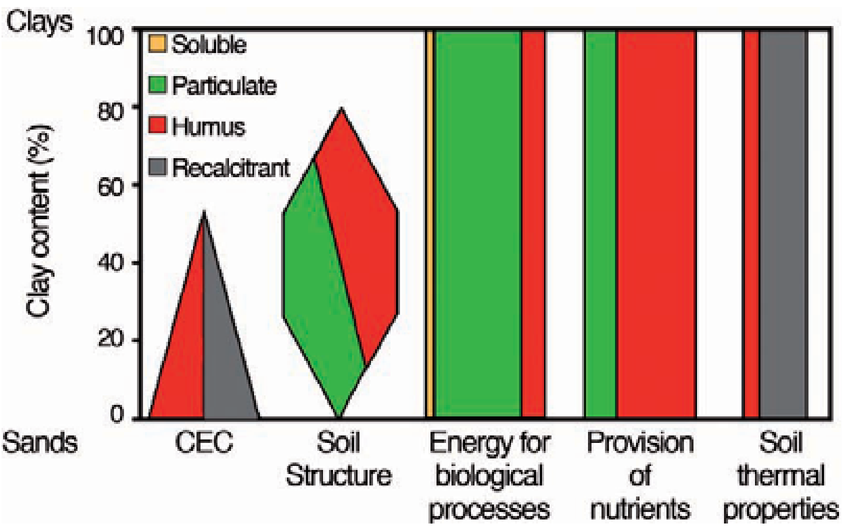


Figure 5.
The width of the colour stripes shows the relative importance of the various carbon pools to different soil functions and will vary as a function of clay content (E. Krull, 2008, CSIRO).

Although plants in general contain the same classes of organic compounds such as cellulose, hemicellulose, starches, proteins, lipids and polyphenols, the proportions of each depend on plant species and maturity, and influence the degree and rate of decomposition.

During the decomposition of organic materials (remains of plants, animals and microorganisms) approximately 60-80% of the organic C reverts to the atmosphere as CO2. This is a rapid mineralisation process and usually takes place within the first year. The remaining proportion undergoes slower oxidation processes and after complex transformations, it either turns into microbial biomass (5-15% of total soil carbon) or is stabilised in the form of humic substances.

5.4 Bacteria

Bacteria are tiny single-celled organisms. There can be up to 1 billion bacteria in a single teaspoonful of healthy soil. The range of bacterial species is equally huge. Specialists exist to manage a huge number of specific functions in soils including breakdown of resistant plant compounds, pesticides and other toxins.

Bacteria can be divided into four broad groupings:

- Decomposers break down a wide range of compounds into simpler forms that become available to plants and other animals in the soil food web;
- Mutualists form associations with plants. The best known of these are the Rhizobia which form nodules on legume roots and fix nitrogen from the air;
- Pathogens are the recyclers of the bacterial world. Through their disease-causing activities, they select weak plants and hasten the breakdown and recycling of the plant material;
- Chemoautotrophs find their energy from non-carbon sources such as sulfur, nitrogen, methane or sodium.

Bacteria are also important for good soil condition. Bacterial exudates help to 'stick' small particles of soil together which leads to aggregation and development of good soil structure.

Bacteria are found in highest numbers in the rhizosphere which is the area around the root zone. Plants exude carbon-rich materials to stimulate bacteria and in return benefit from a range of functions including mineralisation of nutrients for the plant and protection against pathogens.

Bacteria are most adapted to disturbance and can quickly recover from impacts if food, air and water are not limiting.

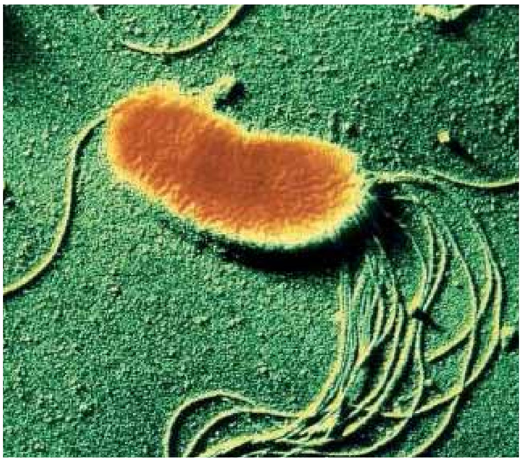


Figure 7.
Pseudomonas fluorescens – this species is common in soils where it protects plant roots against fungal infection and degrades organic pollutants (Photo Researchers Inc.). The 'strings' are the flagella which the bacterium uses to move around.

Resources

Bacterial counts are usually determined by plate counts or direct observation. Two excellent websites to help with understanding bacteria are found at: http://soils.usda.gov/sqi/concepts/soil_biology/bacteria.html and http://www.soilhealth.com/bacteria/

5.5 Fungi

Soil fungi are larger and more complex than bacteria. They are microscopic organisms that are usually multicellular with long thin structures called hyphae. Hyphae may be likened to chains of inter connected cells that share and transport nutrition. The hyphae are usually a few thousandths of a millimetre wide and can grow through very small gaps in soil. This characteristic allows fungal hyphae to explore very large volumes of soil in search of nutrients. Masses of hyphae are called mycelia (singular: mycelium).

Like bacteria, fungi can be grouped into broad categories:

- Mutualists – which include the mycorrhizae – are a group of fungi that live in close association with plant roots;
- Pathogens are the fungal re-cyclers which invade weak plant tissue. In agriculture this means lower plant production or death. Plants need diverse microbial communities to maintain health and to ensure disease organisms are controlled.
- Decomposers (and pathogens) utilise the energy from living or dead organic matter to build fungal biomass. They maintain nutrient cycling through incorporation of nutrients into the fungal biomass and release of those nutrients when hyphae are consumed or die.

Mycorrhizal fungi are a very important part of the soil ecosystem. There are two broad types of mycorrhiza that are important to agriculture – one that grows outside root cells and one that grows on the inside of the root (Figures 6 and 36). Both are involved in nutrient exchange with plant roots. The plant exchanges carbon-rich food supplies with the fungus in exchange for nutrients that the fungus is much more able to extract from the soil. Fungi are very important to soil structure as the hyphae grow around and through soil particles effectively binding them together. Cultivation is very damaging to fungal populations as tillage breaks up the hyphal networks.

Different amounts (by weight) of bacteria and fungi are found under annual and perennial crops. Fungal to bacterial ratios of around 1:1 are commonly found under annual systems while ratios of 10 – 25:1 are more common under perennial systems. The reasons for these differences are discussed further below.

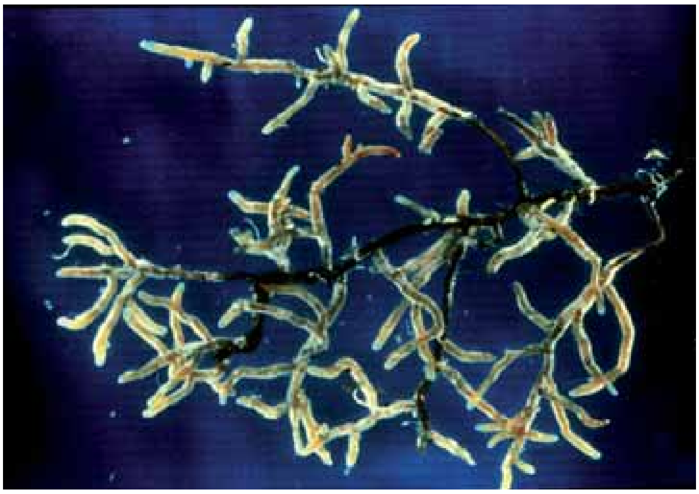


Figure 6.
Ectomycorrhizal fungi are particularly important for nutrient absorption for trees and grapes (USDA, Forest Service, PNW Research Station, Corvallis, Oregon)

Resources

Fungal counts are usually determined by plate counts or direct observation. Two excellent websites to help with understanding soil fungi are found at: http://soils.usda.gov/sqi/concepts/soil_biology/fungi.html and http://www.soilhealth.com/fungi/

5.6 Protozoa

The term Protozoa has been used since the 1820s to describe a diverse group of single-celled organisms which have a nucleus (bacteria do not fall into this group because they do not have a nucleus). The scientific understanding of these organisms has advanced significantly in recent years and it is now recognised that many of what were called protozoa really belong in quite different groups. However the newer classification systems are very complex and for the sake of simplicity the term protozoa will be used here to discuss some of the characteristics of these organisms.

All of the protozoa live in fluid environments. Most are found in marine and freshwater habitats; some live internally in other organisms (and can cause diseases like giardia and malaria); and a small number (around 1,500 out of about 50,000 known species) live in soils. To survive in soil environments which frequently dry out, soil protozoa have developed an ability to shut down their bodies and form a cyst where they can wait until moist conditions return.

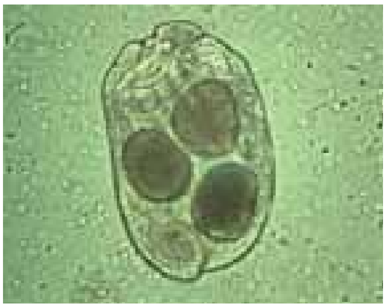


Figure 8.
Protozoan with three ingested protozoa (Andrew Williams, CSIRO)

The three main groups of soil protozoa are the ciliates, the flagellates and the amoeba. Ciliates are so named because they have cilia, which are fine hair-like structures on the animals' surface. The cilia are swept back and forth in a rhythmic fashion to move the animal around in its fluid environment. Flagellates posses a flagellum which is a whip-like external structure. The flagellum rotates like a tiny outboard motor and is used to move around. The amoeba are quite different in that they do not have any recognisable body shape and are more like little blobs of jelly. The amoeba however are perfectly capable of moving around in their environment and do so by changing their shape to whatever form is required. For example, a branch or swelling is formed on one side of the animal facing the direction in which it wants to move. The internal materials of the cell then flow into this new branch which expands as the original form contracts.

Figure 9.
Soil amoeba (D. Metcalf)

From a farming perspective the most significant thing about protozoa is the important role they play in boosting the availability of nitrogen to plants. This occurs because soil protozoa feed primarily on soil bacteria. Bacteria are very rich in nitrogen. So rich in fact that the protozoa can not absorb all of the nitrogen and therefore excrete the excess as ammonium. This ammonium form of nitrogen is readily used by plants. Protozoa can be very abundant in agricultural soils and in the surface 50mm of soil we have recorded more than a billion Amoeba per square metre, and tens of millions of flagellates in the same area. Ciliates are less abundant but their populations can still reach several million per square metre. Because of these enormous numbers laboratories normally record the abundance of protozoa in terms of numbers per gram of soil.

5.7 Nematodes

Nematodes are very small worms usually between 0.3 and 3 mm long, and do not have a segmented body like earthworms. They are even more moisture sensitive than earthworms and depend completely on a film of moisture to move around. They have an external cuticle of collagen which is exuded by the epidermis. The cuticle is permeable to allow water and gas exchange. Like earthworms, nematodes breathe through their skin.

Although they are made up of very few cells and all follow a very simple design nematodes are an amazingly diverse group of animals. There is probably not a mammal, bird, fish, plant or insect anywhere on the planet that does not have at least one species of nematode adapted to living inside it. Nematodes parasitise some common pests such as army worm and beetle larvae. The parasitic species however are only a small part of the story of nematode diversity. In agricultural soils there are many species of 'free living' nematodes which are specialised to feed only on fungi, bacteria, or on other nematodes. Those that feed on bacteria especially are known to enhance the availability of nitrogen to plants. This occurs because bacteria contain more nitrogen than the nematodes can use and they release the excess into the soil as ammonium.

Figure 10.
Nematode affected beetle larva (courtesy UC Davis).

Historically, there has been far more attention paid to the parasitic nematodes than to the free living species, which is understandable. Now however there is increasing research interest in the role of the free living nematodes in soil ecosystems. This interest comes in part from the extraordinary abundance of nematodes in soils. In agricultural soils it is quite common to find several million nematodes per square metre with more in pastures and less in cultivated soils. The nematodes are therefore hard to ignore and their role in soil ecosystems cannot be considered trivial.

Although it can be difficult to identify nematodes to the point where we know exactly what species we are dealing with (and there are many species which haven't even been named yet) there are some strategies for extracting meaningful information from a collection of nematodes. This is because nematodes have specially modified mouth-parts adapted to dealing with their specialised diets. Bacterial feeders for example can be distinguished from fungal feeders and predators by the structure of their mouth-parts.

Some species are also known to reproduce rapidly and in large numbers while others are known to have longer life cycles of up to a year. Using this information it is possible to develop an understanding of the broader ecology of a particular soil. Large numbers of fungal feeders for example suggest that there is a reliable food source of fungi in the soil and similarly bacterial feeders indicate the presence of plentiful bacteria. An abundance of species with long life cycles suggests that there has been relatively little disturbance in the soil ecosystem since these species take a long time to recover if their populations are reduced. Conversely, the presence of many species that reproduce rapidly and the absence of the long life cycle species indicate that there has been a lot of disturbance in the system.

5.8 Collembola

Collembola were observed in every sample collected from cultivated and pasture soils in our study area. Populations of Collembola ranged from just a few hundred to hundreds of thousands per square meter. They are therefore among the most common and abundant arthropods in agricultural soils and play a central role in the way these ecosystems function.

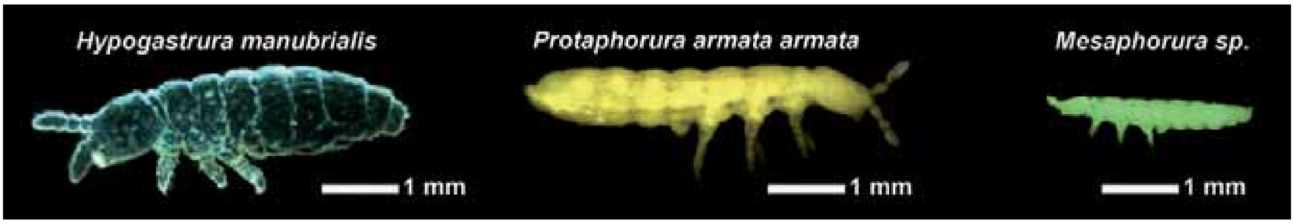


Figure 11a. Soil collembola (D Rodgers).

Most of the nutrients in the diet of Collembola are derived from feeding on bacteria and fungi. However they do not generally eat individual microbes. Instead the Collembola consume organic materials that are partially decomposed and digest some of the microbes living in this material. This speeds up the decomposition process dramatically by shredding organic material into smaller pieces and giving it a good coating of bacterial and fungal spores as it passes through the collembolan gut. An important exception to this generalisation is *Sminthurus viridis*, also known as the 'lucerne flea' - although it is not a flea at all. This species feeds on living plant tissue and in large populations may cause significant damage to legumes in crops and pastures. Sound advice on managing this species can be found in the book 'Tasmanian Pasture and Forage Pests' (see resources listed below).

Figure 11b. Soil collembola (D Rodgers).

The Collembola are sometimes known as 'springtails' because many species possess a forked jumping organ normally held beneath the abdomen. This organ (the furca) can be flicked downward to provide an explosive leap used to escape predators. Most Collembola are just a few millimetres long with the smallest species measuring only 0.25mm and the largest reaching 10mm. Their body shape varies from globular to cigar shaped to elongated with long legs and antennae. Body shape can provide some indication of the habitat of different species. For example, large species with long legs and antennae, elaborate eyes (ocelli) and a large jumping organ are almost certainly surface dwellers. Conversely, species which spend their lives below the soil surface are generally blind and white, have short antennae and legs, and lack a jumping organ.

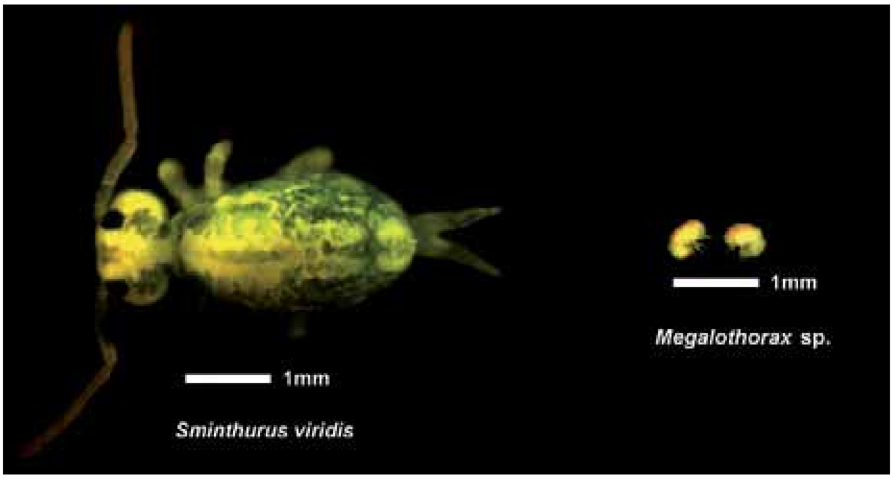


Figure 11c.
Soil collembola (D Rodgers).

Collembola reproduce by laying eggs in the soil and the young mature by direct development, meaning that they are very similar in appearance to the adults. In some species there are elaborate mating rituals during which the female accepts a sperm packet from the male. Most species however do not exhibit this behaviour and some are even parthenogenetic, meaning that females can lay fertile eggs without any contact with males.

A significant role of Collembola in soil ecosystems is as food for predators such as centipedes and mesostigmatid mites. Because they help to maintain populations of predators Collembola help to reduce the likelihood of an invasive pest species establishing large populations. Larger predators such as frogs and skinks and insectivorous birds such as wrens are known to feed actively on Collembola.

Resources

Collembola can be extracted from soil using Berlese Funnels (see Appendix 1) or caught using Pitfall Traps. They can also be easily observed in the field simply by placing a sheet of paper on the ground surface. Collembola will jump onto the paper if the vegetation is gently disturbed.

The best available book on Collembola is – 'Biology of the Springtails (Insecta: Collembola)' by Steven P. Hopkin 1997, Oxford University Press.

For pest management see – 'Tasmanian Pasture and Forage Pests: identification, biology and control' by Peter McQuillan, John Ireson and Catherine Young 2007, published by Tasmanian Department of Primary Industries and Water.

There is also a very good website dedicated to Collembola at – http://www.collembola.org

5.9 Mites

Mites can be very abundant in agricultural soils with populations of hundreds of thousands per square metre commonly encountered. They often account for half or more of the arthropods collected from soils. The two main groups of soil mites are the Mesostigmata which are mostly predators and the Oribatida which feed on decomposing organic material, bacteria and fungi. There are of course many species of mites which are pests in agricultural crops i.e. the Blue Oat mite and the Red-Legged Earth mite. These however belong to a different group called the Trombidiformes and we have found very few of these in soil samples. So the vast majority of soil mites are not pests but play important roles in the structure and function of healthy soil ecosystems. Although some mites can reach several millimetres in length, in agricultural soils most are less than 2 mm and many less than 1 mm long.

Mesostigmatid mites are often white and soft bodied although many have leathery plates on the upper and lower surfaces of their bodies and hardened legs and chelicerae (mouth parts). Mesostigmatids prey on a wide variety of soil organisms including Collembola, oribatid mites, nematodes and the eggs and larvae of many arthropods. Some are highly aggressive hunters and move rapidly around in the soil probing into tiny soil pores for prey. Others are sit-and-wait predators that sit with their raptorial chelicerae held above their heads just waiting for an unsuspecting collembolan or nematode to wander past.

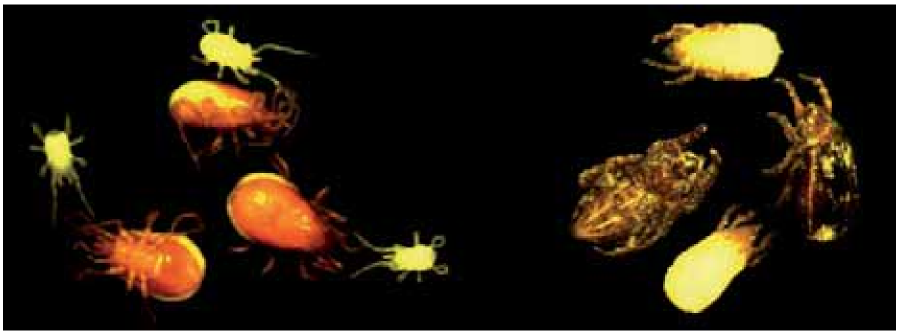


Figure 12. Mesostigmatid (left) and Oribatid (right) mites (D Rodgers).

Because of their role as predators some mesostigmatid mites have been successfully used as biological control agents to control pests such as thrips, bulb mites and fungus gnats. In both the Mesostigmata and the Oribatids the juveniles (nymphs) are pale and soft-bodied when they hatch and develop a hardened exoskeleton as they mature.

The other major group of soil mites, the Oribatida, are sometimes called beetle mites because the adults have a dark heavily armoured exoskeleton like beetles. The juveniles however are generally white, soft bodied and vulnerable to many predators. Some of the juvenile stages of oribatids need to remain immobile for long periods while they mature which makes them even more vulnerable. Oribatids also reproduce slowly laying only a few eggs at a time and maturing over several months.

Although some oribatid mites feed on nematodes most consume decomposing plant material or feed directly on fungi. In feeding on plant residues, oribatids shred the material into small pieces and thereby increase the surface area available to bacteria and fungi. This shredding activity is very significant in speeding up the decomposition of dead plant materials in soils.

A number of studies have shown that soil cultivation has a strong negative effect on mites and populations may be reduced by as much as half by ploughing. The species found in agricultural soils are however adapted to these disturbances and population levels recover over several months. Minimum tillage practices reduce these effects to a significant extent.

5.10 Caterpillars, Grubs and Maggots – The Larvae

Most of the insects we recognise from above ground habitats i.e. flies, beetles, moths and butterflies spend at least part of their life cycle in the soil as larvae. Many of these are familiar as pests such as the larvae of corbie moths and cockchafer beetles. Two particularly good sources of information on the identification and control of these pests are 'Vegetable Integrated Pest Management (IPM) in Tasmania' by Felicity Wardlaw and 'Tasmanian Pasture and Forage Pests' by McQuillan, Ireson, Hill and Young.

Even though some of these pests can cause serious losses to crop and pasture production it is important to keep these problems in perspective. For example, in Tasmania there are only sixteen moth and butterfly species, ten beetles and one fly species that are known to damage crops and pastures. At last count Tasmania had 1377 known butterfly and moth species, 2200 beetle species and 1132 fly species and many, many more species that have not yet been formally described by scientists. A rough calculation shows that only half of one percent of these species causes any problems. Indeed many have beneficial effects when they occur in agricultural systems. Ladybirds and their larvae for example are important in controlling aphids and many other beetle larvae are soil-living predators and prey on the pest species.

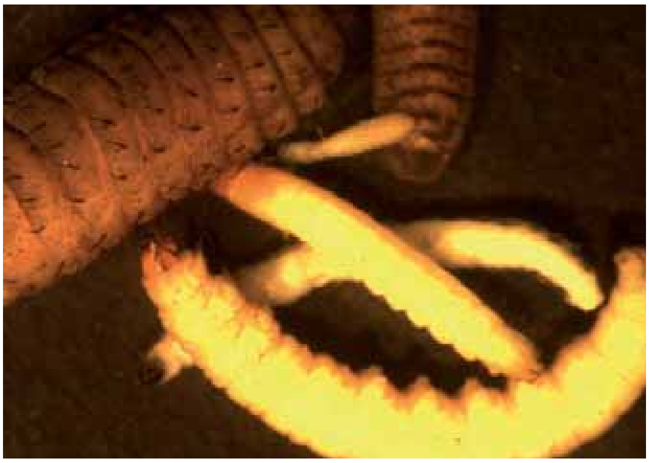


Figure 13. Arthropod larvae (D Rodgers).

At a basic level it is not too difficult to tell the difference between the major groups of larval insects. Fly larvae or maggots generally have a cigar-shaped body, no legs and no obvious head capsule. The larvae of beetles generally have grub like appearance and often curl into a 'c' shape when they are disturbed. Beetle larvae also generally have three pairs of legs toward the front of the body, a heavily armoured head capsule and large chewing mouthparts. Moth and butterfly larvae (as you would expect) look like caterpillars. They are similar to beetle larvae but often have a number of extra sucker-like legs (pseudopodia) toward the rear of the body.

5.11 Centipedes

Centipedes can be reasonably common in cultivated soils and pastures and are an indicator of good soil health. Since they are predators of other soil invertebrates, centipedes rely on populations of other soil animals for food. The presence of centipedes may therefore indicate that there are stable and healthy populations of other soil animals.

In northern Tasmania two species of centipedes *Lamycetes africanus* and *Geophilus longicornis* have been recorded in agricultural soils. Both of these species are relatively small at only one or two centimetres long. Populations appear to range from one or two individuals up to several hundred per square metre, although higher densities are likely to be very localised.

Figure 14.
Centipedes. Lamycetes *sp. (larger specimens often with blue colouring on the body) and* Geophilus *sp. (slender creamy specimens) (D Rodgers).*

Resources

Centipedes can be extracted from soil using Berlese Funnels or caught using Pitfall Traps. Two excellent websites to help with identifying centipedes are found at:
http://www.qvmag.tas.gov.au/zoology/multipedes/mulintro.html and
http://ento.csiro.au/biology/centipedes/centipedeKey.html

5.12 Diplura

Diplura are found routinely but in low numbers in both pastures and cultivated soils and occur in small clusters of up to a dozen individuals.

Like the Collembola the Diplura lay eggs in the soil and the young look very like the adults when they hatch. They never develop wings and live their whole life in the soil. All of the specimens we have seen in ferrosol soils in northern Tasmania have been from the Campodeidae which are a subgroup of Diplura. The specimens we have encountered are eyeless and creamy white in colour and the largest are 1cm in length.

The Campodeids are distinguished by their long filamentous cerci (the tail like appendages at the end of the abdomen). Other Diplura which may be seen in agricultural soils are the Japygids which have their cerci modified into pincer-like appendages. Japygids are carnivores and use their cerci to capture prey such as Collembola and other small soil arthropods.

The Campodeids in contrast are vegetarians and live on a variety of living and dead plant materials. There are no records of Diplura as pest species in either crops or pastures.

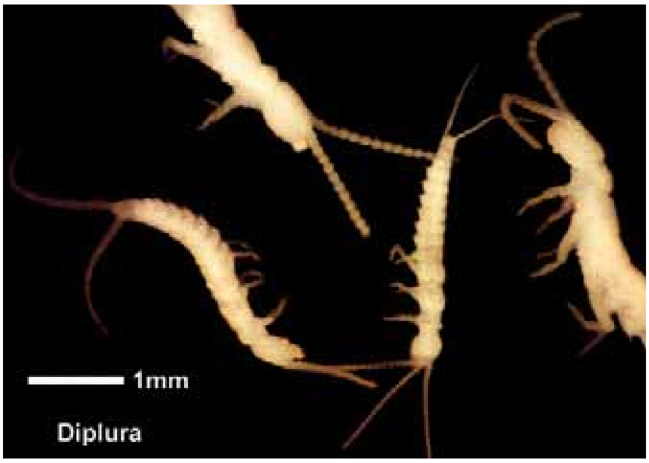


Figure 15.
Diplura spp. from northern Tasmania (D Rodgers).

Resources

Diplura can be extracted from soil using Berlese Funnels or caught using Pitfall Traps. Two excellent websites to help with identifying diplura are found at:
http://soilbugs.massey.ac.nz/index.php and
http://ento.csiro.au/education/hexapods/diplura.html

5.13 Symphyla

Symphyla are small white myriapods related to centipedes and millipedes. The species found in agricultural soils are generally blind, white and only around 5mm long. They are also super-flexible so they can easily do a U-turn in a tiny crevice in the soil. Unlike centipedes and millipedes they only have 12 pairs of legs. Juveniles hatch from eggs with only six pairs of legs and as they mature they moult repeatedly and add an extra pair of legs each time.

Like most soil arthropods they are thought to live predominantly on decomposing organic materials and gain most of their nutrition from consuming soil microbes. Some species are predators feeding on other soil arthropods and some feed on living plant tissue.

There is one species of *Symphyla* (*Scutigerella immaculata*) that is a serious pest in field crops and orchards in Europe and North America where it can cause severe damage to plant root systems. Although this species has recently been found in New South Wales and Victoria, thankfully it has not been seen in Tasmania thus far. The species that we have seen in Tasmanian agricultural soils appear to be entirely new species! This is not too surprising since in the past most of the research effort that has been dedicated to Tasmanian Symphyla has focussed on native forests and cave systems. The fact that we seem to have a few native 'agricultural soil' species and that they are not pests is great news. In both cultivated paddocks and pastures you could expect to find several small clusters of a few dozen Symphyla per square metre of soil.

Figure 16. Scolopendrellidae sp. A Symphylan from agricultural soils in Northern Tasmania (D Rodgers).

Resources

Symphyla can be extracted from soil using Berlese Funnels or caught using Pitfall Traps. Websites that discuss Symphylla are found at:
http://www.qvmag.tas.gov.au/zoology/multipedes/mulintro.html
http://soilbugs.massey.ac.nz/index.php and
http://www.environment.gov.au/biodiversity/abrs/online-resources/fauna/afd/taxa/SYMPHYLA/complete

5.14 Earthworms

Earthworms often make up the bulk of invertebrate biomass in soils. Australian native earthworms are generally sensitive to soil cultivation and have poor dispersal abilities. In agricultural soils native earthworms are therefore very rare and introduced European species are dominant. The positive effects of earthworms on soils are associated with both their feeding and burrowing activities. The effects of earthworm burrowing include the creation of channels which increase the infiltration of water down into the soil profile. This improves drainage and reduces water-logging while also reducing surface runoff. Another important effect of earthworm burrowing is the distribution of surface organic materials deeper into the soil profile. This helps to make nutrients contained in organic residues more easily available to plant roots.

Perhaps the most important effect of earthworms on soils is a result of their feeding behaviour. In consuming surface organic materials earthworms shred the material into much finer particles. This dramatically increases the surface area of the material and makes it much more available for colonisation by bacteria and fungi. Because earthworms do not have any teeth this shredding process occurs in the gut where sand grains ingested by the worm act as grinding stones worked by muscular contractions of the gut. Additionally, many soil bacteria live in the gut of earthworms and are inoculated into the organic material as it passes through. Earthworm castings are therefore conditioned to maximise further decomposition processes.

Not all earthworms eat the same foods and this can have important effects on which species are likely to be found in any particular location. *Aporrectodea caliginosa* for example feeds mainly on dead plant material whereas *Lumbricus rubellus* feeds predominantly on dung. A wheat paddock would therefore not be expected to support a population of *L. rubellus*, but it might have a healthy population of *A. caliginosa* especially if the stubble was retained after harvest.

Figure 17.
Earthworms (D Rodgers).

The higher organic carbon levels commonly found in clay soils are likely to influence earthworm populations. Earthworm preferences for moist habitats are due mainly to the fact that they breathe through their skin. Like the inner tissues of our lungs, a worms' skin must be kept moist so that gasses can diffuse effectively. Land management practices may have a greater bearing on earthworm numbers in terms of how carbon is managed and the input / tillage regimes.

All earthworms are hermaphrodites meaning that they possess both male and female sexual organs, so when they mate, two worms fertilize each other's eggs. Some species are also parthenogenetic meaning that individuals do not need to mate at all but are capable of fertilizing their own eggs.

Many earthworm species also have the capacity to regenerate segments of their body if they are lost or damaged. Some species can regenerate both head and tail segments, some only one or the other and some species neither.

6 What relevance do soil ecosystems have to Tasmanian agriculture?

Farmers are under huge pressure to ensure their operations remain profitable. The development of agriculture in the modern era has seen the application of technology to farming systems like never before. This has resulted in massive increases in productivity but has also had the long-term effect of reducing food prices / terms of trade. As a result, farmers were famously told to 'get big or get out'. There followed significant intensification of farming with higher inputs, removal of trees and hedgerows, shorter rotations and higher stocking rates. Unfortunately, intensification also brought undesired impacts including declining soil productivity, reduction in ecosystem services such as loss of natural controls of pests and disease, and off-site impacts from nutrient and sediment export.

Although the huge gains from the 'green revolution' increased the availability of food to millions of people, the well-documented negative impacts on the soil are clearly unsustainable. In very simple terms, this means that if we keep using the global soil resource the way we have over the past 60+ years, its productive capacity will sooner-or-later fail. Evidence of this is already occurring in various parts of Australia and across the world. Sustainable agriculture requires appropriate management of agricultural resources to meet the needs of humans while maintaining or enhancing environmental quality and conserving natural resources (soil and water quality) for future generations.

> If we keep using the global soil resource the way we have over the past 60+ years, its productive capacity will sooner-or-later fail.

As awareness of the need for agricultural sustainability grows, so also is awareness of the need to review the role of agriculture in the landscape. The term 'agroecosystem' recognises the farm as a unit that is part of, rather than separate from, the regional setting. Agroecosystems are characterised by simpler species mixes and simpler energy flows than natural ecosystems. They are also characterised by higher nutrient imports (and exports) and more frequent disturbances.

The aim of agroecosystem management is to improve the sustainability of farming through breaking down the distinction between 'the farm' and 'nature' as separate entities. Agroecosystems aim to mimic natural processes where possible. For example, an integrated farming system will be mixed (livestock and crops), utilise hedgerows or pockets of native vegetation as shelter and habitat for natural enemies of crop and pasture pests, and will promote high carbon soils with high biological functioning.

Healthy soil ecosystems are important to agriculture because of the range of benefits that follow from better management of soil biota. The economic benefits include reduction in input costs by improving the way resources are used. For example, biologically-driven decomposition and nutrient cycling, nitrogen fixation, nutrient uptake and water storage provide benefits at little or no cost to the farmer. Less fertiliser is needed when nutrient cycling and delivery systems become more efficient and fewer nutrients are leached from the system. Nutrient delivery systems also become more efficient as soil structure improves. Fewer pesticides are needed when a diverse suite of pest and disease-suppressing organisms are represented. For example, the second largest group of organisms found in the Tasmanian study were Mesostigmatid mites (fig 4). This large group of mites contains a significant

> The second largest group of organisms found in the Tasmanian study were predatory mites.

proportion of predatory mites whose role is to control the relative populations of other soil invertebrates. Preservation of high populations of predatory mites is therefore of immense value to farmers.

Improving soil biological management in agricultural systems also provides a range of environmental benefits. The huge range of soil microorganisms includes highly specific bacteria that can degrade toxic products in the soil thereby preventing them from harming other organisms – including humans! Maintenance of good soil structure by a thriving soil biology is very important for the prevention of soil erosion and subsequent sedimentation of waterways.

Figure 18.
Introduced dung beetles bury 1,000s of tonnes of animal waste each year.

The humble dung beetle (an introduced part of our soil biology) plays an important environmental and economic role in agriculture. Between 1997 and 2002, over 1,000,000 dung beetles were introduced into Tasmania. They have continued to bury 1,000s of tonnes of manure since that time, effectively preventing much of the material ending up in waterways, and contributing to soil carbon storage, improved soil structure, more rapid nutrient cycling, and enhanced soil biological processes. The dung beetles' contribution to improvement in soil condition provides an economic benefit but also importantly, supports stock health and productivity by removal of manure as breeding sites for parasitic species.

Ultimately the principal benefit to humans from better management of soil biology relates to future food security. It has been well-documented that the global human population is expected to reach 9 billion people by 2050 and that the calorific needs of those people will be higher than today. The FAO estimates that food production must increase by 50% from today's output. Tasmania has the potential, together with other food producing regions of the world, to contribute to improved future food security. Clearly, this need must be met but in a way that protects the capacity of the soil to meet future demands.

Soil health, and its productive capacity, cannot be maintained or increased without enhanced biological function. An overwhelming body of research has shown that many agricultural practices continue to degrade the soil resource with global soil condition trending downwards. Attention to soil biology is the best possible way to maintain production for expanding markets while protecting the long-term sustainability of agriculture.

Heavy reliance on fertilisers and pesticides, and larger and heavier machinery are damaging to soil biological populations and processes. Aggressive tillage negatively impacts soil carbon stores and increases rates of erosion. Threats from peak oil, peak phosphorus, the availability of clean water and other resource constraints means that farmers and consumers cannot expect our soils to continue to provide cheap and nutritious food indefinitely. Modern farming practices have boosted production, but at a heavy price – one which our non-renewable soil resources cannot afford. Without the huge variety of creatures that made the soil in the first place, we cannot hope to maintain or enhance soil condition to a level needed by future generations.

Without the huge variety of creatures that made the soil in the first place, we cannot hope to maintain or enhance soil condition to a level needed by future generations.

The key to sustainable soil management is modification of management practices so that soil biological processes are favoured. Unlike the increasingly prescriptive or recipe-driven approach to crop production, biological farming requires a deeper understanding of the complexities of natural systems. This requires much re-learning so that farmers can determine the needs of their individual agroecosystem and amend their management practices accordingly.

7 Management Practices

The term biological agriculture has emerged in recent years to describe a suite of practices that support the sustainable management of farming systems. Many farmers do not want to pursue organic agriculture but neither do they want to remain captive to a system that relies on high levels of external inputs. The focus on 'biological' represents a commitment to the previously-missing third leg of the agricultural stool mentioned above. Such farmers are finding a 'middle way' by taking the best from modern agriculture and blending it with more sympathetic approaches to land management.

A biological approach to farming does not mean that fertilisers and pesticides can not be used; rather, a biological approach requires farmers to use inputs in a way that minimises impacts on the health of the system. Blending biology into normal farming practices allows farmers to experiment with new approaches and discover what sustainable land management actually means for them. In this way, farmers can take control of fertility, productivity and profitability back into their own hands.

Management of biological processes are by their nature, complex. Every time we carry out an action, the system will react in some other way. Because of the complexity of natural systems, and soil ecosystems in particular (remember, one billion bacteria in a teaspoon of healthy soil!), any change, whether it is temperature, moisture, an animal's tread, a bird's dropping, or an application of fertiliser will produce a positive or negative reaction from the billions of bacteria and other organisms in the soil. Soil ecosystems are dynamic, that is, they are changing all the time – and they are adapted to change. Therefore, before carrying out any activity on farm, ask yourself if this action is likely to have a positive or negative effect on soil life. If positive, good; if negative, think about what additional strategy you can use to minimise the negative impact on the soil life.

In the following sections we will look at a range of common management practices with a view to understanding which are likely to impede the functioning of the agroecosystem and which are likely to build health.

7.1 Things likely to impede soil ecosystem function

As identified above, soil carbon is the principal energy source for soil ecosystem function. Therefore, anything that reduces the farm's capacity to capture and store carbon is going to contribute to a long-term decline in farm productivity.

Fresh inputs of carbon are critical to maintenance of the carbon cycle. Overstocking / over grazing reduces the net productivity of the land. It greatly reduces root mass and depth. Considering that roots exchange significant quantities of nutrition with the life in the rhizosphere (root zone), loss of a large root mass across a paddock will result in major decline in soil biology with consequent declines in nutrient and carbon cycling. Over-grazing to the point of loss of groundcover can be even more damaging. Bare soil is vulnerable to erosion by water and wind. Because organic carbon is usually the lightest soil component, it is easily blown away. Wind erosion studies carried out by DPIPWE showed that soil carbon represents an overly-large component of wind-blown soil.

It is clear that anything that negatively impacts on the structure of the soil will impact on soil organisms through collapsing of soil aggregates, and interruption of water and air movement. Compaction caused by traffic or animals can greatly reduce oxygen availability or create anaerobic (oxygen-free) zones around plant roots. This usually results in plant stress, reduction of plant growth and major changes to the biological community living in association with the plant roots. Many of the significant root pathogens thrive in anaerobic conditions. Poorly structured soils therefore result in an imbalance between desirable and undesirable organisms. Well structured soils, on the other hand, support much higher populations of aerobic (oxygen-loving) microbes. High populations of aerobic organisms compete very effectively with anaerobic organisms (seeing as they have different habitat and food requirements) and help keep their numbers in check. This is the basis of what are known as suppressive soils – soils that suppress the expression of disease even if it is present in the soil.

Following crop harvest, it is normal agricultural practice to till the soil to relieve compaction and recreate a fine tilth for sowing. Aggressive working of the soil damages soil structure primarily through physical impacts on soil aggregates. The fracturing of large and small aggregates results in the loss of physical protection of the organic carbon. This carbon is then vulnerable to being degraded by bacteria and fungi, particularly if nutrients (especially N) are in good supply.

Fallowing land over winter is a common practice in Tasmanian cropping landscapes. There is a range of risks associated with bare fallow including soil erosion by water or wind. From a biological perspective, bare fallows represent a major break in biological function. With no fresh organic matter being added to the system, the millions of mites, springtails, beetles, worms and assorted grubs suddenly find themselves in a famine and die off or go into a form of hibernation. Of the soil-dwelling microbes, many, including those that live in close association with plant roots, will form spores and die (their survival mechanism), fungi may die or shrink to a fraction of their former size while others will quietly live on consuming whatever scarce rations they can find until the next crop is planted and nutrient cycling starts again. Continuous ground cover is critical to normal ecosystem function.

Continuous ground cover is critical to normal ecosystem function.

Of all the soil organisms, bacteria are most adapted to disturbance. This means their populations can plummet or 'explode' with variations in moisture, air and nutrients. Whilst fungal to bacterial ratios in the order of 0.75:1 to 1:1 for annual systems and 10:1 to 25:1 or higher for perennial systems are recommended by some soil microbiologists, results from the DPIPWE SCEAM project – which looked at a wide range of Tasmanian cropping soils – showed fungi to bacteria ratios of 0.15:1 to 0.25:1. This shows that populations of bacteria relative to fungi are very high. This may be because disturbance or other land management practices impact more on fungi than bacteria. If higher populations of fungi are deemed necessary for a particular land use, adjustment of management practices may be required.

There is a lack of good data on the impact of different land management practices on populations of soil organisms and the data that does exist does not always report consistent outcomes. For example, some researchers report that microbial communities can recover from one-off applications of pesticides within 20-40 days; others report more profound long-term impacts on vegetation communities up to 16 years after a single herbicide application.

Whilst assessment of the impact of land management practices on soil life was beyond the scope of this project, this and other work done by DPIPWE showed significant differences in biological populations of microorganisms and larger soil animals between different land uses. For example, total arthropod numbers (soil insects, mites, worms etc.) on conventionally managed pasture sites was orders of magnitude greater than cropped sites. There was not a large difference between total numbers of arthropods on comparative conventional and organic sites although the species mix was quite different. The suggestion from this data is that land management practices do influence the mix of soil animals but more research is required to determine how this happens.

As our understanding of soil biology improves, so also will our management responses. Given that soil ecosystems are highly responsive to change, we need to improve our awareness of how they change in response to various practices. For example, how does fertilising affect total numbers of organisms; does it affect just one or two species; do some fertilisers have a bigger impact than others on numbers or species; and what about other chemicals or land management practices? Are the changes positive or negative? How long does a particular response (positive or negative) last? How can I maximise the positive effects and minimise the negative effects?

Specific answers to these questions may be true for one farm but may not apply on another. Clearly, this has the potential to become quite complicated. However, many farmers are working out the best approach for their own properties using observation, trial and error, and by thinking about the need for new management practices to promote agroecosystem health.

7.2 Things likely to build soil ecosystem health

7.2.1 Tuning your soils

Most agricultural soils are not well tuned, that is, few are physically, chemically or biologically optimised to grow food and fibre and lack ideal levels of soil carbon, pH, nutrients and beneficial organisms. Often the first thing we do before planting a crop is take a soil test to identify the main limiting factor to profitable production. Then we add fertilisers including lime but usually only to the point where the limiting factor is overcome. Seldom do we think about optimising soil conditions for maximum root development, product quality, pest and disease resistance and biological function.

The idea of tuning your soils is illustrated by the comparison of a car that is perfectly in tune with a car whose timing is a bit out or where the brakes pull to one side. The driver of the in-tune car will use less fuel and have a smoother ride. The driver of the out-of-tune car will complete the journey by managing, or compensating for, the shortcomings of the vehicle. But, it may be assumed that the in-tune car, if maintained in-tune, will continue to provide service to the driver for a lot longer than the out-of-tune car.

The drive to increase productivity to reduce food prices for consumers whilst maintaining profitability for the farmer explains why there has not been an emphasis on optimising soil condition for plant growth and biological function. Past extension advice to farmers focused on maximising profit by *only* providing the minimum inputs necessary to achieve a particular yield. Investing in the condition of the resource was regarded as a waste of money if there was not going to be an immediate financial return. The folly of such behaviour becomes obvious if we apply the same thinking to the maintenance of our cars, tractors or other farm machinery. Neglecting the maintenance of significant farm resources is widely recognised as bad business practice.

Tuning soils is about optimising biological, physical and chemical conditions. All of these components are interrelated. We can no longer manage our farms by addressing biological, physical or chemical limitations in isolation.

We now know that the ‘sufficiency level of available nutrients’ approach to fertility management can ‘mine’ the soil of its resources. We also know that soils that have become biologically, chemically or physically unbalanced are *more* reliant on high levels of external inputs to achieve the required yield, have lower water holding capacity and produce crops with a higher requirement for pest and disease protection. We have become expert at driving out-of-tune soils, that is, expert at producing food and fibre from unbalanced soils lacking in good health.

So how do we go about tuning our soils?

Firstly, we should remind ourselves of the needs of soil organisms for food, water and shelter. Obviously organic carbon is central to this, but so also is availability of appropriate nutrition – the idea of a balanced diet applies not only to humans but to every other life form as well, from soil organisms to plants and livestock. Optimising soil biological function requires optimisation of soil physical and chemical conditions to support air and water movement, root development and nutrient availability. In turn, biological processes support physical and chemical functioning by contributing to soil structure, aeration, water holding capacity, chemical buffering and nutrient cycling.

Soil physics is concerned with the dynamics of physical soil components and their phases as solids, liquids, and gases. The solid phase of the soil is usually described by a texture test, i.e. how sandy, loamy or clayey is the soil. As soil texture is very hard to change, management of the biological and chemical properties becomes very important from a production point of view. The arrangement of the soil particles (i.e. promotion of good soil structure) is strongly influenced by good management of the biological and chemical processes.

Soil chemistry is concerned with the availability of nutrients (organic and inorganic chemical elements) and the promotion of good physical conditions for the biological component to prosper. Traditionally we have focused on improving soil pH in our naturally acid soils. This is usually because at low pH values, there is an imbalance among the cations (positively charged ions) such as Calcium, Magnesium, Potassium, Aluminium and some trace elements which affects the availability of other nutrients. Optimising cation balance is a first step towards optimising conditions for soil biological function.

There is growing acceptance that well structured, chemically balanced soils will have cations in the following approximate proportions (as a percentage of total Cation Exchange Capacity): Calcium (Ca) 68%, Magnesium (Mg) 12%, Potassium (K) 7%, Sodium (Na) 1%, Hydrogen (H) 12%. Cations in these proportions will result in a soil pH of about 6.5. Most soil tests give results against these 'ideal' standards and also provide a reading of the Ca:Mg ratio. Ideally this should be 5:1 to 7:1 but many Tasmanian soils have high Magnesium and show Ca:Mg ratios in the order of 2:1 or 1:1. However, many trials have been carried out which showed that production (yield) is *not* dependant on the Ca:Mg ratio and that problems with high Magnesium (usually heavy and hard setting soils) can be managed with appropriate water and fertiliser application, and heavy machinery. However, as discussed above, our focus on production (yield) has come at a cost to soil quality and biological function.

Chemically balanced soils generally mean a pH of somewhere between pH6.2-6.8. When chemically balanced, available nutrients are in optimal supply and production is not limited by toxicity or deficiency of any one element. With appropriately applied water and nutrition plants can grow and yield successfully outside these pH ranges but for plants to display maximum vigour and maximum resistance to pests and disease, pH values closer to neutral (and ideally with Ca:Mg ratios in the range of 5:1 or 7:1) are required. The main reason this has not been promoted is because the cost of adjusting the Ca:Mg ratios of many soils would be prohibitively expensive and because the constraints of many imbalanced soils can be managed with fertiliser inputs.

It is important to stress that soils outside these parameters can still be very productive if managed well. The point is that soil condition can almost always be improved. Efforts to improve soil usually focus on 'fixing' the main limiting factor (doing the minimum required) rather than working towards optimal condition. Optimising the condition of your soil requires 'tuning' the various elements to maximise its productive potential. Improving the soil's chemical and physical environments is a critical first step for healthy biological function and a healthy agroecosystem. When nutrients, air and water are available in good supply, and contaminants are eliminated or present in very small quantities, conditions will be suitable for soil biological processes to flourish.

So, to appreciate the importance of maintaining our soils in tune, let us return to the analogy of the car by contrasting our use of soils and our use of cars. Soil formation rates are about 0.5t / Ha per annum while soil loss in Tasmania has been measured at up to 148t / Ha per annum. In this specific instance, the soil in that paddock is being used up about 300 times faster than it is being replaced, or conversely, the soil replacement rate is 0.34% of what it needs to be to sustain current livelihoods and meet the needs of future generations. How long will the soil last at that rate? And what happens when its productive capacity has been washed out to sea?

If we apply that factor (0.34%) to the manufacture of new cars we would find that instead of the 937,000 new cars sold in Australia in 2009, that number would drop to about 3,186 per annum with no chance of an increase. If car owners wanted their children or grandchildren to have the benefits of car travel, every car would be perfectly in tune, and cars would be driven in a way that maximised the chances of passing them on to future generations. And owners would be proud if their car could be passed on in as good or better condition than when they received it.

So it is with sustainable soil management.

The majority of Australian soils are old. They have lost their youthful condition and have become chemically unbalanced. Our agricultural practices were born in a younger land. Application of European farm practices to the Australian landscape has resulted in our soils being degraded and eroded much faster than they can regenerate. It is therefore critically important to develop an approach more suited to the capacity of the Australian farm landscape. The first step is to tune and chemically rebalance our soils in a way that promotes maximum biological function, maximum nutrient cycling and maximum carbon storage. At the same time we need to modify soil management practices in line with the needs of an ecological system. Damage to soil can and must be prevented. Improved management can re-build soils so that those soils will be available to future generations in order that they might feed themselves.

Figure 19.
Sustainable resource management requires us to do whatever we can to maintain the resource in optimum condition

7.2.2 Carbon farming

Unfortunately, it is very easy to run down stocks of soil carbon but building them up again takes considerable time and careful, skilled management. The term 'carbon farming' is emerging along with a new awareness of the importance of proper management of this resource. There are three ways to protect and increase the quantity and quality of carbon in your soils. The first is avoidance of damaging practices; the second is growing carbon in your soil; and the third is making, importing or re-distributing carbon for application to your soil. Protecting and increasing your soil carbon is fundamental to good soil ecosystem function. No carbon, no life!

> Protecting and increasing your soil carbon is fundamental to good soil ecosystem function. No carbon, no life!

We have covered much of what needs to be said about avoidance of damage to soil carbon in the previous section. No till, and minimum tillage have caught on over the past 15 years. Stubble retention, effluent use, sacrificial paddocks, drought-lotting and rotational grazing have all emerged in response to the need for improved land management practices. An important new development is gaining momentum on Tasmanian cropping farms. Controlled Traffic Farming (CTF) is being trialled by DPIPWE for application to intensive vegetable production. It is demonstrating great potential to support sustainable soil management by significantly reducing damage to soils associated with random vehicular movement. By avoiding compaction and aggressive tillage, cropping soil is maintained in good condition and continues to improve each year. Production is enhanced due to improved structure, enhanced carbon sequestration, improved microbial biomass and better crop uniformity and pack-out. All of these management practices avoid damage to soil carbon while maximising stores of soil carbon.

Having said this, the results reported in this trial for the controlled traffic plots were disappointing. This may have been due to a combination of factors including the crop (potatoes which scored poorly for biological function across all treatments), and site history. Although we were not able to re-sample on this site, subsequent sampling on a separate controlled traffic / conventionally managed site – also on red soils in northern Tasmania – showed no significant difference between treatments in the top 50mm. However, on this second site sampling was undertaken at 125-175mm which showed significantly greater arthropod populations on the controlled traffic site than on the adjacent conventionally managed site. Further work on this site, which looked at arthropod numbers from the surface through to 300mm, also showed significantly higher numbers on the controlled traffic site.

These findings are consistent with changes in soil physical properties under controlled traffic which show major improvements in soil structure and bulk density particularly below 100mm depth. These changes appear to facilitate movement of arthropods deeper into the soil profile.

Figure 35. Controlled Traffic Harvest of Potatoes in northern Tasmania (DPIPWE).

The second strategy for carbon farming is growing your own. The capacity to sequester carbon (remove from the atmosphere and store in the soil) depends on the productive potential of your soil and the climate in your area. As a general rule, cool moist climates can store more carbon than warm, dry climates. Soils with large clay content will store more carbon than sandy soils. An expert review of soil carbon sequestration potential for the Australian Government's 2008-9 Caring for our Country Business Plan found that most Tasmanian agricultural soils have capacity to sequester more carbon.

Growing your own is also dependant on your management practices. As mentioned above, bare fallow effectively deprives the system of the opportunity to make and cycle carbon. The greater the quantity of biomass you grow, and the more you can return to the soil (e.g. green manure crops, stubble retention, long-cycle grazing management), the more carbon you will capture, and the more your soil ecosystem will benefit.

Green manure crops must again become a cornerstone of soil fertility management. In general terms, it takes 50 tonnes of dry matter per hectare to raise soil organic carbon by 1%. This is not something that can be done in one year. Return of vegetation to the soil must become a normal part of crop rotations.

Green manure crops must again become a cornerstone of soil fertility management.

There is growing awareness of the potential for healthy pasture soils to sequester vast amounts of carbon, considerably more than the same area under trees. This is due to the potential for huge root growth on perennial pasture species. The principle does not apply to the same extent for annual pastures. Grazing management that supports full groundcover and development of large root systems is one of the most effective and cheapest ways to sequester large quantities of carbon in your soil.

The third strategy for carbon farming is making / importing or re-distributing carbon for application to your soil. Making / importing carbon refers to compost-making or purchase from off-farm. Compost-making is a skill which, like many others, is crafted and honed over many years. Unfortunately, compost-making is not a large part of the Australian farming tradition. Many farmers have no experience in compost-making for a variety of reasons including time restrictions, lack of knowledge, lack of a perceived need to use compost and ease of access to fertilisers. However, a large body of research exists that consistently shows the range of benefits that follows from the use of compost on a wide range of farms, from broadacre cereal to intensive vegetables to perennial horticulture. Good compost will have a carbon : nitrogen ratio in the order of 12:1. Not only does good compost represent a substantial injection of carbon, the quality of that carbon is like money in the bank in view of the high proportion of humic compounds it contains. When compost is made from local ingredients, large quantities of native soil organisms populate the compost and are added to the soil. This gives soil ecosystem processes a 'kick-start' and greatly contributes to nutrient cycling, and plant and animal health.

Re-distributing carbon refers to effluent management and re-use. Nutrients are naturally concentrated in those parts of the farm where animals congregate such as dairy lanes and holding pens, stock water troughs and under trees. Strategies to re-distribute manure across the property will support carbon capture and will reduce the risk of nutrient losses through run-off from wash-down or heavy rain. Such strategies should include irrigation of dairy effluent, increased numbers of water troughs and management of stock movement across the farm. For example, proponents of Natural Sequence Farming seek to maximise the benefits to the farm of nutrients deposited in manure. They recommend over-nighting stock on the higher parts of the farm so that nutrients from animal waste are deposited high in the landscape in contrast to nutrients deposited in or close to waterways where they may be quickly lost from the farm. This has the added benefit of promoting carbon build-up and biological function on those parts of the farm that are often dry or lacking in productive potential.

7.3 Managing the micro herds: how to grow two tonnes of soil animals per hectare.

In Section 2 we noted that one teaspoon of soil can contain up to 1 billion bacteria. That equals a mass of over two tonnes of livestock per hectare! In this section we will look at management practices that aim to increase and maintain high biological function in your soils.

As has been discussed in the previous sections, and been shown in work done by DPIPWE in northern Tasmania, there is a strong correlation between the quantity of soil carbon and the level of biological activity in the soil. The previous section covered management practices that help to capture and store soil carbon with a view to promoting improved ecosystem health. In this section we will examine the growth in complementary practices and products that aim to promote improved biological function. Many of these may have a role under Tasmanian conditions and we will briefly discuss some currently available products and strategies.

In the same way that care and judgement are required when selecting fertilisers or other inputs for your farm, care and judgement are required when selecting alternative inputs. For better or worse, many of these inputs have been grouped under the heading "snake-oils". This is good in that it makes farmers very careful about basing their decisions on good information. It is bad when it becomes a 'scare' or 'shame' tactic and prevents experimentation and learning. The challenge with using alternative inputs is learning what they are for, when to use them, how often to use them and how much to use.

A farmer's decision to use alternative inputs can represent the first step in a process of discovery aimed at farming in a more sustainable way. This will probably also require adjustments in cultural practices, i.e. how you till, what fertilisers you will use (or which ones you won't use again), how you will modify your use of chemicals, how you will feed your soil animals etc. etc. Farmers who have adopted a biological focus agree that there are challenges to understanding the needs of a living system. However, they also report significant improvements in personal satisfaction as their understanding grows and as the health of their farming system improves.

7.3.1 Feeding your soil animals

Although it has been mentioned previously, it is worth repeating that soil carbon and soil biological function go hand in hand. No carbon, no life! We simply need to ensure that the conditions for growing carbon and cycling carbon are right. If we do this much, the bugs will do the rest.

We have covered most of the cultural practices that promote capture, storage and cycling of carbon in the soil. It is now important to consider some commonly available alternative inputs that aim to promote biological function in service of agricultural production. Many of the alternative inputs discussed in this section <u>are not</u> substitutes for conventional fertilisers. Rather, they are primarily used to promote improved soil health through activating the biology in the soil. <u>How</u> they are used will depend on the condition of your soil and how they are combined with other management practices.

We simply need to ensure that the conditions for growing carbon and cycling carbon are right. If we do this much, the bugs will do the rest.

It should be noted that no assessment of specific products was carried out as part of this project. The remainder of this section will briefly consider the likely benefit together with farmer experiences of some of the more popular inputs.

7.3.1.1 Humates

As discussed above, soil carbon is the fuel that drives biological processes. It can be grown through green manures, stubble retention or improved grazing management. It can be added via compost or manure. In addition to these methods, carbon can also be added using liquid or granular humates, fulvic acid or biochar. Humic and fulvic acids are part of naturally occurring humus – the most valuable form of organic carbon in the soil. Humates are normally applied to soil while fulvic acid is more beneficially applied as a foliar or as a chelating agent for fertilisers. Proponents of humates (supported by a significant body of research) claim a wide range of benefits to soil and plant health including: increasing the soil's cation exchange capacity (CEC); chelating soil nutrients; improving nutrient uptake, especially phosphorous, sulfur and nitrogen; reducing the need for nitrogen fertilisation; removing toxins from both soils and animals; stimulating soil biological activity; solubilising minerals; improving soil structure; acting as a storehouse of N, P, S and Zn; and improving water-holding capacity for better drought resistance.

Humates represent a good example of the need to learn what a product is for and how to use commercial preparations. Significant increases in production have been reported following the application of humates; however, under other circumstances results have been disappointing. The experience of farmers suggests that the best way to use humates for crop production is to stabilise and improve the efficiency of fertilisers, particularly nitrogen. Humate-coated urea and phosphate are commercially available. The producers claim that humates can reduce the volatility of urea and at the same time provide a carbon source to promote biological activity. It is also claimed that plant uptake is enhanced due to improved root cell permeability.

Humates are recommended for the promotion of improved soil fungal levels. This will be important for perennial systems such as vineyards or orchards, particularly if the land is being converted from cropping or pasture where the fungal : bacterial ratio may be low. By contrast, fulvic acid is regarded as a bacterial food. Application direct to soil can result in rapid bacterial response but the effect can be short lived.

7.3.1.2 Biochar

Biochar is yet to be trialled under Tasmanian conditions. Results from trials in NSW and Western Australia are very promising and have demonstrated the potential for significant production benefits. Biochar adds a form of carbon previously thought to be inert. Current understanding suggests that it is anything but. It is now referred to as recalcitrant carbon in view of its extremely long persistence in the soil – 100s if not 1,000s of years. Its chemistry is such that its agronomic contribution is least when it is young. Similarly, its contribution to biological function is least when it is young – although in trials it has been shown to deliver significant production benefits in the first year. Early indications are that biochar is like wine; it gets better with age. Addition of this form of carbon has the capacity to significantly enhance soil carbon stores, improve soil structure and deliver agronomic benefits for many years after incorporation.

It is important to note that the quality of biochar is directly related to its parent material. Biochar made from poultry manure will contain useful (but not large) quantities of nitrogen, potassium and sulfur. In contrast, biochar made from green waste (e.g. forest thinnings) is quite low in available nutrients.

7.3.1.3 Fish and Seaweed

Fish and seaweed products can promote improved plant physiological function and soil biological function. Seaweed can increase the plant's photosynthetic rate, root mass and weight. It can also increase frost tolerance and boost the plant's immune system. Recent Tasmanian research suggests that seaweed improves plants' stress responses. It increases biological function in the soil by stimulating microbial processes and by stimulating the plant to produce higher levels of root exudates.

Processing of fish as fertiliser or soil conditioner usually involves hydrolysing the protein. This results in breaking the protein down into its component amino acids. Amino acids are readily taken up by both plants and microbes. Research has shown that soil microbes are far more efficient at capturing free amino acids in the soil than plant roots. Application of fish emulsion to the soil will therefore boost soil microorganism activity. Users of fish emulsion also recommend foliar applications for increased resistance to pest and disease, and improved plant vigour and fruit quality.

7.3.1.4 Molasses

Molasses contains high proportions of simple carbohydrates. The use of molasses as a food source to boost bacterial populations is increasing. Rates in the order of 10 litres / Ha are recommended.

Molasses is most useful to 'kick-start' a soil that is biologically inactive. An increase in bacterial numbers will promote the development of the soil food chain including bacterial-feeding protozoa, nematodes and soil arthropods. Prolonged use of molasses without improved carbon management practices is likely to deplete soil nitrogen levels with an associated drop in crop production.

Molasses is naturally high in iron so care may be required with prolonged use on high iron soils. Care is also required to ensure that spikes in biological function following molasses application do not temporarily tie up nitrogen and reduce the growing vigour of the crop.

7.3.1.5 Inoculants

Inoculants are intended to increase biological activity by direct application of microorganisms to the soil. There is a number of ways this can be done. Traditionally soils were inoculated with manure or compost as these materials have very high numbers of microorganisms. Inoculation moved to commercialised products such as EM (Effective Microbes) and *Trichoderma* spp. More recently, compost tea has caught the attention of farmers in view of its ease of use for broad acre application in contrast to the cost associated with handling and spreading large quantities of compost. Compost tea brews the biological component of the compost and applies the organisms to the soil / crop / pasture. Whilst some research has shown very poor survival rates of applied biology, some growers report remarkable crop responses including improvements in fruit quality and increased frost tolerance. Given the potentially huge number of variables involved in making compost tea, (quality of compost, brewing techniques, timing, application methods, soil conditions etc.) it is difficult to predict likely responses. It may be expected that compost tea-making, like compost-making, is a skill that needs to be practiced to gain the reported benefits.

Inoculation with mycorrhizal fungi has shown significant benefits although specific practices used to inoculate different plants vary considerably. Mycorrhizae are a group of fungi that have a symbiotic (mutually beneficial) relationship with plant roots. Mycorrhizae act like a massive extension of a plant's root system and many possess specialised functions for accessing nutrients (such as phosphorous) from the soil. Applications of P have been shown to reduce populations of mycorrhizae in the soil.

Figure 36. Mycorrhizal fungi colonising a root (courtesy of Paula Flynn, Iowa State University Extension)

7.4 Blending biology into standard farming practices

Improving management of soil biology does not require an 'organic' approach to production but it does involve improved understanding of the impact of our farming practices on soil life. Clearly, improved management of soil biology will not come about with simplistic 'input substitution' thinking. Rather it requires a review of all aspects of farming practice.

Farmers who have adopted a more holistic approach report a re-discovery of their observational skills which allows them to pick up on subtle changes in animal health, soil condition, expression of pests or disease, or crop performance. There is an emphasis on 'subtle' changes. Improvements in system health can occur slowly. Most farmers agree that turning a farm around takes at least three years, others say seven years, while others say it takes a lifetime. Care, patience and observation are required to understand how changes in farm practices impact on soil and system health.

> Care, patience and observation are required to understand how changes in farm practices impact on soil and system health.

Proponents of a biological approach to soil health recognise that disturbance of any kind is likely to upset the delicate biological balance in soils. This includes application of fertiliser or herbicides. Given that modern farming is dependent on the use of fertilisers and herbicides, recommendations are needed to reduce negative impacts of common agricultural practices on soil biology. Given that carbon is the main currency of soil biological processes, an addition of a carbon source at every 'disturbance' is recommended so that soil microorganism populations negatively impacted by the 'disturbance' have a food resource available to support rapid recovery. As an example, fulvic acid and citric acid added to RoundUp have been shown to increase herbicide efficacy while reducing the impact on soil microorganisms. The fulvic acid (a bacterial food) will allow bacterial numbers to rebound quickly to maintain microbiological health while the citric acid reduces the pH of the herbicide mix thereby increasing its efficacy. Farmers need to experiment to determine how to use this concept with other herbicides or pesticides.

Although little research has been done with regard to the impacts of different fertilisers on soil life, there seems to be a consensus that some fertilisers support improved biological function while others do not. Fertilisers that have lost favour from a biological perspective include superphosphate, anhydrous ammonia and muriate of potash. Observational reports from Tasmanian farmers suggest that superphosphate reduces worm numbers and elimination from the program was followed by the return of worms and improved biological function. Research from NSW, Queensland and elsewhere shows negative effects from high nitrogen fertilising in the form of soil carbon loss and soil acidification. Excess nitrogen can leach calcium from the soil leading to low pH values. In addition, the loss of calcium negatively impacts on soil organisms. Muriate of potash (potassium chloride, KCl) is about 52% potassium and 48% chloride. KCl is usually recommended in high quantities, partly because of its relative cheapness. The excess chloride will leach but can take calcium with it. Chlorides can build up in heavy wet soil with negative impacts on yield. KCl has the highest salt index of any commonly used fertiliser and can burn seedlings and roots of sensitive crops, and damage microbial communities due to osmotic shock. Fertilisers vary in acidity and salt index, both factors likely to impact on soil biology. Many farmers are reducing the recommended amount of fertiliser by 10% and are replacing it with humates or seaweed to the same dollar value. This strategy results in no additional cost but it includes a powerful carbon source to feed soil microorganisms and help them to quickly rebound from the disturbance of the fertiliser application.

A lot more work needs to be done to understand how various inputs impact on soil biological function. The difficulty with getting clear research findings lies in the variation between paddocks and management practices. In the short term farmers need to closely observe impacts of various management practices on the biological component that can be monitored using a 10x lens or other practices described in this book. Only by becoming intimately involved with the biology of your soil can you improve your management practices to achieve healthier outcomes.

8 Conclusion

The tools presented in this book will help farmers to observe and understand the impacts (positive or negative) on soil animals from different fertiliser, pesticide or cultural practices and will equip those who have a desire for sustainable land management to explore new dimensions in agriculture.

Soil ecosystem health is a journey, not an end point. Managing farming systems for healthy livestock and healthy nutritious crops requires very high levels of skill borne out of experience, enquiry and a commitment to discovery over the long-term.

Underneath our feet are huge numbers of organisms that have co-evolved over millennia with the plants that make up their ecosystems. Each organism is adapted to a special niche. Bacteria, fungi and other soil animals have a staggering range of specialities all designed to efficiently dismantle and process the enormously diverse forms of organic matter found in our soils, and make the energy from that source available as food for plants to grow.

Clearly we need to improve our management of soils so that we are sustained into the future. Improved understanding of the biological processes that support the development of healthy soil will increase the social, environmental and economic sustainability of agricultural systems, increase the quality of our produce and increase the personal satisfaction of farmers.

Soils Alive!

Part II

Technical Report:

Ecological properties of some Tasmanian agricultural soils

9 Part II - Technical Report

In the preceding sections we have discussed some of the principles underlying soil ecosystem function and its importance to agriculture. Although these principles are largely common to agricultural landscapes in temperate regions, this project provided the opportunity to test these soil ecosystem concepts in a Tasmanian setting.

Over four seasons, this project accumulated a body of information on populations of soil microorganisms and arthropods. Additional work through the Tasmanian Soil Condition, Evaluation and Monitoring (SCEAM) project, and other projects that collected soil microbiological data was drawn on to build our understanding of soil biological properties of Tasmanian soils. Although this represents the 'tip of the iceberg', these projects together provide some insights into the ecological properties of some Tasmanian agricultural soils under a variety of management systems. In this section we present the results of this work and trust that this will demonstrate the relevance of soil biology and ecology to Tasmanian agricultural systems.

9.1 The study sites

Because biological systems can have very different characteristics in different geographic areas we decided to focus on a small area in the central North of Tasmania between Gawler and Elizabeth Town. Because soil type can also have a significant effect on the make-up and functioning of biological systems, we limited our studies to the red Ferrosol soils that are the backbone of agriculture in this region. In collaboration with local landholders we selected six farms and two paddocks on each farm as study sites.

In terms of their management these twelve study sites were:

- A long term dryland pasture under organic management
- A conventionally farmed dryland pasture going into a grain cropping phase
- A conventionally farmed irrigated dairy pasture
- An organic cropping paddock in fallow with retained stubble from a grain crop
- An organic fodder cropping paddock used for grazing, silage and hay production
- A conventionally farmed cropping paddock going from poppy production into a lupin green manure crop
- A conventionally farmed cropping paddock going from brassica production to poppy
- An organic wheat paddock going into a pasture rotation phase
- An organic potato paddock going into a brassica crop
- A conventional pyrethrum paddock
- A conventionally farmed potato paddock with controlled-traffic and,
- A conventionally farmed potato paddock with random traffic.

We collected a range of samples from these sites in summer, autumn, winter and spring. On each sampling occasion the samples collected from each site were:

- Six soil cores of 150mm diameter and 50mm depth from which we extracted soil arthropods using Berlese Funnels (with soil carbon analysed after the arthropods were extracted)
- Six earthworm samples collected from 250 x 250 x 250mm sample holes.
- Six soil moisture samples.
- Three soil samples which were analysed for soil nematodes and soil protozoa.
- One bulk sample analysed for fungal and bacterial biomass.

The results of these studies are provided below in graphical form. Before presenting these results, a few preliminary comments may be useful as a guide to their interpretation.

9.2 Units of measurement

The body size of an organism is an important consideration in developing some expectations of what we may see in the results. As a general rule, the smaller an organism is the more of them we expect to find per unit area sampled. Smaller organisms also tend to reproduce much faster and in larger numbers than larger organisms. Bacteria can thus occur in populations of billions per gram of soil, protozoa being slightly larger have slightly smaller populations and so forth. These factors have some implications for the way in which we can measure such populations. It makes sense for example to record populations of arthropods in terms of numbers per square metre and this might range from a few hundred individuals to many thousands. Bacteria on the other hand could number billions of billions per square metre and such quantities can become very difficult to comprehend. Fungi can be even more problematic in that a mass of interconnected fungal hyphae may in fact be considered a single organism. To overcome these problems and to make the data for bacteria and fungi comparable they are both recorded in terms of biomass (simply the weight of all of a particular organism per unit area or volume). Bacterial and fungal data are thus recorded in micrograms of biomass per gram of soil. Nematode and protozoa data are expressed as numbers per gram of soil and earthworms and arthropods as numbers per square metre.

9.3 Graphical display of results

Results are presented in graphical form in Section 13 – Figures.

Although the units of measurement make sense for the organism we are trying to measure, they can be difficult to compare to one another. How does a population of so many nematodes per gram compare to so many earthworms per square metre? We could use a number of calculations and formulae to convert all of the units for each group of organisms to compare with all the others but this could become very confusing. Instead we have simply used a ranking approach to display the results. We began by ranking the sites from highest to lowest in terms of the average number of arthropods found per square metre over the entire sampling period. We then plotted all of the other results keeping the sites in this same sequence. This allows many visual comparisons to be made e.g. between sites, between different organisms and between seasons etc. For example it is relatively easy to see if the sites with the highest numbers of earthworms also had the highest fungal biomass and so forth.

As well as these variations between different groups of organisms, we would expect to see variations in space and in time, that is from place to place within a paddock and also from season to season in the same paddock. It is important to measure these variations so we can have a sense of which differences between paddocks are meaningful and which are not. To provide a sense of how large the spatial variations were we have included T-shaped 'error-bars' in many of the graphs below (for those who are statistically minded these are based on the standard error of the mean). In these graphs, the top of the bar indicates the mean or average value calculated from a number of samples and the error-bar indicates how variable the actual data was. For example, a very small error-bar indicates that all of the samples were very similar and a large error-bar indicates that some or all of the samples were very different from one another. Small error-bars also suggest that the average or mean value is a reasonable estimate of what is going on across the whole paddock. The larger the error bars the less reliable the mean is.

Although the term 'error' has some negative connotations and may suggest a 'mistake', this not the case. In fact these 'statistical' error measurements provide us with an important understanding of how variable or how consistent are the things we are trying to measure and how confident or sceptical we should be concerning any interpretation of the results.

10 Results

10.1 Arthropod abundance

Arthropods may achieve populations as high as 180,000 /m2 in dryland pastures and may be as low as just a few thousand in intensively cropped soils(see Figure B.1). There is also a clear gradient from high arthropod abundance on the sites where the soils are least disturbed, through intermediate abundance with intermediate disturbance, to low abundance where the soils are most disturbed (i.e. in potato crops where the soil is completely turned over). An interesting exception to this trend is the pyrethrum paddock in which there was no cultivation or soil disturbance during the sampling period. The relatively low abundance of arthropods on this site may be related to the level of herbicide and fungicide use associated with the production of this crop. It may also be due to an allelopathic (the inhibition of growth in one species by chemicals produced by another species) effect of the plants themselves.

There is no clear seasonal trend and it appears that populations of arthropods may peak on these sites at any time of year. Further analysis may show that steep falls in populations are associated with particular management actions.

10.2 Arthropod diversity

The number of arthropod Orders present on a site is closely associated with their abundance (see Figures B.1 & B.2). The more arthropods there are on a site the more diverse are the groups that are present. Oribatid mites, Mesostigmata and Collembola were present in every sample we collected. The additional groups were often moth, beetle and fly larvae with groups such as spiders, centipedes, Symphyla and Diplura occurring less frequently. To some extent the diversity of arthropod groups can be used as an indicator of soil ecosystem health. So without counting every single arthropod, a check of the number of Arthropod Orders present will provide an indication of the health of the system. One advantage of this approach may be that this kind of 'diversity' measure seems to be less variable within a site than the overall abundance of arthropods. Further analysis of these results is required to validate this suggestion.

Figures B.3a, b and c illustrate the relative abundance of arthropod Orders in the samples we collected. Figure B.3a shows that across all of the samples we collected, the Collembola, Mesostigmatid and Oribatid mites dominated and the other Orders made up a much smaller fraction. Figures B.3b and B.3c illustrate the point that a diverse range of Orders seems to be associated with a large number of individuals i.e. 1973 individuals in the sample with 11 Orders present and only 29 individuals in the sample with only three Orders.

10.3 Collembola abundance

The seasonal average for Collembolan abundance shows a very similar trend to that shown for all arthropods (see Figure B.4). To some extent this is not surprising given that the Collembola made up a large proportion of the arthropods collected (statistically these two sets of data are therefore auto-correlated). This may suggest that simply counting and identifying the Collembola would provide a good indication of the abundance of arthropods across these sites. Some of the data were highly variable, especially in the autumn samples from the 'Dryland pasture to barley' site. Although the mean abundance value is very high for this site the error bars indicate a large degree of variation in the numbers of species in these samples. This is due to samples being taken during a 'swarm' event of a single species of *Hypogastrura*. Species in this genus are well known for this behaviour and in Europe they are known as 'snow-fleas' because they form large dark masses as they swarm across snow fields. It is worth considering that without this one species the overall mean for this site would probably be much lower. This kind of 'spike' in the data is also typical of many soil organisms.

10.4 Collembola diversity

Although there was no clear pattern of seasonality in the abundance of Collembola there is a strong indication here that there are fewer Collembola species present in each paddock during summer (see Figure B.5). This is not unexpected since the Collembola are generally sensitive to desiccation and many species would be expected to decline in hot dry conditions. This does not mean however that these species are entirely absent from the paddock. They may simply be seeking refuge deeper in the soil profile in cooler moister conditions. Explanation of population fluctuations of Collembola and other arthropods requires further research. The results here are also consistent with those presented for the arthropods in general in that there is a decline in the number of species as management-related disturbance of the soil increases.

The pie charts shown in Figure B.6 illustrate the relative abundance of different species of Collembola in the samples we collected. The top pie chart shows that across all of the samples we collected there is no particularly dominant species of Collembola. There are several species which occur in almost all samples and a few that occur only on one or two samples. This is a typical pattern for assemblages of Collembola. The two smaller charts illustrate some of the variations that occur in this pattern. The chart on the lower left shows one of the samples dominated by *Hypogastrura* sp. This pattern of dominance is not typical and may be the result of sampling during a collembolan swarming event. The other samples we collected were more like that illustrated in the chart on the lower right.

10.5 Earthworm abundance

The graphs presented in Figure B.7 show that the pattern of earthworm abundance across the sites bears a striking resemblance to that of the arthropods and the Collembola. Like the two preceding sets of data there is a clear pattern of higher abundance on sites with less disturbance to the soil profile and lower abundance in the more frequently disturbed soils. There are some obvious gaps in this pattern on the two fallow sites. This may be due to the naturally patchy distribution of earthworms but requires further study. The results also suggest that there is an increase in earthworm abundance during Winter and Spring. However, because we only sampled to a depth of 250mm it may be that the results simply reflect the movement of earthworms closer to the soil surface when soil moisture levels are seasonally higher. Where disturbance is consistently low and soil moisture is consistently high i.e. on the irrigated pasture site, earthworm abundance is consistently high.

10.6 Nematode abundance

The results for nematode abundance present a similar pattern to those described for arthropods and earthworms although the pattern here is less consistent (see Figure B.8). In general there appears to be a trend toward higher nematode abundance on sites with lower soil disturbance and lower abundance with higher disturbance. The obvious exception is in the data for the conventional brassica paddock. On this site the high abundance of nematodes in autumn and winter may be explained by the presence of crop residues following the brassica harvest but if this was causing an increase in biological activity we would expect the same response to occur in the arthropods and earthworms. Overall the size of the errors relative to the means suggests a high degree of consistency in abundance of nematodes in the samples, the exception being the autumn data for the brassica paddock. There is some indication of seasonal patterns with generally lower abundance in summer and higher abundance in autumn and winter.

10.7 Protozoa abundance

The results for protozoan abundance illustrated in Figure B.9 are highly variable both in terms of the fluctuations in mean values and in the size of the errors relative to the means, especially in some of the results for winter and spring. This suggests that considerable caution is required in interpreting these results. However as indicated in the introduction to this section the protozoa, being very small and simple organisms, can reproduce very rapidly and can attain very large populations. The results here are probably a reflection of this reality even though this does not make interpretation any easier. These results suggest if anything, a reversed pattern to that observed for arthropods, earthworms and nematodes. There does appear to be a trend towards higher protozoan abundance on sites with higher soil disturbance and lower abundance with lower disturbance.

10.8 Microbial biomass

The results for microbial biomass (i.e. bacterial and fungal biomass combined) represent only single bulk samples from each site and there is no measure of variation within the sites. Although this is a standard procedure and is recommended by many commercial laboratories it does mean that we lack important information about the variability of the data. All interpretations of these results are therefore made with considerable caution[1]. The results for combined bacterial and fungal biomass show only a moderate degree of seasonal variation (see Figure B.10). Although there is some indication on several sites of lower microbial biomass in winter there is not enough consistency in this pattern to regard it as a general trend. There does however appear to be a pattern of higher microbial biomass associated with both high and low levels of soil disturbance and lower microbial biomass on sites with intermediate levels of disturbance.

10.9 Fungal to bacterial biomass ratio

The fungal to bacterial biomass ratio has been discussed above as a commonly used index of microbial soil health. In Figure B.11 we have simply divided fungal biomass by bacterial biomass, thus a 1:1 ratio would be plotted as 1, a ratio of 10:1 would be plotted as 10 and so forth. These results show that the highest ratio achieved was just above 2:1 for the winter sample from the dryland organic pasture. A majority of the other samples returned values below 1:1. There is also a trend in these results such that this ratio is higher in the less disturbed soils and lower in the more disturbed soils. This pattern is consistent with that observed for arthropod Orders, the Collembola, earthworms and nematodes. It is also consistent with the results from other microbial analyses from other projects. The individual results for fungal and bacterial biomass underlying this pattern are outlined below.

10.10 Bacterial Biomass

The results for bacterial biomass show some tendency towards an autumn peak in biomass (see Figure B.12).

[1]*We also note that due to a handling error in a commercial laboratory the data for summer microbial biomass cannot be used. An unfortunate delay of a month between the sampling date and the time when the samples were analysed led us to regard these data as highly unreliable.*

In the absence of a summer data set however this can only be a very tentative conclusion. The other pattern that emerges from these results is higher biomass in low and high disturbance soils and lower biomass at intermediate levels of disturbance. These results are primarily responsible for the pattern described above for overall microbial biomass. The autumn and spring data contribute substantially to this pattern while winter bacterial biomass was more even across the sites.

10.11 Fungal biomass

The results for fungal biomass (Figure B.13) show a strong trend of higher biomass in less disturbed soils to lower biomass in highly disturbed soils. This is remarkably similar to the trend describe above for arthropod Orders, Collembola, earthworms and to some extent nematodes. Paddocks with higher levels of soil disturbance (i.e. the potato paddocks) had relatively and consistently low fungal biomass. In contrast paddocks with relatively low levels of soil disturbance had higher levels of fungal biomass in general and reached higher peaks at different times of the year. The trend in these results is consistent with results from the above-mentioned SCEAM project and other studies. Although disturbance was low on the pyrethrum paddock, fungal biomass is as low as on disturbed sites. This suggests some other process that is antagonistic to fungal biomass. As suggested when considering arthropod abundance above, the antagonistic process could be due to high herbicide and fungicide use on the crop or an effect of the biologically active compounds produced by the pyrethrum crop itself.

10.12 Soil Carbon

Soil carbon is one of the most important variables we measured in this study since one of our major objectives was to improve our understanding of the relationship between soil carbon and soil biological activity. In reviewing these results we emphasise that we sampled only the surface 50mm of soil for these analyses. This is because the top 50mm is the most dynamic part of the soil profile in terms of both biological activity and soil carbon turnover. In most other studies soil carbon would be measured in either the top 75mm or even 300mm of soil and because soil carbon generally declines with depth in the soil profile, such studies would be expected to report lower overall values for soil carbon. As discussed in section 5.3, soil carbon occurs in a variety of forms from charcoal, which remains stable in the soil for thousands of years, through to dissolved carbon which can be rapidly consumed in biological processes. We are conducting further studies on the soil carbon fractions to understand how the sites may differ in their composition. At present however we will discuss only the results for total carbon.

The results (see Figure B.14) show that there was considerable variation in soil carbon levels both seasonally within sites, and more generally between sites. The variability within sites will be the subject of further study. We expect however that some of this will be due to random variation i.e. no two samples from the same paddock could be expected to return 'exactly' the same values even with the most precise analysis. More important however will be an examination of the different carbon fractions within each sample. Our expectation here is that those sites with the most within-site variation will be those with the highest levels of labile or easily soluble carbon.

The variation between sites is greater than the variation within sites and reflects the trend we have seen in the biological data relating to disturbance. Lower disturbance supports higher sequestration and maintenance of soil carbon. The organic dryland pasture has exceptionally high soil carbon with values of between 8 and 10%. This is followed by the irrigated pasture site and the organic bare fallow and fodder cropping sites with values close to 6%. The dryland pasture to barley, pyrethrum and potato paddocks returned values of closer to 5%.

The conventional brassica and organic wheat to pasture sites had values between 4 and 4.5% and the fallow paddock with a lupin cover crop had approximately 3.5%.

It should be noted that soil carbon levels are not an immediate consequence of soil biological activity but rather are a consequence of the long-term history of biological activity. This is discussed further below.

10.13 Soil moisture

Moisture is generally regarded as a significant factor in driving soil biological processes and was recorded whenever we collected any biological samples. These results broadly reflect the very dry summer and very wet winter conditions experienced in the region during the period of our study. The error bars plotted here (Figure b.15) indicate that there was relatively little variation in the moisture conditions within each paddock, meaning that there were no particularly wet or dry patches. Although there were some substantial differences between the overall moisture conditions from site to site this does not seem to be related to differences in the abundance or diversity of any of the biological characteristics we studied. This suggests that soil moisture can be discounted as a cause of the differences we observed in the biological characteristics of the sites. Interestingly, the site with the highest soil moisture was the organic dryland pasture site and the site with the lowest soil moisture was the conventional dryland pasture-to-barley site and yet these two sites were probably the most similar in terms of their biological characteristics. However, the organic dryland pasture site has close to double the soil carbon of the dryland pasture-to-barley site which would greatly enhance its moisture holding capacity.

11 What do the results mean?

One of the main objectives in this study was to collect and publish a body of information concerning the ecological properties of some Tasmanian agricultural soils under a variety of management systems. The reason for doing so was to provide a yardstick or a reference point against which the biological outcomes of different management systems or even the characteristics of different soil types may be measured. We hope therefore that these results will assist farmers and agricultural scientists to interpret the results of any biological testing they may carry out on agricultural soils in Tasmania.

Overall the results show that there is a great deal of variability in the abundance and / or biomass of different soil organisms across a variety of agricultural management systems. Some of this variation can be identified as random 'noise' or as seasonal variation. However, even allowing for these variations there are still substantial differences associated with different management systems. This is a very positive outcome because it means that the impacts of agricultural management systems on soil biological properties can be measured, interpreted and acted upon.

> ...the impacts of agricultural management systems on soil biological properties can be measured, interpreted and acted upon.

In reviewing these results we focus on some of the relationships between different components of the soil ecosystem rather than simply repeating the results themselves[2]. In terms of these interrelationships our results suggest that there are three broad categories of soil organisms, *viz*. those which show positive linkages (or correlations), those showing negative linkages and those which seem to function independently of other soil organisms.

The abundance of protozoa for example seems to have a negative relationship to the abundance or biomass of most of the other organisms we studied. So where the protozoa are most abundant, arthropods, earthworms and nematodes are least abundant and *vice versa*. This may be because the protozoa are able to develop large populations only where conditions prevent other groups from competing for resources. However, confirming such an explanation for this pattern would require a great deal of further study.

The biomass of bacteria on the other hand seems to have no relationship whatsoever to the abundance or biomass of any other soil organism. In other words bacterial biomass can be high, low or intermediate regardless of arthropod abundance, earthworm abundance or fungal biomass etc. Bacterial biomass considered on its own could therefore be regarded as a very poor indicator of soil health or ecosystem function. This may be due to the incredible diversity of bacteria and their equally amazing ability to exploit a wide range of resources under almost any conditions. Some bacterial species for example thrive in highly acid soils or in the complete absence of oxygen and some may live quite happily on a diet of chemicals that are highly toxic to other organisms. As noted above, bacterial populations can also respond extremely quickly to changes in the local environment. Laboratory analysis establishes the status of the population at the time of sampling. A few days of hot or cold weather, a pesticide application or a good shower of rain are likely to have a major impact on populations of bacteria. These variables may explain why bacterial biomass seems so unpredictable and difficult to interpret.

The third set of organisms comprises the fungi, arthropods, earthworms and nematodes. The results show that there is generally a positive relationship between these groups in terms of their biomass and / or abundance and diversity. So where we find high fungal biomass we also find high numbers of arthropods, earthworms and

[2] *Although we will not report here on statistical results, these comments are guided by a matrix of Spearman's rank correlation coefficients calculated for the relationships between seasonal average data for the biological variables we have studied.*

nematodes or many different arthropod Orders and species of Collembola. This relationship is strongest between the fungi and the Collembola and other arthropods, weaker between the fungi and earthworms and very weak between the fungi and nematodes. The results also suggest that there may be several questions worthy of further study. The relationship between fungal biomass and earthworm abundance for example may be much stronger when we consider which actual species of earthworms we are dealing with or if we could control some of the factors such as limitations on earthworm dispersal. Equally, a more detailed analysis of various nematode sub-groups may be useful. For example we may find that there is a much stronger relationship between the nematodes and fungi if we exclude those nematode species that are known to feed only on bacteria.

In general however these results are very positive because they suggest that some groups of soil organisms can be useful as indicators of the overall health of the soil ecosystem. Perhaps the best of these indicators is fungal biomass since it has generally positive relationships with most of the other soil organisms. For the same reason, the abundance and diversity of Collembola and the other arthropods appear to be good indicators of general health of the soil ecosystem.

Perhaps the best of these indicators is fungal biomass...

One of the most positive aspects of the results is the fact that even on those sites with the poorest levels of biological activity, all of the building blocks of a healthy system remain present (even if they are present only at very low levels). These soils therefore have the potential to respond rapidly to positive changes in management. Sites that have been intensively and consistently cropped for many years may have low levels of biological activity at present but they are likely to improve dramatically if management practices such as reduced tillage, cover crops, green manures and pasture breaks are included in rotations. In other words these soils are not biological deserts. They are far from dead and retain all of the essential components of healthy functioning ecosystems. All that is required is that they are treated a little differently.

These improvements in our understanding of the biological properties of agricultural soils are especially important because they improve our capacity to manage carbon in these soils. In this context it may have been expected that the levels of soil carbon we measured in this project would be strongly related to the levels of biological activity. This however misses a vital point. Soil biological activity does not govern the actual level of soil carbon but rather it indicates whether soil carbon is likely to be accumulating or declining. In much the same way, a business may have vast assets (e.g. naturally high carbon in Tasmanian red soils) but if it is managed poorly the assets will decline, and conversely, a business that has very few assets, if well managed, will accumulate assets. If the agro-ecosystem is being well managed (i.e. if biological function is good) it is likely that system health is improving. So in the long run, it is the way the processes are operating that matters rather than the status of the system at any one time.

A project designed to provide a clear demonstration of the outcomes of soil biological processes in terms of soil carbon would take several years and this was beyond the scope of this project. However, we can make some reasonably confident predictions. As suggested above, sites with high levels of soil biological activity should accumulate soil carbon and *vice versa*. The consistency of soil biological activity is also important. For example a site where low levels of soil biological activity occur in only one out of several years (for example a long term pasture which is periodically cultivated and re-sown) will probably accumulate more soil carbon than it loses. Conversely, a site where high levels of soil biological activity occur in only one year out of several years in which biological activity is generally low, will probably lose more soil carbon than it accumulates over the entire period.

12 Conclusion

This project has shown just how much there is yet to learn about soil biological processes in Tasmania. Overall, the results indicate that there is substantial life in our soils. However, the question remains as to the effectiveness of these populations in terms of effective nutrient and carbon cycling. How intact are they as functioning ecosystems?

We welcome the opportunity to establish some baseline data and to reiterate the need for best management practices to maximise the benefits of soil biological processes. We hope that this work marks the start of a new era of interest in the living component of our soils, and a consequent improvement in the management of our soils for the benefit of future generations.

13 Figures

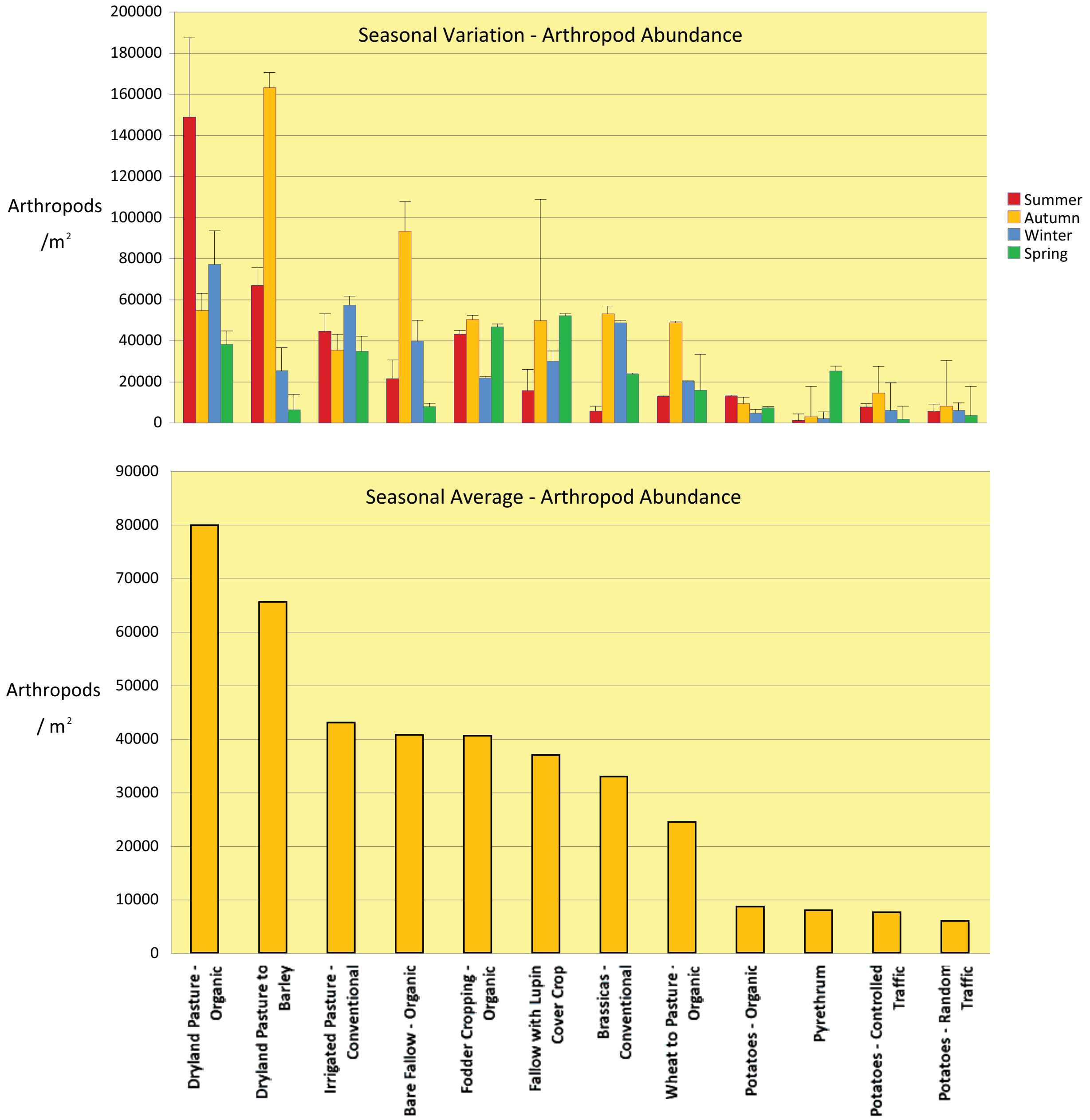


Figure B.1. Seasonal variation – arthropod abundance

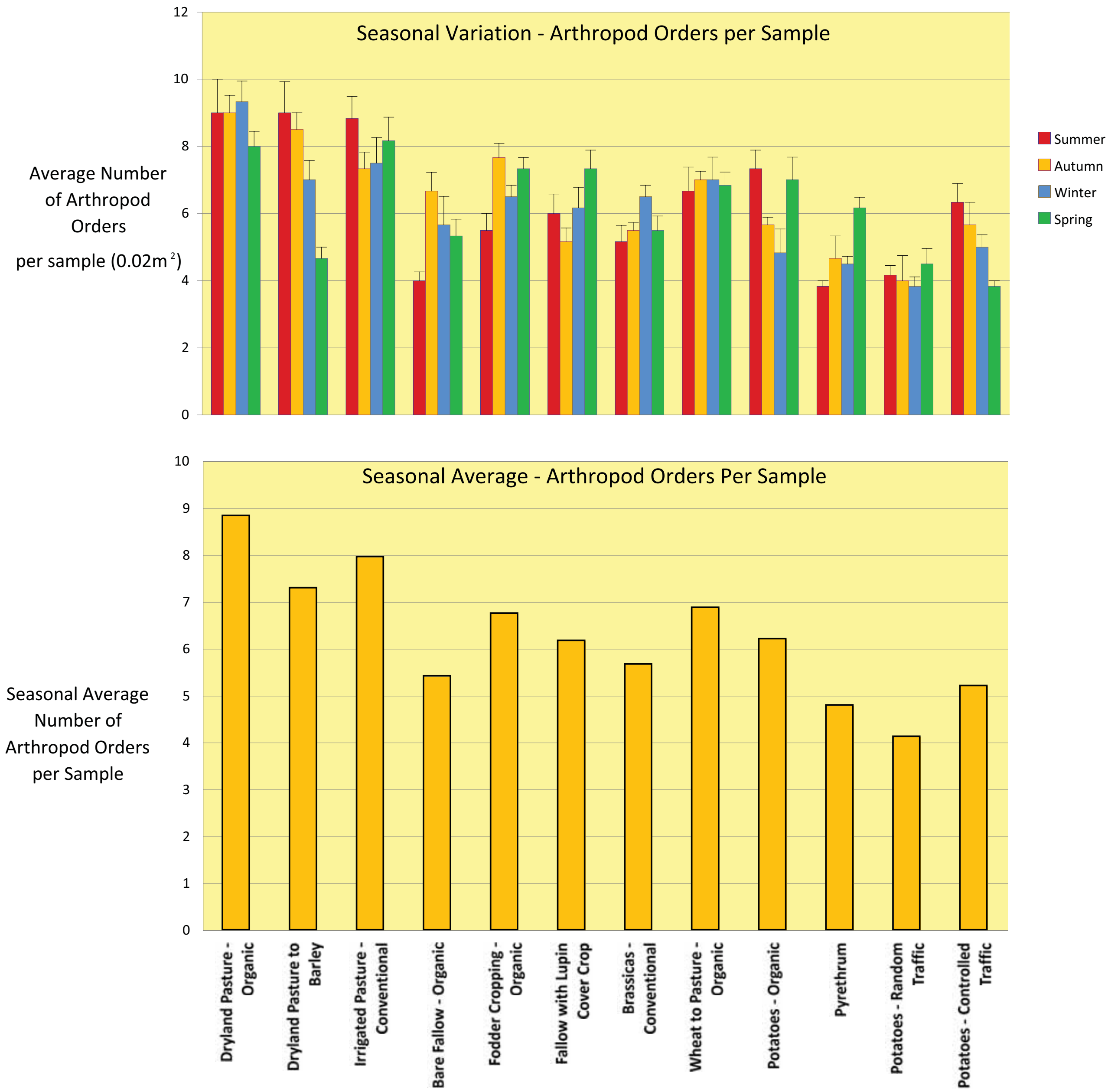


Figure B.2. Seasonal variations and averages – arthropod Orders per sample

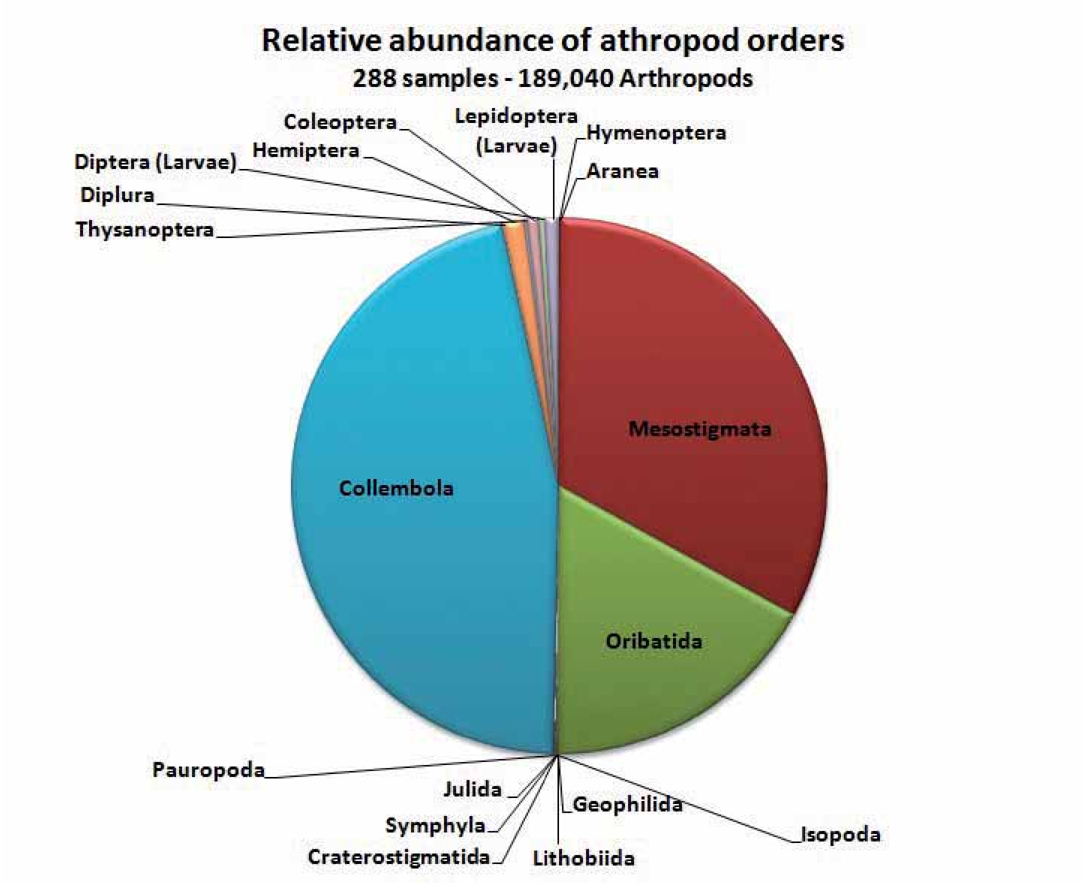


Figure B.3a. Relative abundance of arthropod Orders from Tasmanian ferrosols

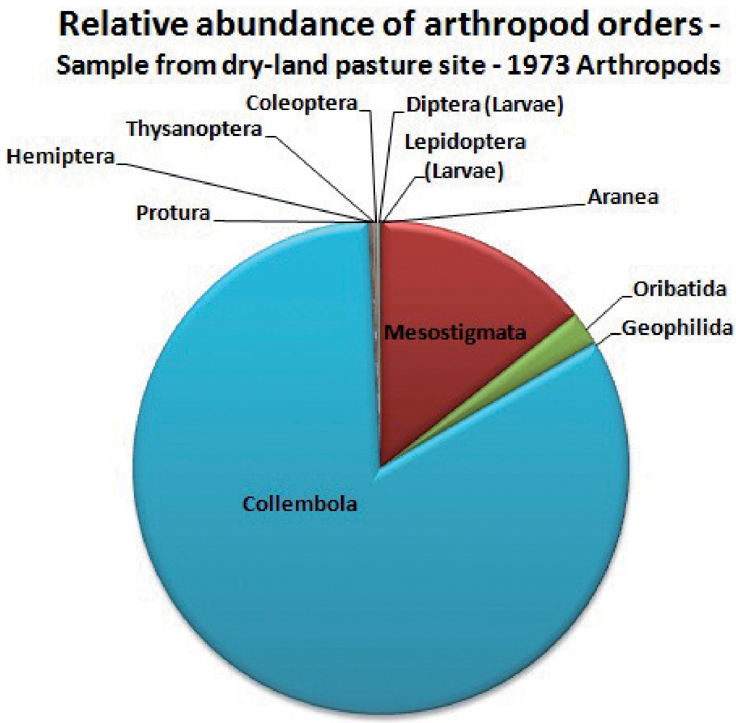


Figure B.3b. Relative abundance of arthropod Orders from dryland pasture sites

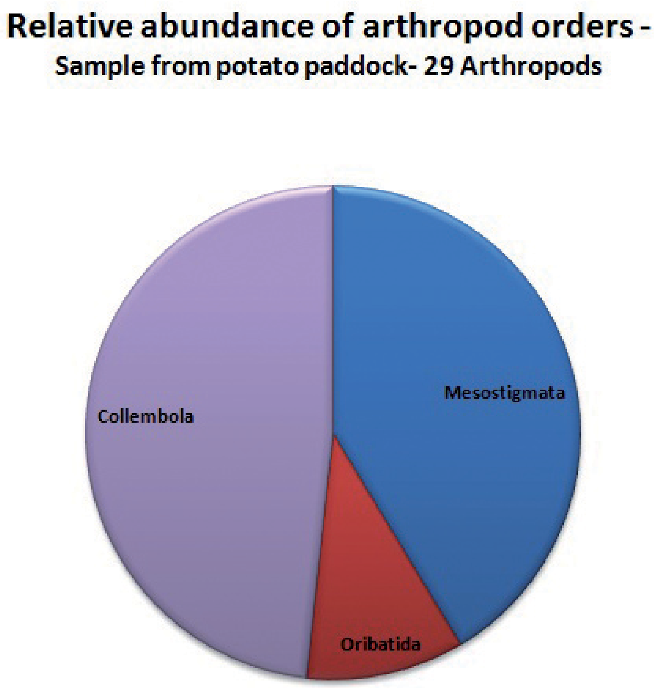


Figure B.3c. Relative abundance of arthropod Orders from potato paddock

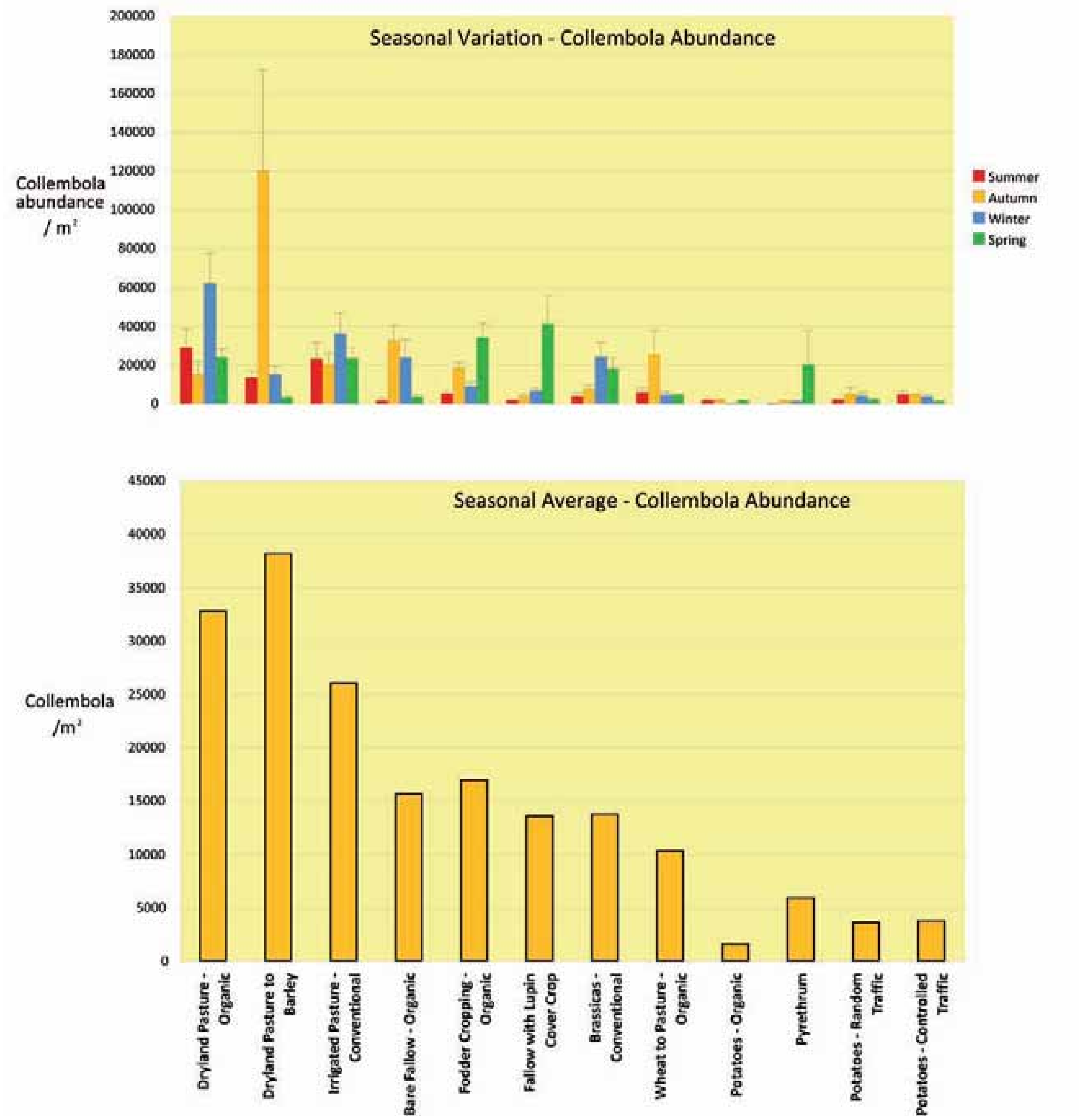


Figure B.4. Seasonal variations and averages – Collembolan abundance.

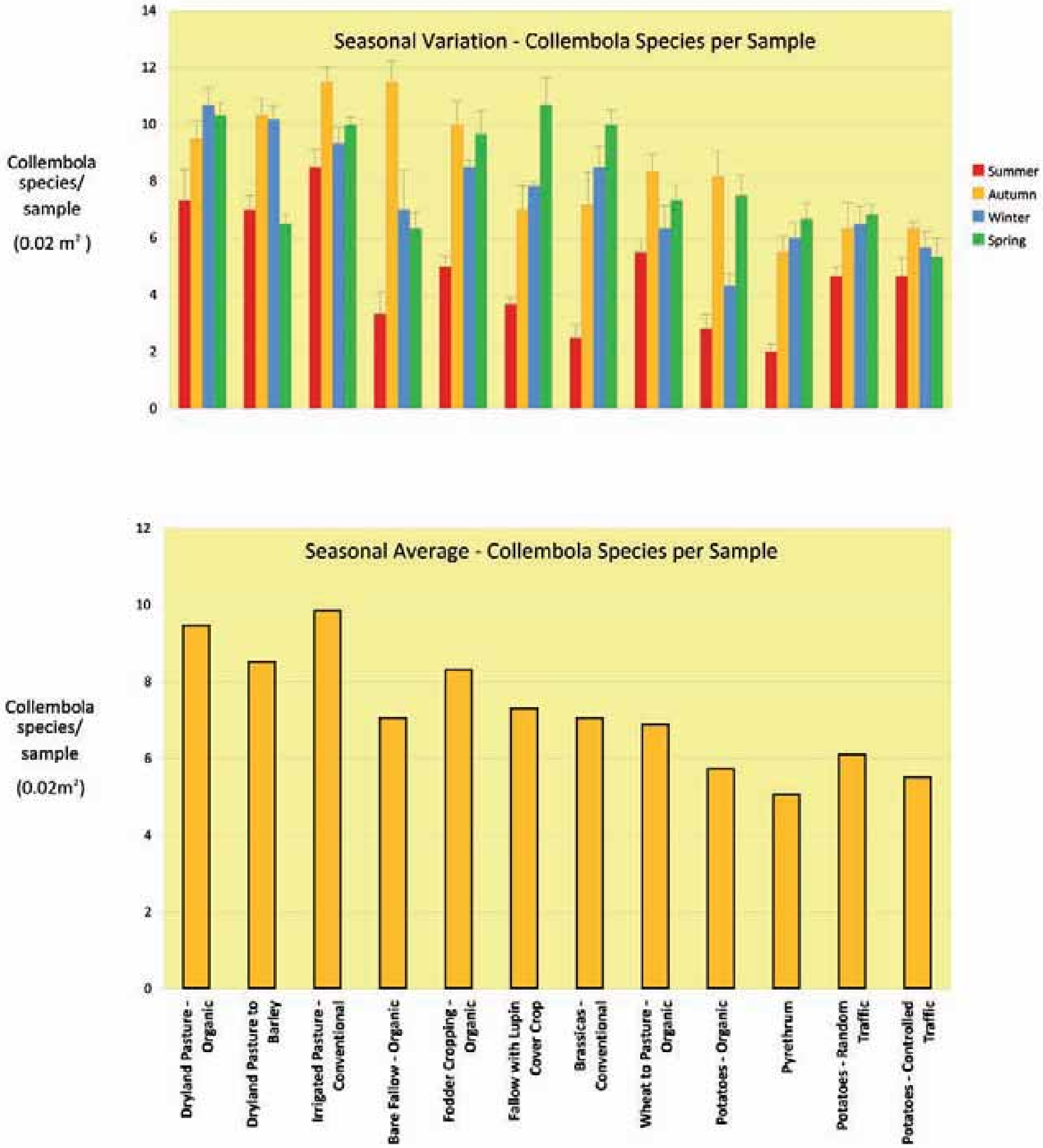


Figure B.5. Seasonal variations and averages – Collembola species per sample

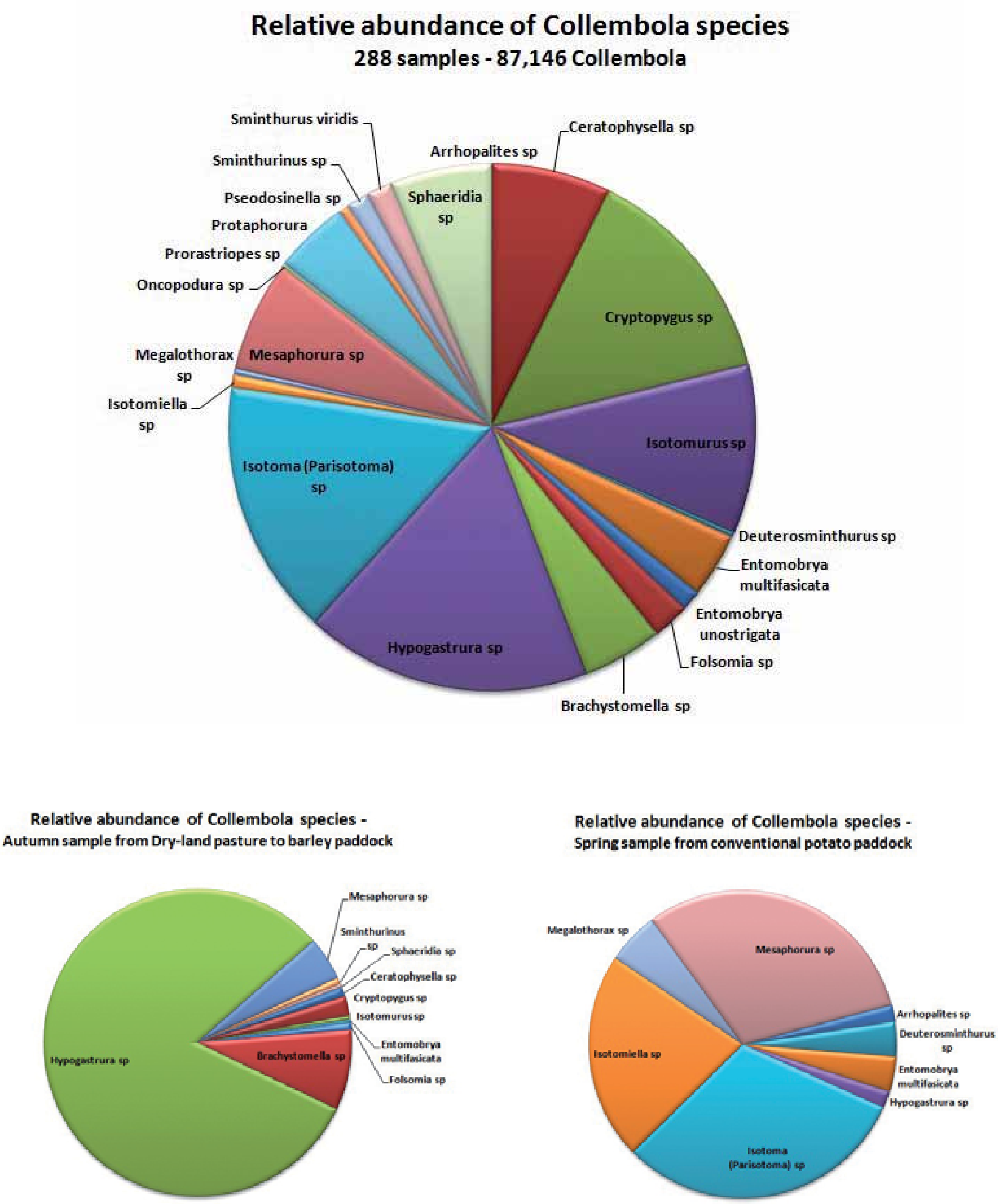


Figure B.6. Relative abundance of Collembola species, overall and from selected samples.

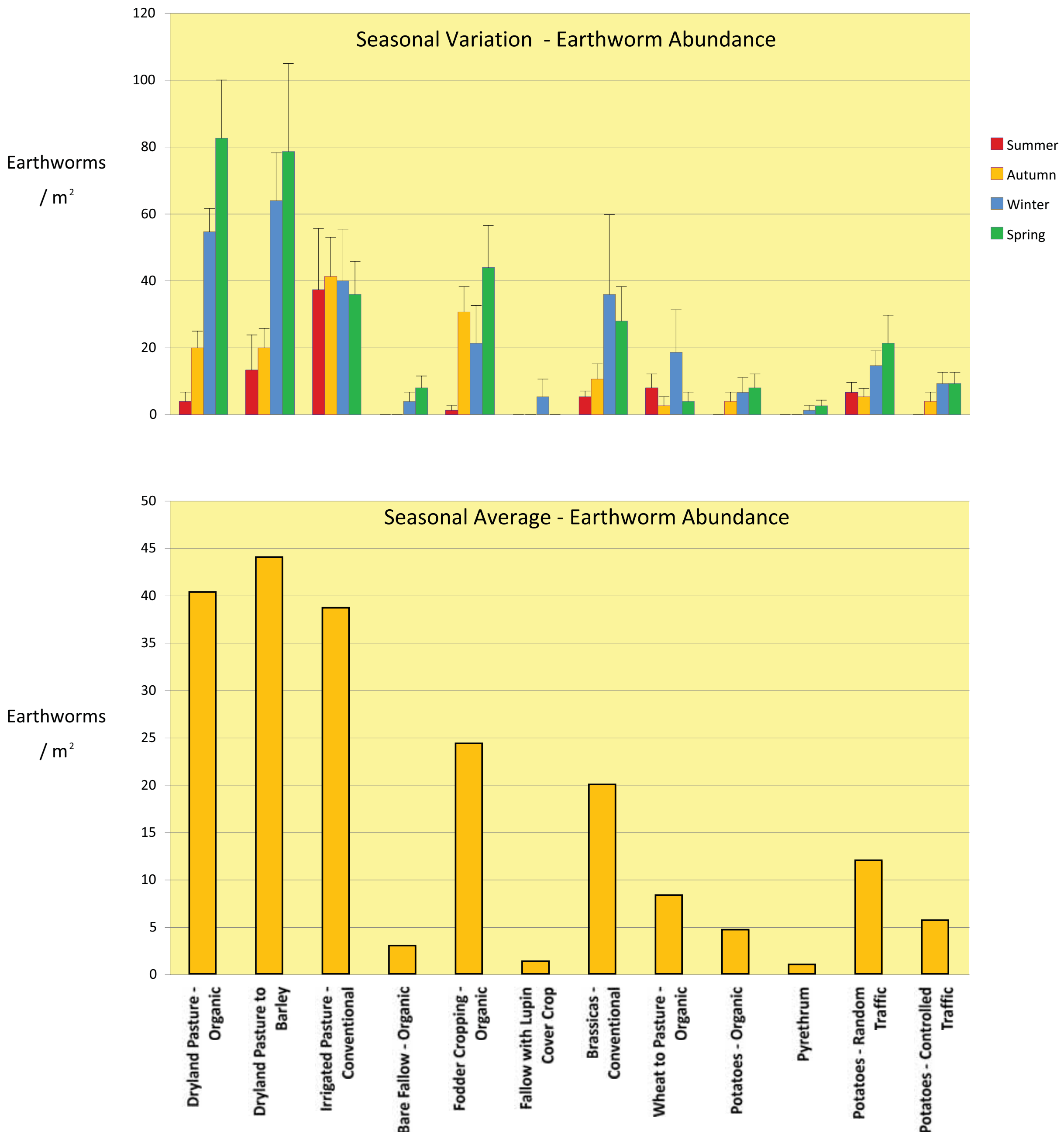
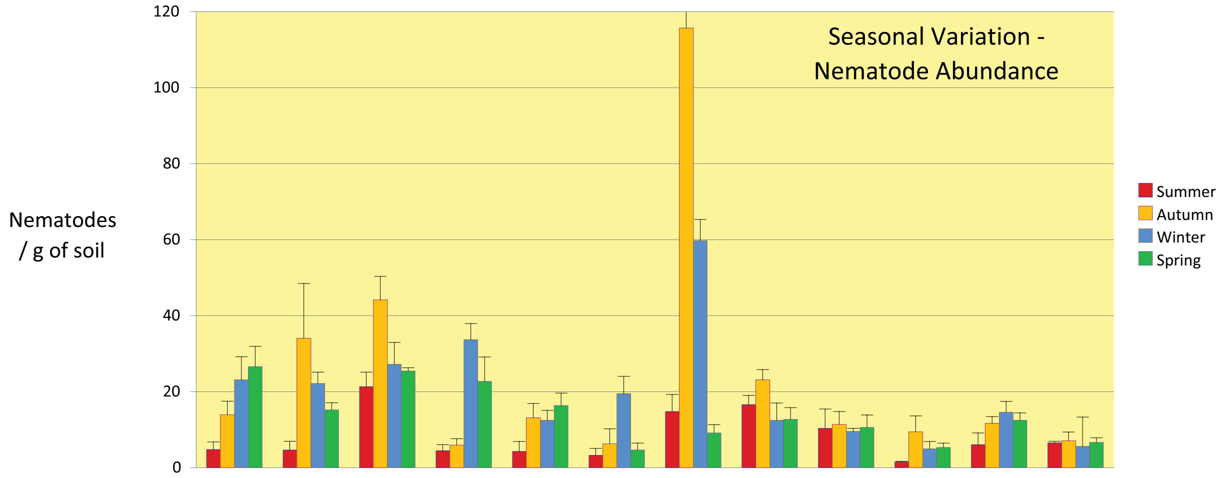


Figure B.7. Seasonal variations and averages – Earthworm abundance



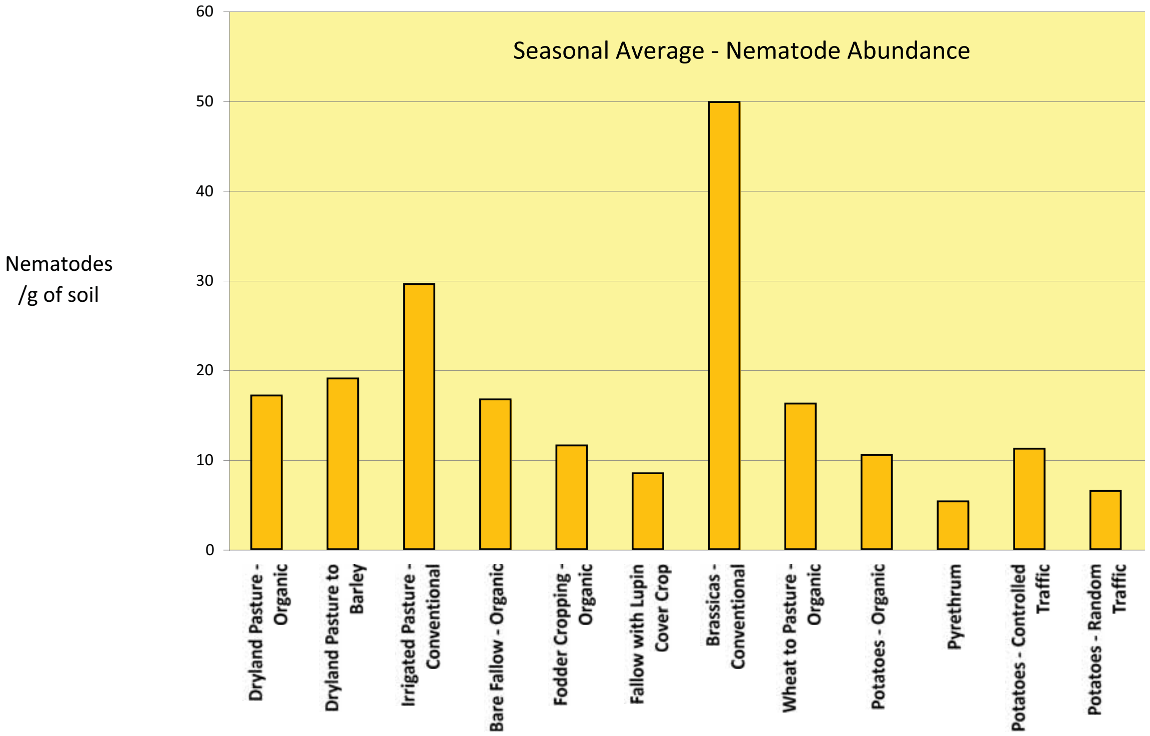
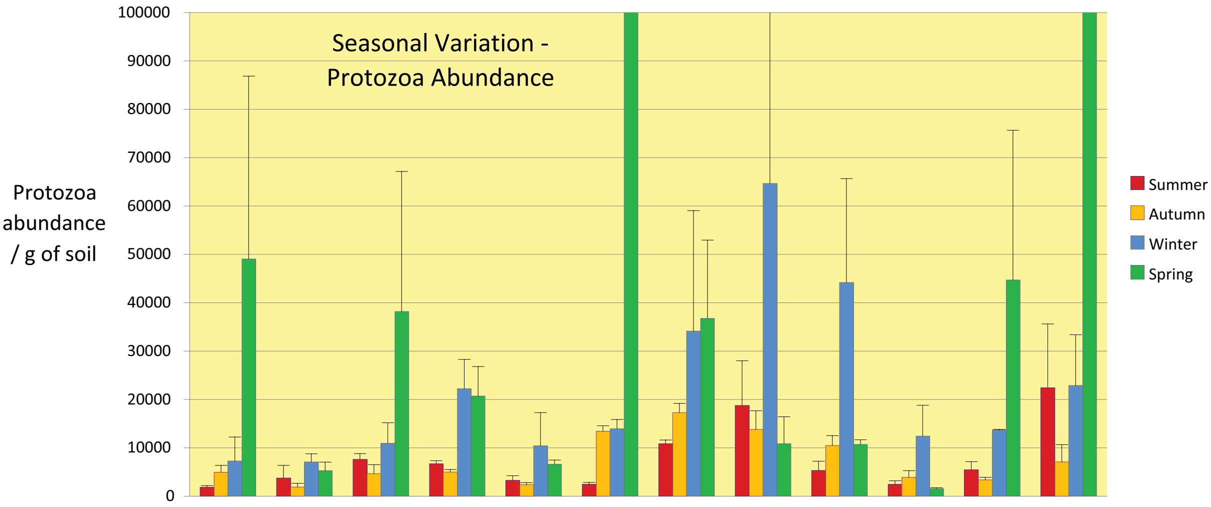


Figure B.8. Seasonal variations and averages – Nematode abundance



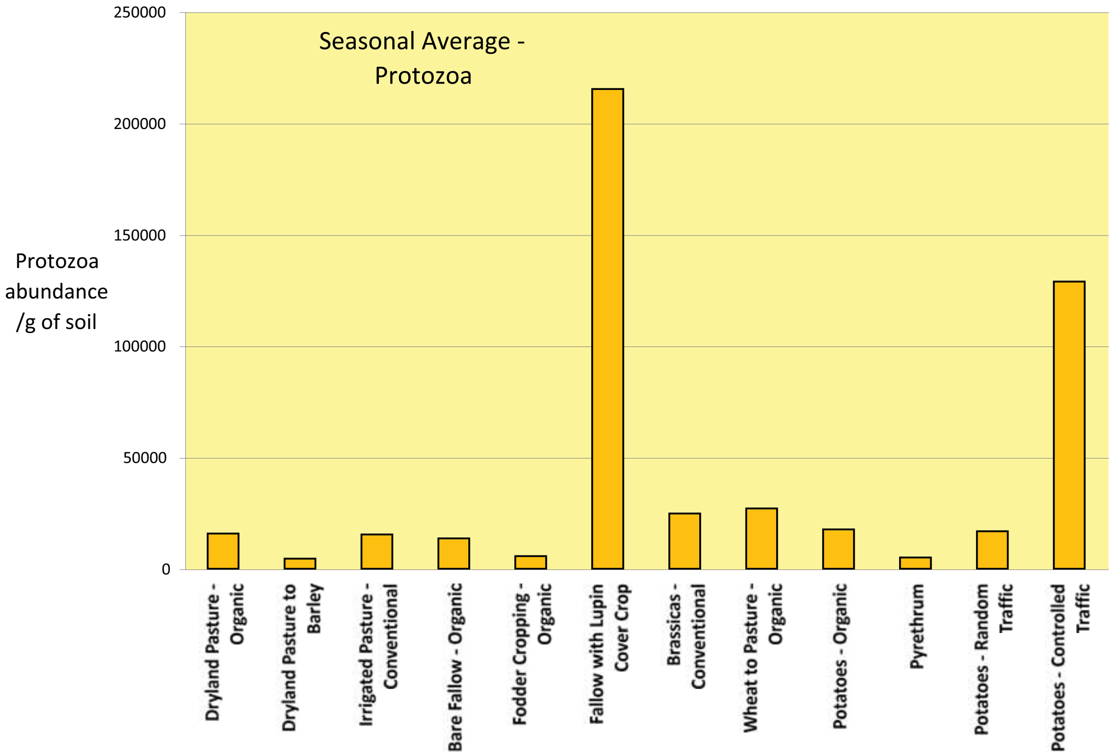


Figure B.9. Seasonal variations and averages – Protozoan abundance

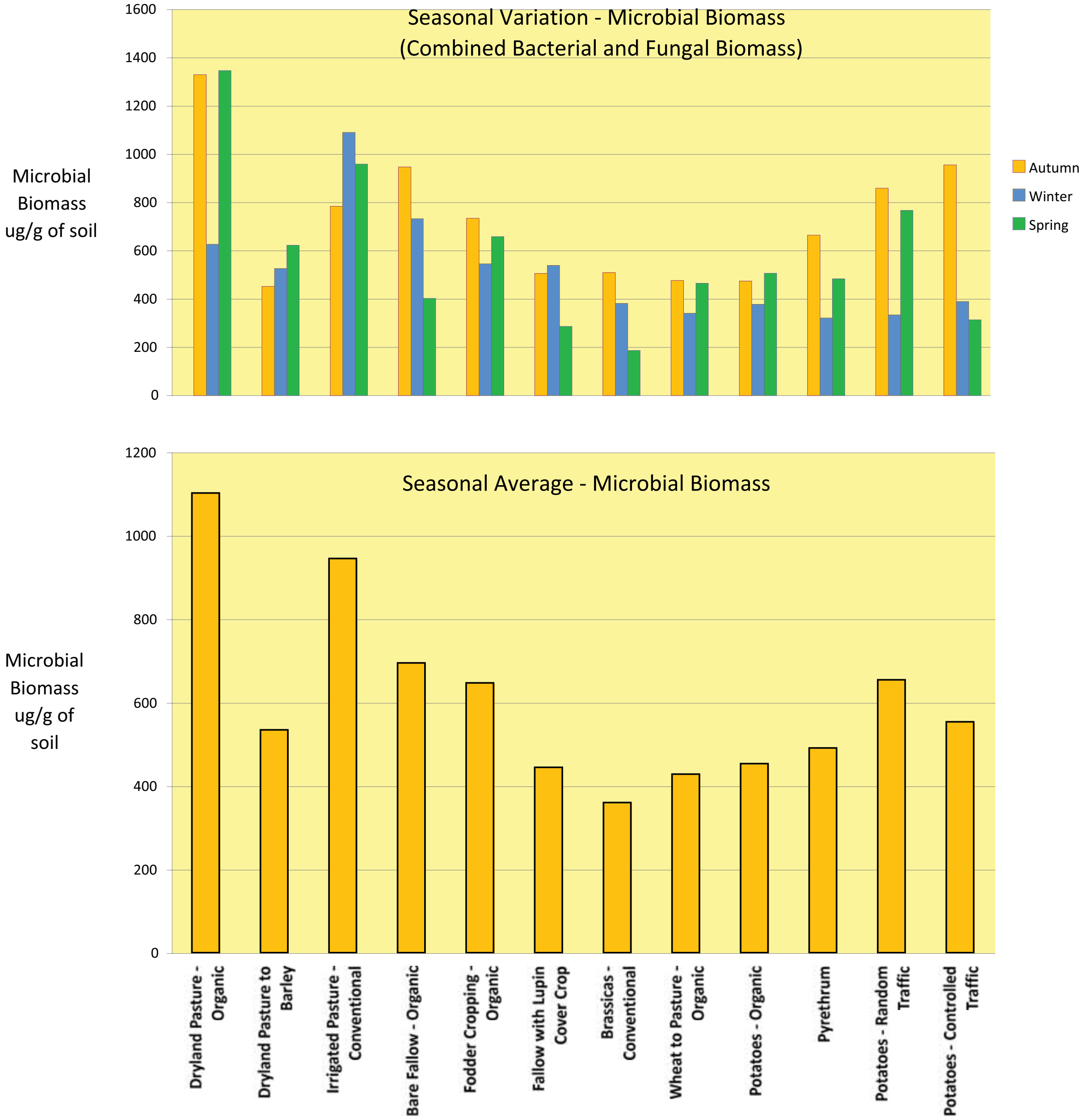
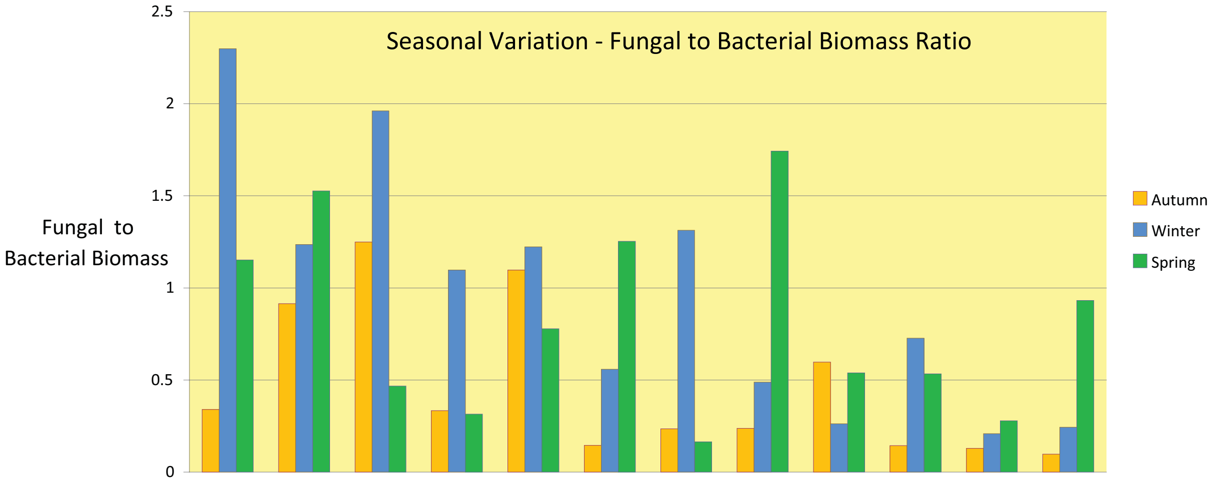


Figure B.10. Seasonal variations and averages – Microbial biomass



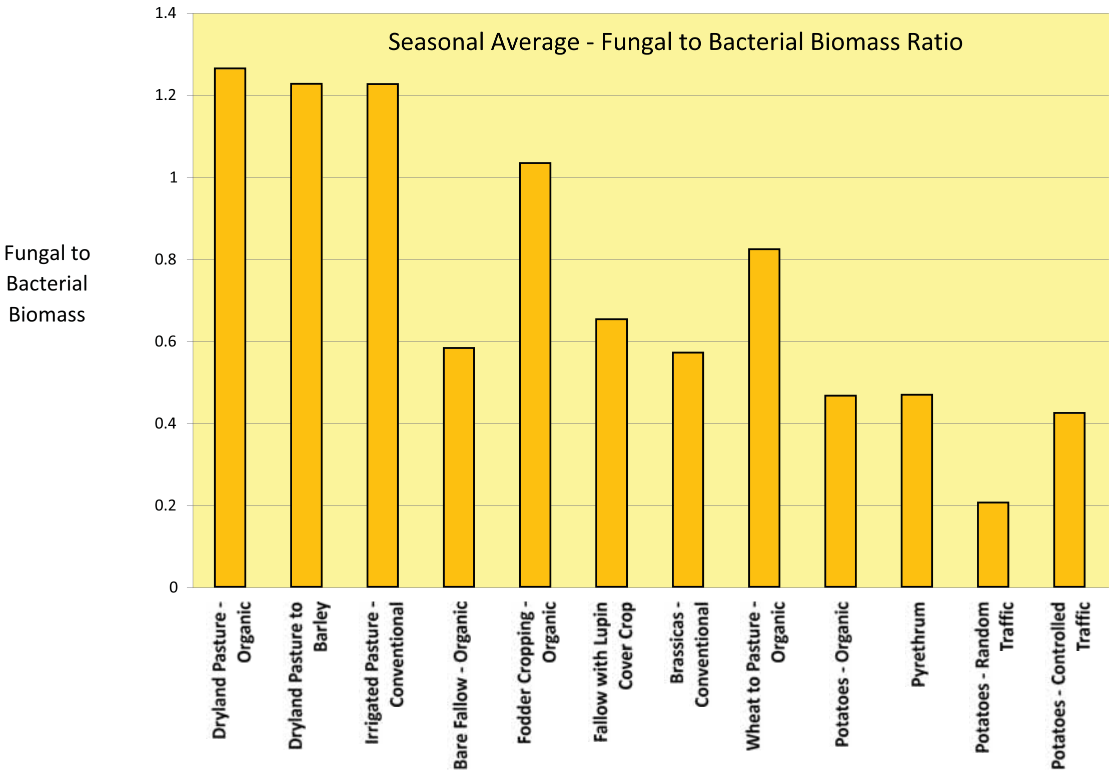


Figure B.11. Seasonal variations and averages – Fungal to Bacterial biomass ratio

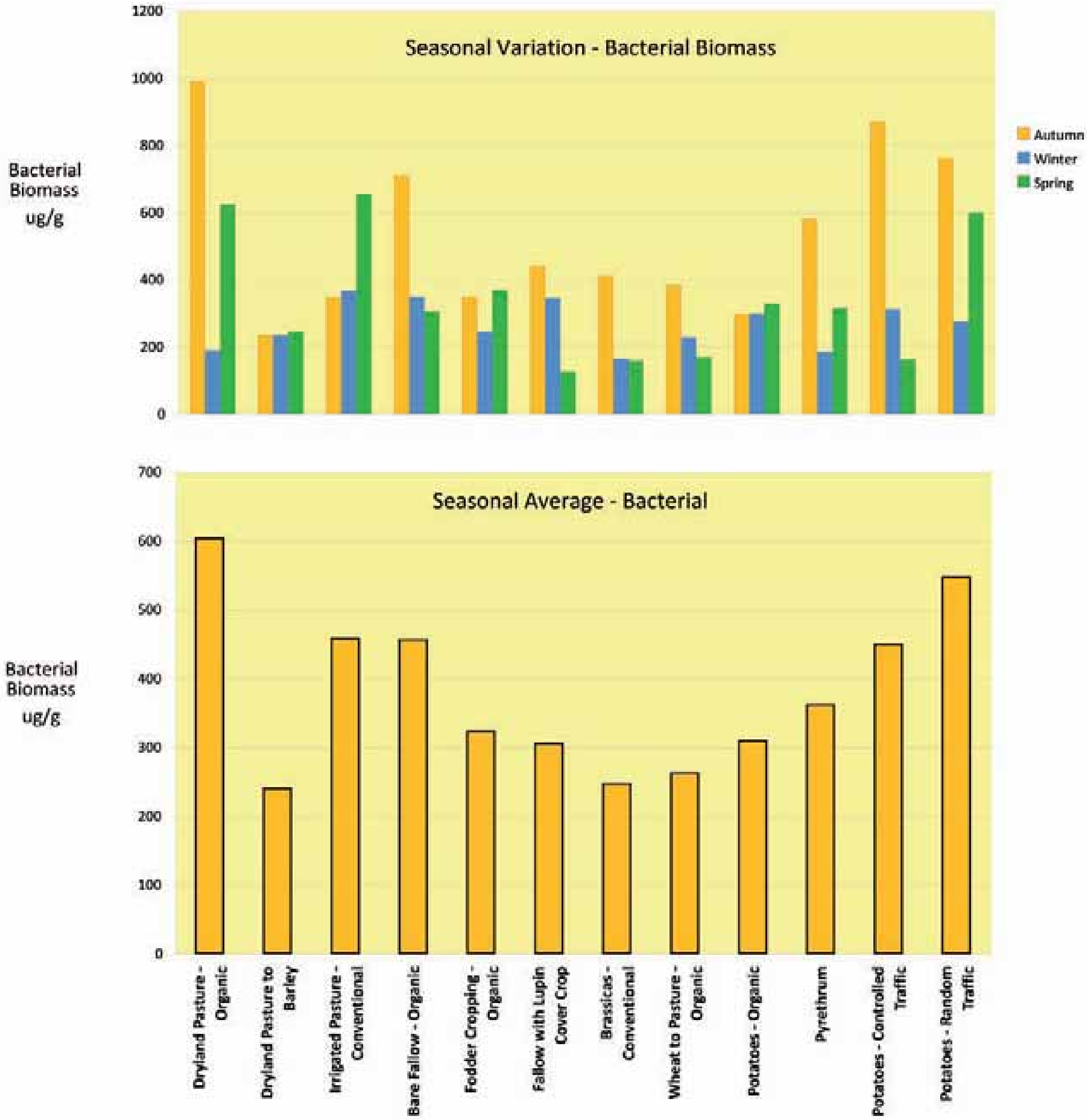


Figure B.12. Seasonal variations and averages – Bacterial biomass

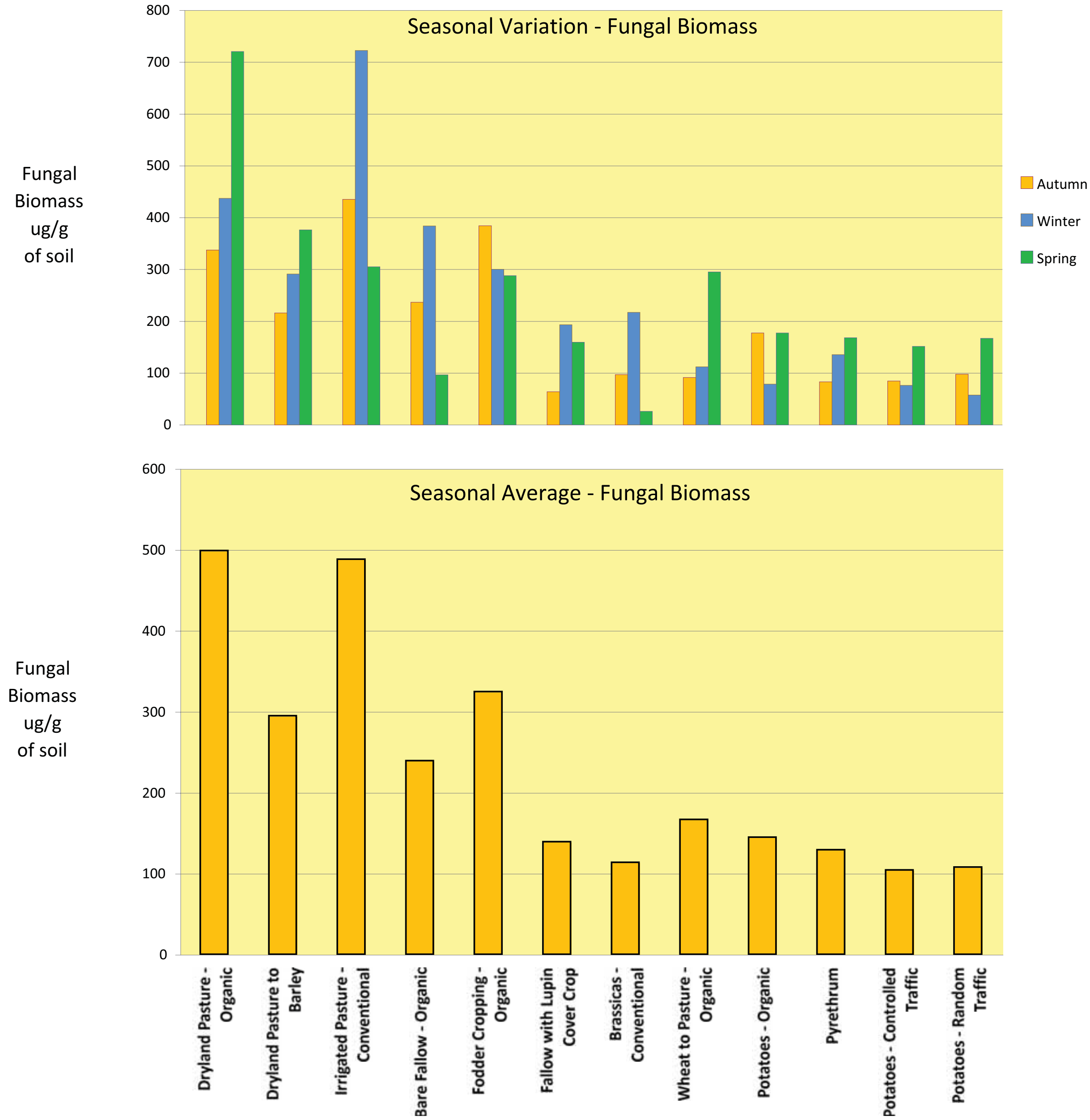


Figure B.13. Seasonal variations and averages – Fungal biomass

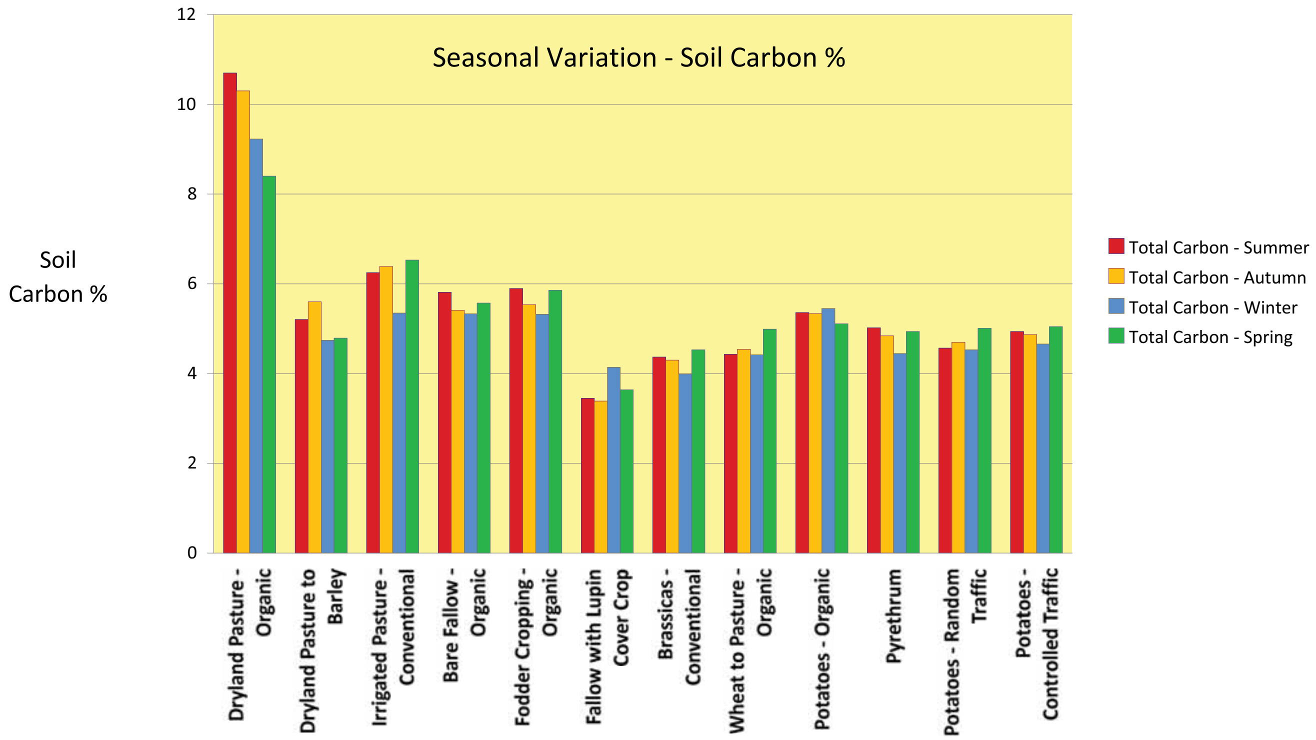


Figure B.14. Seasonal variation – Soil Carbon %

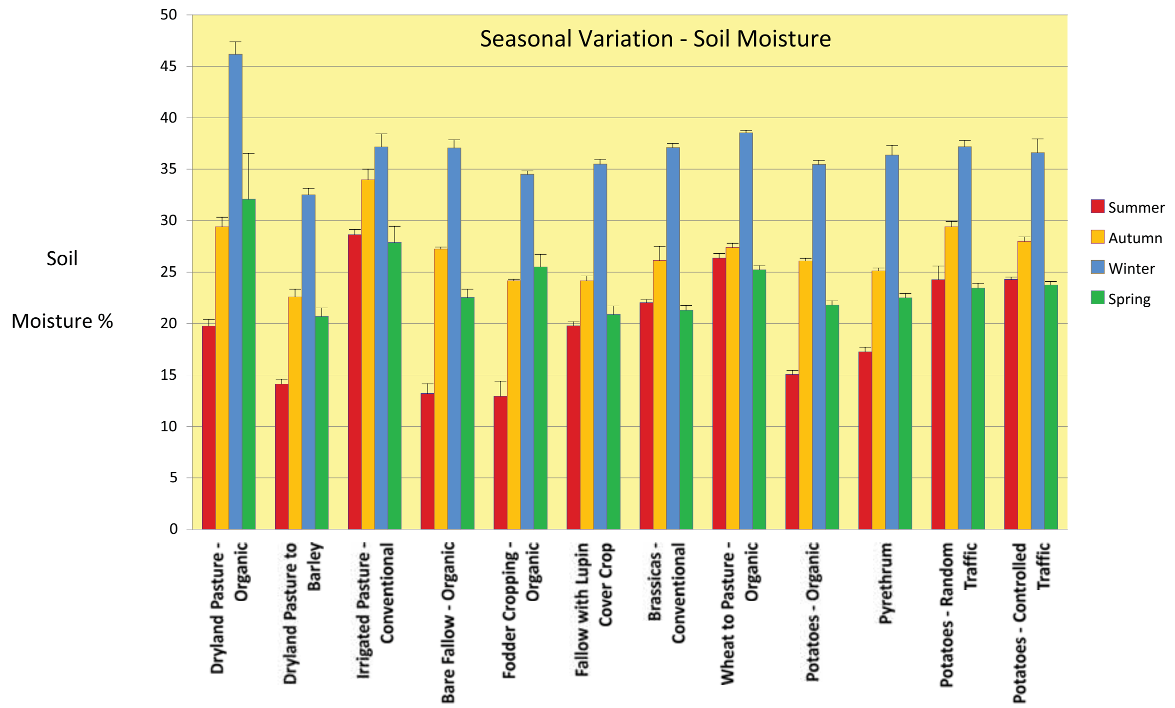
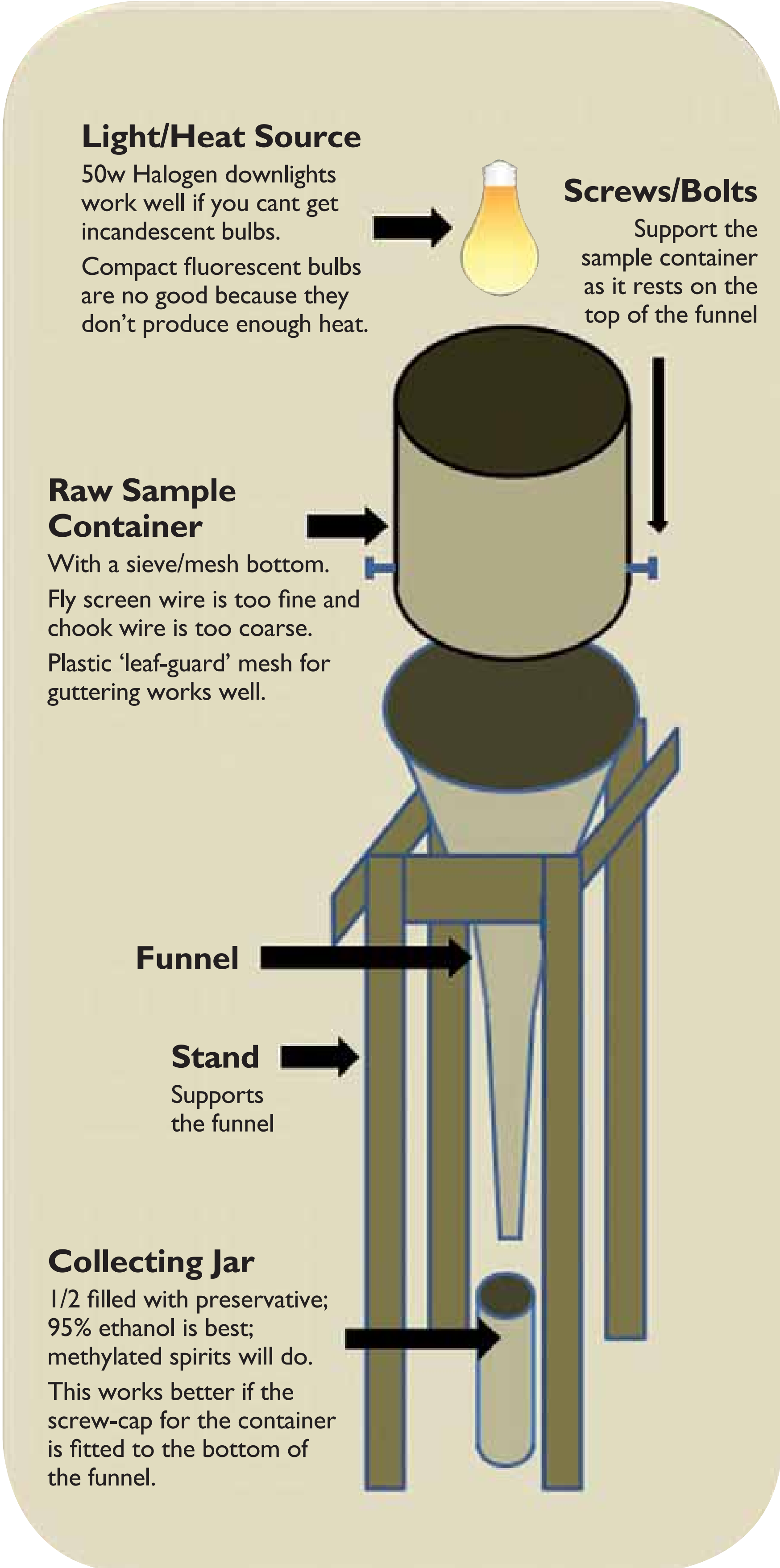


Figure B.15. Seasonal variation – soil moisture

Berlese Funnel Basics

Berlese funnels have been used for more than 100 years to extract arthropods from soil samples and are very easy to make and use. The basic idea is that soil arthropods don't like too much light and heat and when the soil starts to dry out they will move down deeper into the soil where it is cooler and moister. Soil ecologists exploit this behavior by placing a sample into a container with a mesh bottom. A light source is then placed over the sample to gently dry it out. This drives the arthropods down into the funnel and from there they fall into a collecting jar containing ethanol or a similar preservative. After about 48 hours the collected arthropods can be counted and identified to provide information about the ecology of the area where the soil was sampled.



15 Appendix 2 – Recommended reading

Andersen, A, 2000, *Science in Agriculture – advanced methods for sustainable farming*, Acres USA

Bell, M, Seymour, N, Stirling G, Van Zwieten, L, Sutton, G and Moody P, 2004, 'Impact of management practices on activity of soil biota and productivity constraints in Vertosols of the northern grains region', in *Soil Biology in Agriculture: Proceedings of a workshop on current research into soil biology in agriculture*, ed. Rebecca Lines-Kelly, Tamworth Sustainable Farming Training Centre, 11-12 August, 2004. Dept. of Primary Industries, NSW Government.

Bellows, B 2001, Nutrient Cycling in Pastures, www.attra.ncat.org viewed 13th April, 2005.

Beus, CE and Dunlap, RE 1990, 'Conventional versus alternative agriculture: the paradigmatic roots of the debate', *Rural Sociology*, 55(4), pp. 590-616.

Bowden, B 2004, 'The Soil Fertility Debate: Choosing Between Different Recommendation Systems', *Australian Soil Club*, Vol 1, No 4, June 2004, www.soilhealth.com viewed 26th October, 2004.

Conacher, A & Conacher, J 1995, *Rural Degradation in Australia*, Oxford University Press, Melbourne.

Cork, SJ, Shelton, D, Binning, C and Parry, R, 2001, 'A framework for applying the concept of ecosystem services to natural resource management in Australia', in *Third Australian Stream Management Conference*, August 27-29, 2001, Rutherford, I, Shelton, F, Brierly G and Kenyon, C (eds.). Cooperative Research Centre for Catchment Hydrology: Brisbane pp. 157-162.

Dovers, S. 1992, 'The history of natural resource use in rural Australia: practicalities and ideologies', ch. 1 in *Agriculture, environment and society: contemporary issues for Australia*, eds G. Lawrence, F. Vanclay & G. Furze, Macmillan, pp.1-18.

Edgington, LV and Walker, JC 1958, 'Influence of Calcium and Boron Nutrition on Development of Fusarium Wilt of Tomato', *Phytopathology*, vol. 48, pp.324-326.

Fitzgerald, SM, White SD, Dickinson, AA and Goldman, B, 2003, 'A survey of Sigatoka leaf disease (*Mycosphaerella musicola* Leach) of banana and soil calcium levels in North Queensland', *Australian Journal of Experimental Agriculture*, 43, 1157-1161, CSIRO Publishing.

Gupta, VVSR and Roget, DK, 2004, 'Understanding soil biota and biological functions: Management of soil biota for improved benefits to crop production and environmental health', in *Soil Biology in Agriculture: Proceedings of a workshop on current research into soil biology in agriculture*, ed. Rebecca Lines-Kelly, Tamworth Sustainable Farming Training Centre, 11-12 August, 2004. Dept. of Primary Industries, NSW Government.

Kinsey N and Walters, C 1999, *Hands-On Agronomy*, Acres USA

Krull, E, Skjemstad, J & Baldock, J, 2008, '*Functions of Soil Organic Matter and the Effect on Soil Properties*', GRDC Project No CSO 00029, CSIRO, SA

Roget, D and Gupta, VVSR, 2004, 'Impact of management practices on soil microbial functions in alkaline Mallee soils', in *Soil Biology in Agriculture: Proceedings of a workshop on current research into soil biology in agriculture*, ed. Rebecca Lines-Kelly, Tamworth Sustainable Farming Training Centre, 11-12 August, 2004. Dept. of Primary Industries, NSW Government.

Wheeler, PA and Ward, RB, 1998, *The Non-Toxic Farming Handbook*, Acres USA

Zimmer, GF, 2000, *The Biological Farmer*, Acres USA

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