HANDBOOK

TROPICAL SOILS

A GUIDE TO SOIL HEALTH

FOR AUSTRALIAN FARMERS & GRAZIERS

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HOW TO USE THIS GUIDE

This user guide is designed to help you manage your soil's health practically, based on a modern, 21st century approach. It is broken into sections. You can jump between the sections as you need. Use the table of contents on the next page to go to the relevant section of interest.

1. INTRODUCTION

Who is this guide for?

Why we have developed this guide and who will benefit from it.

2. KNOWLEDGE BASE

Getting to know your soils.

If you want to learn the essential theory about tropical soils, then look in Section 2. It covers key topics like soil types, soil biology, soil organic matter, soil structure, nutrient cycling and soil chemistry.

3. GUIDING PRINCIPLES

Ten principles of regenerative soil management.

Section 3 outlines the principles that underpin successful modern day soil health management. These can guide your soil decisions.

4. STEPS TO SOIL HEALTH SUCCESS

Pathways to healthy, productive soils.

Section 4 provides you with a simple guide to help you on your journey to improving your soil's health. It covers the suggested steps for taking action if you are in tropical grazing, cropping or orcharding.

CONTENTS

1. INTRODUCTION

Photo courtesy of James Leech

WHY THIS USER GUIDE?

The whole of life on earth depends upon soil. Soil supports all the natural landscapes across the planet as well as the agricultural landscapes that we rely on for food and fibre.

Across the tropics of northern Australia, from the savannah to the rainforests, from pastoral country to the farming districts to our parks and gardens, all plants and animals depend upon soil to live, so do we. Soil is a key hub in any landscape. It is where water, plants, animals, air and the earth all meet, exchanging energy and nutrients and enabling life.

In any farm business, people are the most important element for success. But the topsoil is a close second. As soil underpins all plant and animal growth, your soil is vital for the success of your farm business. It is a key part of the natural capital that supports a grazing property in the Gulf, a cane farm in the Burdekin, a tropical fruit orchard in the Wet Tropics or hay production in the Northern Territory.

Soil is an asset in any farm business and like any asset, you need to keep it in good condition. If your soil is in poor condition, then plant growth will be impacted. The term we use for a soil in good condition is ***soil health***. Soil health describes the state of a soil system. It includes a soil's physical, chemical and biological aspects.

Healthy soil helps make farming and grazing businesses more resilient, efficient and profitable in the long term. Well-managed soil leads to better agricultural productivity, improved water quality and healthy landscapes. Therefore, if you manage soil, it is important you look after it. It is a valuable part of your farm business.

Soil health is not the same as ***soil fertility***, which refers to the level of nutrient elements in a soil. For example, a soil may have a high level of fertility, but it may be in poor health. When a soil is in poor health, then plant roots cannot grow well and the nutrients in the soil will not be cycling or available for plant growth. Just because a soil is fertile does not mean it will support a productive and profitable farm enterprise. It also needs to be in good condition. It needs to be healthy.

From pastures to tree crops to sugar cane and hay production, soil is the foundation of every farming system across the Tropics of Australia.

Photo courtesy of James Leech

Liming a cane field to improve soil acidity in the Wet Tropics. Using fertilisers in this paddock will not be efficient if the soil has constraints like soil acidity or compaction. Fixing soil health is the first step in improving productivity.

There are two key aspects to soil management: looking after your soil's health and managing its fertility, the soil nutrients. While the two are interconnected, in agriculture we often focus mainly on managing nutrients for our crops and pastures. A higher priority is to manage soil health well first; otherwise you will be wasting your nutrient dollars. Nutrients will not be used effectively if soil function is compromised.

If you are farming or grazing in the tropics, then you know that tropical agriculture has unique challenges. One of these challenges is managing tropical soils. There are common factors that influence soils everywhere on earth. These include geology, land form, climate and vegetation. In the tropics, some of these factors, especially the climate and high temperatures, influence soils and how they function in unique ways. Therefore, managing soils successfully in both the Wet and Dry Tropics requires a good understanding of how soils work and how the tropical climate influences them.

WHO IS THIS GUIDE FOR?

If you are a farmer or grazier in the tropical areas of northern Australia, then this guide is for you.

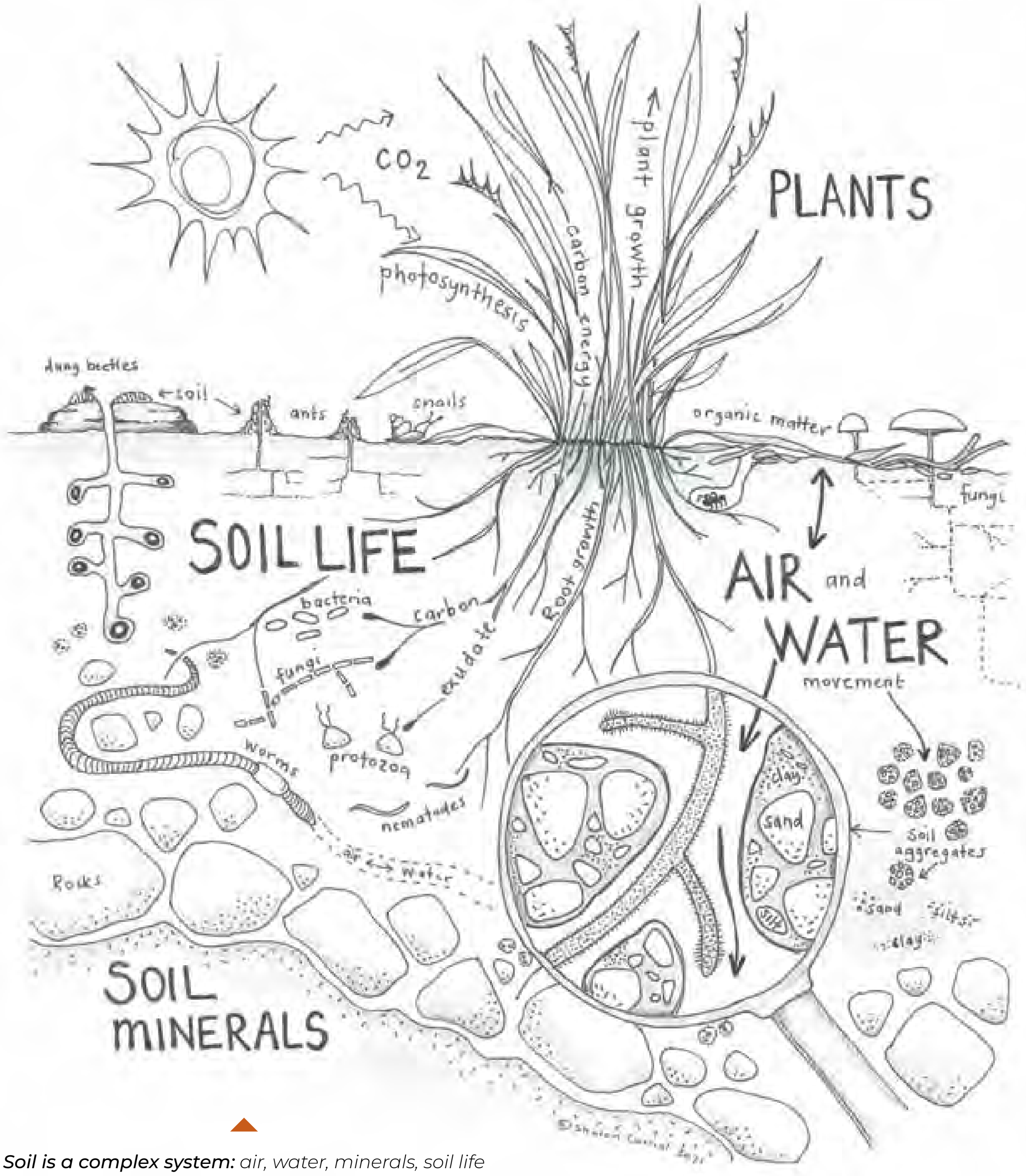
It covers the Dry Tropics as well as the Wet Tropics, with a focus on Central and North Queensland. However, if you manage tropical soils in the Northern Territory and northern Western Australia it will also be useful for you as much of the information applies. This guide contains practical stories of farmers and graziers who are successfully managing soil health effectively in the tropics. These examples may help you improve the soil health on your property.

2. KNOWLEDGE BASE

GETTING TO KNOW YOUR SOIL

WHAT IS SOIL? A 21ST CENTURY VIEW.

For thousands of years farmers have known that good soil structure, also called tilth, has been essential for growing and pastures.



Soil is a complex system: air, water, minerals, soil life and plants all interact to create a topsoil.

However, since the beginning of the modern era, as scientists began to explore soils in more depth, there has been a debate about what soils are and how they work.

Two main views have been put forward: that ***soil chemistry*** is the most important aspect of soils and can be used to explain how they work; or that the community of life in a soil, the ***soil biology***, is the most important aspect. For most of the second half of the 20th century, from after the Second World War, the first view dominated. Until recently, managing soils for agriculture has meant a strong focus on soil chemistry over other areas like soil biology and soil organic matter.

In recent years it has become clear that this 20th century perspective on soils is outdated and needs revising. We now realise that, along with soil chemistry, soil biology and growing plants are critical parts of the soil story. We are learning that soils and plants are in a two-way relationship and that biological diversity is also important.

Not only do soils influence plant growth but plants also influence soils and how they function. We are discovering that soils are ecosystems and that we need to apply systems and ecological science to manage them well. The main components of this soil system are air, water, plants, soil minerals and the community of soil life.

The 21st century view is that your soil is a ***self-organising system***! When you pick up a handful of soil you are holding one of the most important and complex substances on Planet Earth.

A handful of soil has as many living things in it as there are people on the earth. Your soil is not only an important asset for your farm business, it is also a complex, living system. In this system the living and non-living parts all interact, self organising into a stable, productive balance. Chemistry, biology and physics all combine. When disrupted, this balance can be lost and a soil system can degrade, resulting in a whole range of problems.

All life in the tropics depends on balanced soil systems to thrive, including our agricultural enterprises. The great challenge in managing agricultural soils, then, is to keep them balanced and healthy. Of most importance is the thin layer of soil on the surface, often less than 30 cm deep, where most of the action occurs. We call this layer the ***topsoil***.

The topsoil is where most of the action happens.

HOW SOILS WORK!

For thousands of years farmers have known that good soil structure, also called tilth, has been essential for growing and pastures.

The topsoil is where water, air, nutrients, energy and life meet on Planet Earth. Around 400 million years ago, life first left the oceans and primitive plants started to evolve and colonise the land. They did this in partnership with a range of microscopic life including archaea (relatives of bacteria), bacteria and fungi. These microbial partners helped early plants to access nutrients from the air and bare rocks. The first topsoils were born.

Since that time, many other organisms like insects and small animals have joined the soil community. Plants and their soil partners have since co-evolved over hundreds of millions of years creating the complex soil communities that we manage as our topsoils today.

We can think of the way soils work as a network of relationships between water, soil minerals, soil air, soil life and plants. Every living thing on earth needs food and a suitable environment to live. The network of relationships between members of the soil community and plants, along with the soil minerals air and water, organises into a topsoil, creating an optimal environment for the whole community.

At the heart of a topsoil is a profound relationship between plants and microorganisms that has evolved over millions of years. All plants have evolved a process where they give off sugars and other compounds into the soil from their roots. This process is called ***exudation*** and is one of the most important processes on Planet Earth. Through this process plants provide the soil community with energy in the form of ***carbohydrates***.

Using this energy, the microbes in the soil access nutrients from the soil minerals and sometimes from the soil air. Plants provide energy to the life in the soil and in return for this energy, the soil life supplies nutrients to plants. At the heart of a soil system then is a trade: energy for nutrients.

The reason for this trade is that plants are great at accessing energy through the process of ***photosynthesis***. Transforming the carbon in the air, carbon dioxide gas, into carbohydrates, they create their

Compounds given off by plant roots feed energy to the soil community; in turn this community of soil life helps the plant to access nutrients. Through this process the pattern of a topsoil is created. A healthy sugar cane soil near Tully in North Queensland.

own energy. However, accessing nutrients and water is more challenging as they are not so easily available for plants. Plants access these from the soil by building root systems. A plant's roots act as its digestive system, absorbing nutrients and water from the topsoil.

Generally, most nutrient elements are tightly bound up in minerals in the soil, so plants need help to access them. In the tropics two processes help make nutrients available from soil minerals: firstly natural weathering of soil minerals by rainfall releases some nutrients. Secondly, an equally important part of the nutrient cycling story, is the soil microbes. Soil fungi and bacteria have evolved ways to access nutrients from soil minerals, but their problem is that they need energy, so many of them live in close association with plant roots where they can access energy in the form of sugars that plants exude from their roots. The nutrients they access from minerals are then exchanged with plant roots for this energy. Most of this exchange happens around the roots of plants, in the ***root zone***. This area of a soil is also called the ***rhizosphere***.

The rootzone is one of the most important parts of a soil. The larger this zone, the more healthy the soil usually is. Examining the size of the root zone, like in this sugar cane paddock, is a great way to assess soil health.

Over time lots of other relationships have evolved in soils as more and more microbes and soil organisms have joined the soil party, creating the soil community we see today. Many members of the soil community live by ***decomposing*** the ***organic matter*** that plants produce as they grow. This includes the litter on the soil surface as well as dead roots given off by plants underground. Organic matter contains energy, nutrients and water, so it's a food source for much of life in the soil. Other soil organisms get their food by preying on these decomposers or on other soil predators. The result of these complex biological relationships in the soil is sometimes called the ***soil food web***.

However, there is more to soil than the soil food web. Soil life influences a soil's chemistry and minerals and vice versa. The soil community also creates different types of soil organic matter including soil humus, a type of stable organic matter. Finally, the life in the soil also influences a soil's structure. Soil structure is how a soil is physically arranged. In turn, the structure of a soil influences how much air and water enters a soil and what type of soil community can live in it.

In a balanced soil system this complex set of dynamic relationships, between plants, soil life (microbes and organisms), air, minerals, structure and soil organic matter, results in a stable, high-functioning topsoil. Such soil is adapted to the local environment and climate. What emerges is a soil that provides an optimal environment for plants and soil life to thrive. When a soil is balanced and stable, it is healthy. The aim of farmers in the agricultural landscapes of the tropics is to build and maintain healthy soils so they can remain productive in the long term. This can be challenging because we often need to modify and disturb soils to meet our farming goals.

Managing a soil for health and agricultural production can be tricky. Sugar cane paddocks are often compacted. This is a result of intensive farming practices, especially heavy machinery. Using strategies like controlled traffic farming to repair the soil structure is a key goal of modern sugar cane production. Here a soil is being tested for compaction.

TROPICAL SOILS: HOW THEY FORM

Soil scientists have been studying soils since Charles Darwin. One of the things they were trying to work out was how soils form. What is the cause of the diversity of soils we see across the earth? Russian scientists were amongst the first to examine soils systematically. In 1941, an American soil scientist named Hans Jenny had a brainwave and came up with a simple equation to explain how soils form. It is now called **Jenny's Soil-Forming Equation**.

The five soil forming factors: ***Geology, Life, Climate, Topography & Time***

The five factors in this equation blend in different ways across the earth, creating the amazing diversity of soils we see. As in other regions of Australia, the tropics have a wide range of different soils, from the cracking soils of the Mitchell Grass Downs to the bright red soils of the Atherton Tablelands, from the dark brown soils of coastal swamps to light coloured sandy ridges, the diversity of soils across the tropics is due to these five soil-forming factors combining in unique ways.

GEOLOGY

Rocks are the first key ingredient in forming a topsoil. Rocks are made up of minerals and, as they break down, they release these minerals. We call this process ***weathering***. These minerals give a soil some of its most important characteristics including its colour and fertility along with an amount of sand, silt and clay. Rocks are called ***parent materials*** by soil scientists. Think of rocks as one of your soil's parents. Due to geological history, different areas have different minerals as they have come from different rocks. Hence, across the tropics different soils have different colours, textures and levels of fertility due to the different minerals they come from. You may not see any rocks in the area where you live but the minerals that make up your soil have come from rocks at some point in the past.

The geology of landscapes varies across the tropical north. The Mitchell Grass Downs of North-Western Queensland.

Coastal plains and hills near Townsville

Granitic coastal mountains in the Wet Tropics near Gordonvale, Queensland.

LIFE

At the same time as rocks are breaking down and forming minerals in a soil, life is growing on the surface. All kinds of plants, from lichens growing on bare rocks, to mosses, grasses, shrubs and trees, grow in topsoils. They do this through the process of ***photosynthesis***. Fixing carbon from the air they combine it with the nutrients and water they get from the soil. This process allows them to grow, creating vegetation or ***plant biomass***.

Over time some of this plant biomass returns to the soil either as litter and leaf fall on the surface or as dead root mass underground. This process creates soil organic matter, supplying the soil community with their food source. Much of the life in the soil, from bacteria and fungi to earthworms and termites, depends on this organic matter as their food source. So they decompose the ***soil organic matter*** to access energy and nutrients.

In a rainforest a large load of litter continually falls to the ground. This provides a food source for the diverse range of organisms in a soil community. A unique aspect of healthy forest soils is this thick layer of mulch on the surface.

Under different types of vegetation, different patterns of soil emerge. For example, in a rainforest, you see a soil pattern develop, shaped by the forest vegetation. Forest soils typically have a distinct thick layer of litter on top. Under this layer is another layer of dark stable organic material called ***humus***. These layers in a forest soil have formed from the large amount of litter, leaves, stems and branches that fall from the canopy of the forest trees to the soil surface each year. In these soils most of the organic matter is supplied to the top of the soil from above.

In a grassland environment, there is less litter falling to the soil from the stems and leaves of the plants. Instead, the large volume of fibrous roots of perennial grasses supplies the soil with most of its organic matter under the ground. In grasslands there is not usually a thick, distinct dark layer at the surface. Instead, the topsoil often has a single uniform topsoil layer of minerals, organic matter and plant roots mixed together.

In pastures and grasslands the fibrous root systems of the grasses usually create a topsoil that usually does not have the distinct layers found in forest soils.

The amount and type of vegetation strongly influences the formation of any topsoil in any location across the tropics. Land management activities like farming and grazing influence what type and how much vegetation is growing at any site. So our management activities strongly influence soils because of how we manage vegetation.

CLIMATE

Two main climatic influences shape a soil: rainfall and temperature. The tropics typically receive high annual rainfall. Over geological time, water from rain weathers soil minerals, changing their chemistry and colour. Due to the intensity of rainfall, soils in the Wet Tropics in particular, have high rates of mineral weathering. This intense weathering means that in high rainfall areas many nutrients are leached from the soil, resulting in soils with low chemical fertility. Intense weathering can also lead to high levels of soil acidity.

The high temperatures of the tropics ensure that soil life is constantly active. The rate of soil organic matter breakdown is high leading to soils with low levels of organic matter as the soil community breathes most of the soil carbon back into the air as carbon dioxide through a process called ***respiration***. This is particularly an issue in the Wet Tropics regions.

A further issue of Dry Tropics regions is the long dry season. During this time the soil system is relatively dormant. However much of the carbon in a soil's litter layer can be broken down and lost to the air through the process of ***oxidation*** through this long dry period as the soil surface heats up. The surface organic matter slowly breaks down under dry hot conditions.

High rainfall and high temperatures are two important forces that shape soils in the tropics. In areas of very high rainfall like the Daintree rainforests of North Queensland, the weathering of soil minerals is relentless.

TOPOGRAPHY

The position of a soil in the landscape, known as its ***topographical location***, also influences the type of soil that forms. Soils at the top of hills and crests are generally shallower than those along creek lines and further downslope. This is because over time gravity moves soil minerals and sediments downslope. Minerals and clay can move downslope either through or on top of the soil. They are usually carried along in water as it flows downhill. Because of this process, soils at the bottom of slopes often have a higher clay content than those on hill slopes and crests. Soils on floodplains receive sediment from the upper areas of the surrounding landscape, so they tend to be deeper and often contain higher levels of fertility.

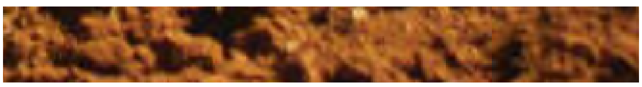
One of the reasons soil varies so much across a landscape is the terrain. Despite similar geological history, soils vary across the Atherton Tablelands in North Queensland due to initial volcanic activity and then gravity and rainfall acting on soils through time.

Flat coastal landscapes in the Wet Tropics are dominated by floodplains of the rivers. Soils in these floodplains are highly variable. Different sediments are deposited in different places over time as a river changes its course.

TIME

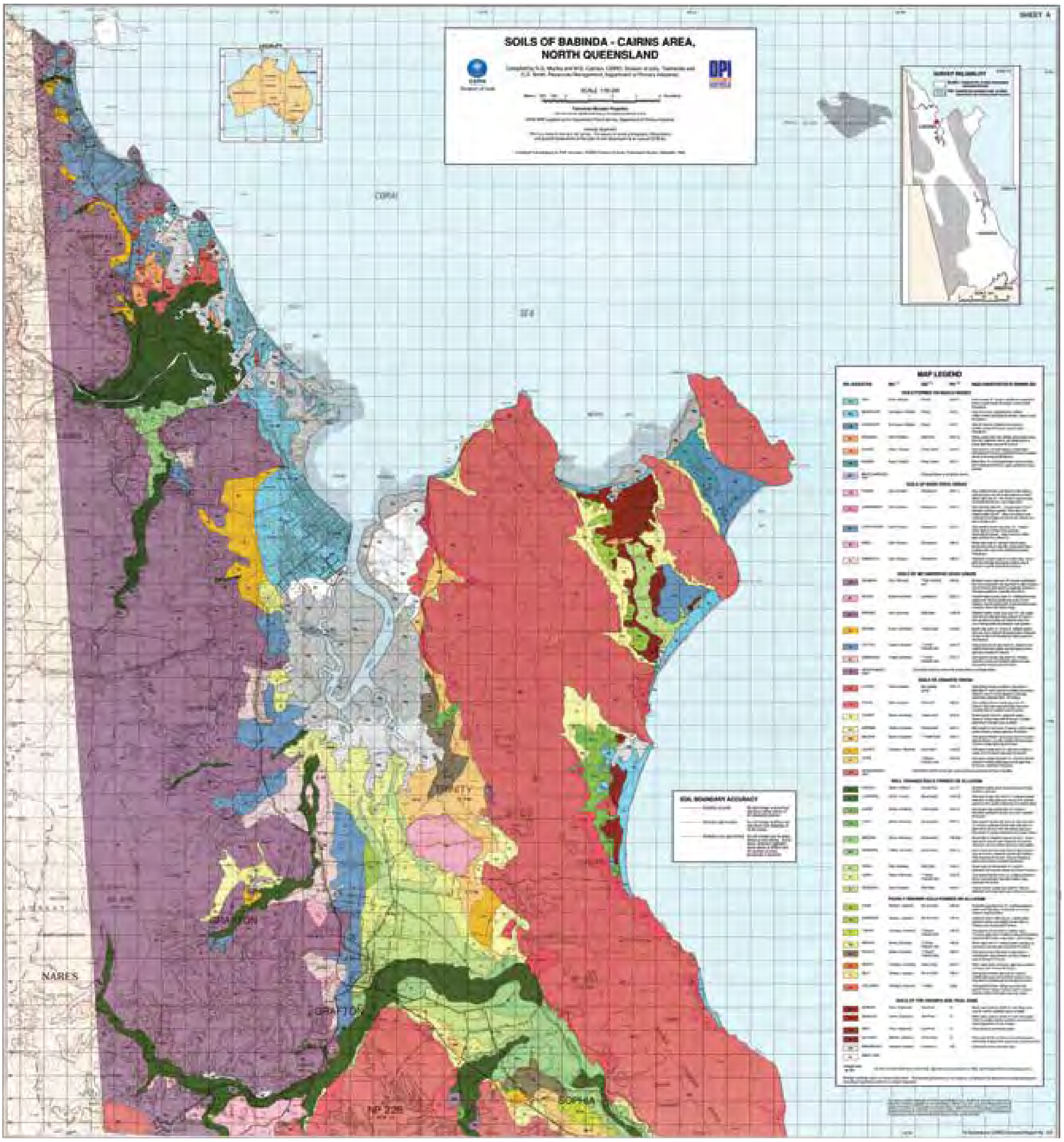
The longer a soil has been exposed to weathering from rain, wind and life, the more the minerals in that soil are altered. Generally, the older a landscape is geologically, the more its soil minerals have been changed by climatic and life forces. Soils on ancient landscapes tend to have low levels of fertility, because there has been more time for the nutrient elements to be leached away to the sea over millions of years. Across much of northern Australia the landscape is old. This means that in many areas of the tropics ancient topsoils with low fertility are present. However, in areas of recent volcanic activity like the Atherton Tablelands, younger soils with high levels of fertility occur.

A low fertility tropical soil south of Darwin. This highly weathered soil is high in aluminum and iron. Many other nutrient elements have been leached away over geological time.



SOIL TYPES: ONE SIZE DOES NOT FIT ALL

The different combinations of the five soil forming factors mean that, from a practical point of view, there are lots of different soil types across the tropics of Australia.



This map of soils in the Cairns district of North Queensland shows the complexity of soil types across a region.

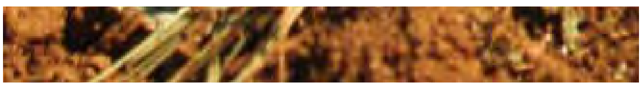
You may know the local names for some of the different ***soil types*** in your district. For example, heavy floodplain soils, sandy ridges, red soils, peat soils and gravelly soils are just some of the names used to describe local soil types in the tropics.

Soil scientists have classified Australian soils into 14 general ***soil orders*** to try to group the wide range of soil types into some manageable categories. Many of these soil orders can be found in the tropics. Each soil order has certain key characteristics that make it unique. These characteristics do not usually change greatly under management. They are the fairly permanent, long term properties of a soil.

Over many years the soil types in different regions have been described and mapped in Australia by state government agencies. This helps us understand the complexity of soils in an area as well as giving insights to manage them effectively.

Soil orders and soil mapping are an important way to categorise soils as it helps to understand them better. However, from a practical agricultural perspective, a simpler approach to defining soil type is to look at those relatively permanent aspects of a soil that directly influence its use for agriculture at the paddock scale. These permanent aspects of your soil generally do not change much under management, with some exceptions. Importantly, they often determine what farming activity is best suited in any location.

At this field day near Bowen, Queensland, the host grazier, Bob Harris, lined up all the different soil types on his property. He has at least eight different soil types, all of which need careful management.



There are three key aspects of a soil's type that influence practical soil management. A fourth key aspect, soil colour, does not necessarily influence day to day management but it does tell us a lot about a soil type. The important management aspects of soil type are:

1. **SOIL FERTILITY**
2. **SOIL TEXTURE**
3. **SOIL COLLOID**
4. **SOIL COLOUR**

Overall, various soil types are not "good" or "bad". They are just different. You cannot really change a soil's type greatly. The aspects of soil type are relatively permanent and so you need to manage a soil within the limitations of the soil type. However, different soil types will be suited to different agricultural activities.

A medium textured, moderate fertility soil type near Bellenden Ker, North Queensland.

A coastal peat soil type being used to grow sugar cane in the Wet Tropics. These soil types can be a challenge to manage for agriculture.

Knowing your different soil types is important because they influence every farm management decision you will ever make on that paddock. From tillage to irrigation to production goals, everything is influenced by the underlying soil type you are managing. The soil types on your property can be determined from soil maps but often field assessment helps you get a more accurate idea of where your different soil types are on a property.

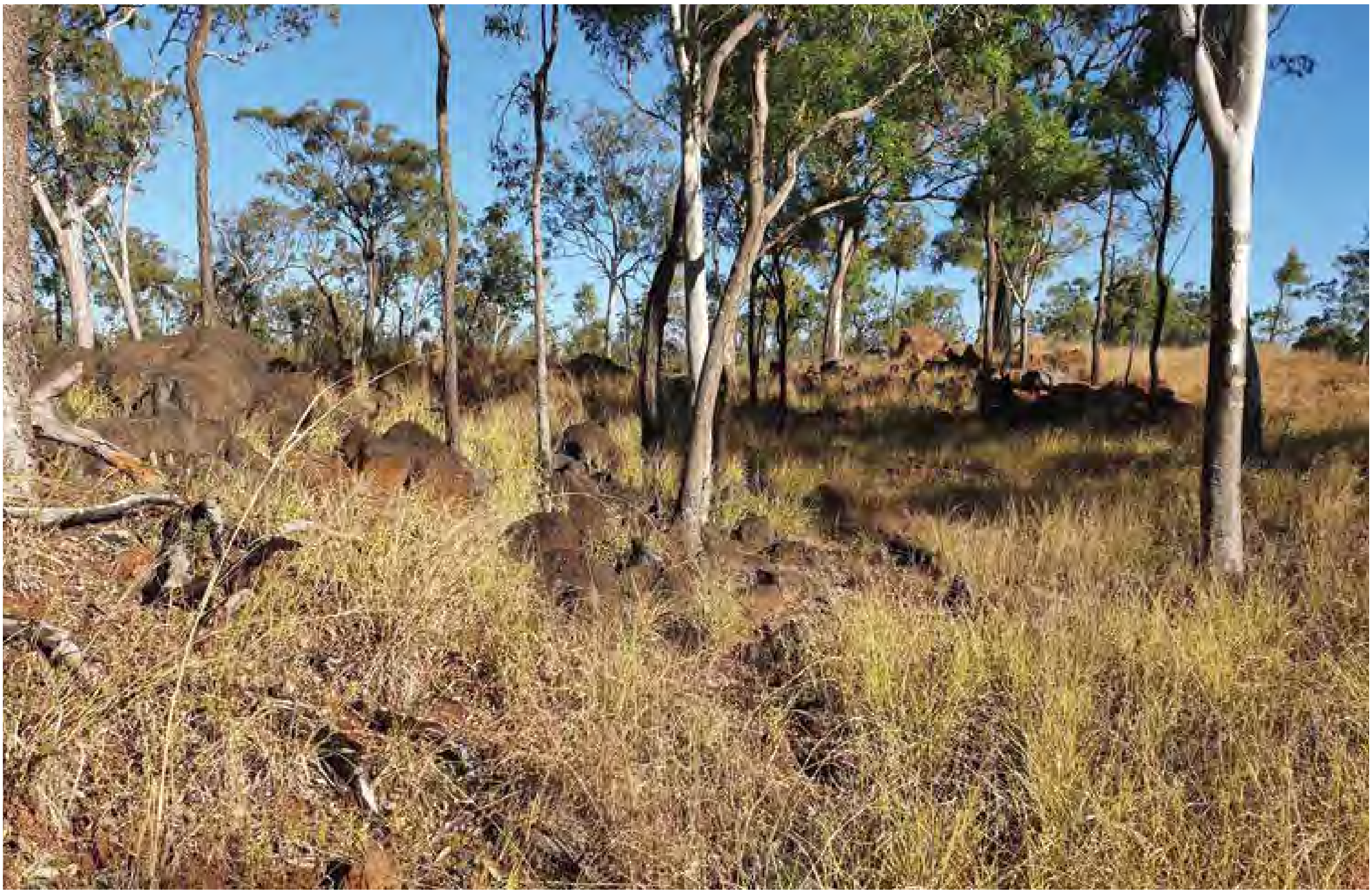
SOIL FERTILITY: BORN OF EARTH & SKY

Most nutrient elements in a soil come from its minerals. Different soils contain different types of minerals. The term we use for the type and amount of different minerals in a soil is mineral composition.

The term we use to describe the level of nutrient elements in a soil is soil fertility. Some soils contain more nutrients than others because their mineral composition contains relatively higher levels of macro-nutrient elements like calcium, phosphorus and sulphur and micro-nutrients such as zinc and copper.

Low fertility soils contain minerals that are relatively low in nutrient elements. Low fertility soils are often high in minerals containing aluminum, iron and silicon. This is due to the mineral composition of these soil types. They often have high levels of quartz minerals in them. In the tropics some soil types have high levels of iron oxides. So the geological origin, the rocks, that formed your soil's minerals determine your soil's mineral composition.

Overall soil fertility varies widely across tropical soil types. For example, tropical soils that form from granite rocks tend to have quite low levels of nutrients because of the way the granite rocks formed. Granite rock is dominated by quartz, a mineral which does not contain many nutrient elements. Granite-based soils tend to have low levels of soil fertility. Soils that have formed on geologically young basalt type rocks often contain much higher levels of nutrient elements because the minerals in basalt are often high in nutrient elements such as calcium, potassium and trace elements. However, there is also variation in basalt soil types due to a range of geological factors.



Basalt country in North Queensland. Derived from volcanic minerals these soils can have very high levels of many nutrients. The phosphorus levels in these soils are amongst the highest in Australia.

On coastal and inland flood plains soil fertility between soil types can vary widely as the process of floods and river movements over time mixes soil minerals greatly. The table below compares the total fertility levels in some tropical soils across northern Australia.

ESTIMATED TOTAL NUTRIENT LEVELS IN VARIOUS TROPICAL AUSTRALIAN SOILS

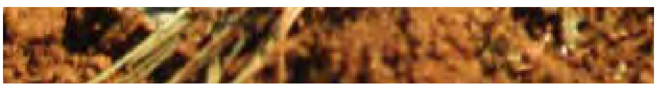
		1	2	3	4	5	6	7	
Nutrient	**Symbol**	Katherine NT Dry Topics	Dimbulah Qld Dry Tropics	Palmerston Qld Wet Tropics	Mirriwinni Qld Wet Tropics	Collinsville Qld Dry Tropics	Hughenden Qld Dry Tropics	Woopen Creek Qld Wet Tropics	**General Range**
Calcium	**Ca**	182	263	153	85	1272	52 613	1400	50 - 50 000
Magnesium	**Mg**	52	250	314	115	620	3095	1912	100 - 50 000
Potassium	**K**	81	836	Under 50	379	313	1607	1565	50 - 2000
Sodium	**Na**	Under 50	137	Under 50	Under 50	150	85	87	50 - 500
Sulphur	**S**	Under 50	65	663	173	63	120	337	50 - 1000
Phosphorus	**P**	Under 50	132	2301	147	74	325	856	50 - 2500
Zinc	**Zn**	1.3	5	75	8	16	180	85	5 - 50
Manganese	**Mn**	99	194	1567	111	237	411	1013	50 - 2000
Iron	**Fe**	6571	15 944	183 389	29 523	7197	14 387	35 615	2500 - 200 000
Copper	**Cu**	1.7	8.5	63	4.8	4.7	62	29	1 - 50
Boron	**B**	Under 2	Under 2	Under 2	Under 2	Under 2	2.1	3	1 - 50
Silicon	**Si**	916	2579	538	556	1047	702	1080	500 - 3000
Aluminium	**Al**	2329	6569	104 617	6349	4358	15 503	37 832	2000 - 150 000

Soil tests taken from soils across the tropics of Australia. Results provided by EAL, Southern Cross University NSW. All results are from a NATA and ASPAC accredited lab. All measurements are in parts per million (ppm). Sample depth 0-10cm. Nitric Acid Digest Test.

A further factor that influences the fertility of tropical soils is the high rainfall and temperatures. In the Wet Tropics these factors drive the high rate of weathering of soil minerals. This in turn leads to more nutrient elements being dissolved and then leached out of soils into streams and creeks. Eventually these nutrients make their way to the sea. Hence, intense weathering is another factor leading to low fertility levels in some tropical soils.

Although most nutrient elements in a soil come from its minerals, one essential element, nitrogen, does not. Nitrogen is a gaseous element meaning that it exists mainly in the earth's atmosphere. Nearly 80% of our atmosphere is made up of nitrogen. We breathe nitrogen in and out with every breath we take. The nitrogen content in a soil comes from the air. It is converted from a gas into a biological form in the soil mainly by specialised bacteria that have evolved the ability to "fix" nitrogen from the air. So the level of nitrogen fertility in a tropical soil depends mostly upon the biological activity and organic matter levels in a soil rather than its mineral composition.

The root systems of legumes have small nodules that contain specialised bacteria living in partnership with the plant. These bacteria fix nitrogen from the soil air, making it available to plants.



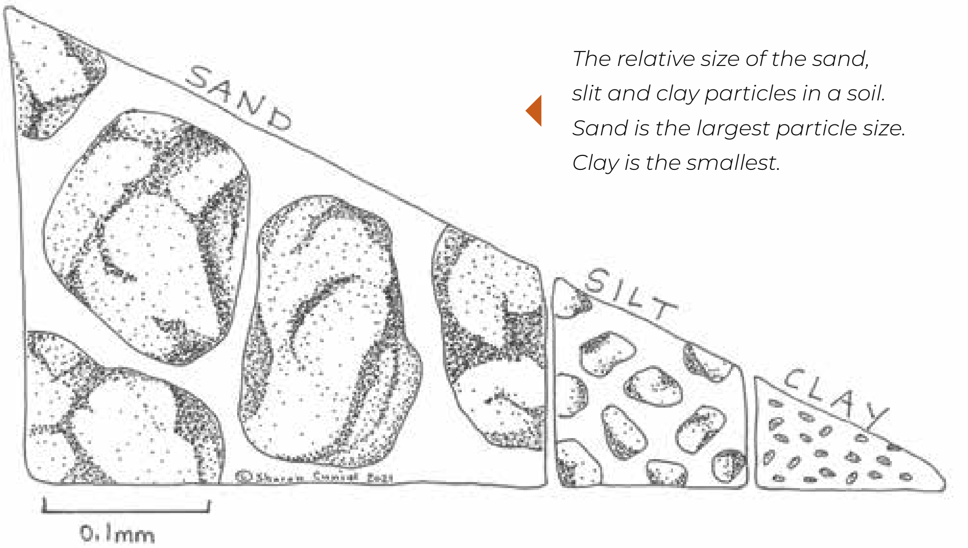
Although soil fertility is a very important part of a soil's type, having a soil with low fertility does not mean it cannot support a productive and profitable farm business. Many successful tropical agricultural enterprises are run on low fertility soil types. It is important that as a farm manager you understand your soil's type. That way you can manage it for the best outcome.

This mango orchard near Katherine in the Northern Territory is on highly weathered soil. Despite being low in nutrient elements this orchard is productive and supports a profitable farm business.

SOIL TEXTURE: THE FEEL OF A SOIL

As soil minerals weather through time, not only do they supply nutrient elements, they also break down physically into different sized particles. The three main particles in a soil are *sand*, *silt* and *clay*.

The proportion of these different particle sizes in a soil depends strongly on its mineral composition. Some soils consist of mainly sand particles. Others are dominated by clay particles. Soil ***texture*** is the term we use to describe the proportion of sand, slit and clay any soil contains. Just like soil fertility, a soil's texture strongly depends upon the type of rock that its minerals are formed from. Different rock types weather into different proportions of sand, silt and clay.



The relative size of the sand, slit and clay particles in a soil. Sand is the largest particle size. Clay is the smallest.

A soil with a clay texture near Bowen in Queensland.

A soil sample will have either a gritty, silky or smooth feel depending on how much sand, silt or clay it contains.

SAND is the largest particle in a soil. A soil containing a large portion of sand grains will have a coarse, gritty feel when held in your hand. The soil texture of soils high in sand is said to be ***sandy***.

SILT particles are smaller than sand and give a soil a silky or greasy feel. The texture of a soil with a high proportion of silt in it is said to be ***loamy***.

CLAY is the smallest particle in a soil. Clay particles also give a soil a smooth feel. A soil with a high proportion of clay in it is described as a clay soil. Soils with a high clay content are sometimes called ***heavy*** soils.

Across the tropics there is a wide range of soil textures depending on the underlying geology. An example of clay soils is the cracking clay soils of the Mitchell Grass Downs country of north-western Queensland. Many floodplain soils across the north have a loamy texture and there are many areas of the tropical north where sandy, coarse textured soils occur.

Texture strongly influences some important soil properties including soil structure, water infiltration, water holding capacity and the ease with which a soil can be tilled. The texture of a soil does not readily change as it is an inherited property, coming mainly from a soil's minerals. Soil texture can be assessed quite easily in the paddock using the "***ribbon test***". The main classes of soil textures are listed in the table below, along with the amount of clay they contain.

*Assessing soil texture can be done quite easily in the paddock by using the "**ribbon test**" to assess the clay content of the soil.*

Another way that soil texture is described is through the soil texture triangle. This triangle visually shows the different soil texture categories based on how much sand, silt and clay they contain.

SOIL COLLOIDS: THE HIDDEN CHARGE IN A SOIL

What are soil colloids? As soil minerals break down they create different physical particles in a soil including sand, silt and clay. The amount of clay in a soil not only influences its texture. Clays are unique in that they have special properties that also influence a soil's chemistry and physical structure.

Clay particles are tiny, about five microns or less in size. Compare this to most bacteria which normally do not get much bigger than about one or two microns. Another unique property of most clays is that they have a huge surface area to their mass.

These two aspects of clay: being tiny and having a large surface area, mean they behave in special ways compared to the other particles in a soil. In chemistry super-small particles that have a large surface area to their mass are known as ***colloids***. Colloids are unique in that they often have an ***electrostatic charge*** on their surface. Because of this charge on their surface, colloids have special properties. One thing colloids do is stay in suspension when they are mixed in water.

Think of milk: it is a suspension of fat colloids in water. Or a muddy dam: the water in the dam is full of clay that is in suspension in the water. Each clay particle has an electrostatic charge around it.

The clay in soils, being a type of colloid, gives your soil an electrostatic charge. In soils this electrostatic charge of clay is crucial. In soils this charge is usually negative and is on the surface of each clay particle.

Soils with a large proportion of clay tend to have a large charge compared to soils with a small amount of clay in them. Some types of clay minerals naturally have a large charge while others do not carry much electrostatic charge at all.

This soil near Katherine has a tiny colloid size. Applying small amounts of fertiliser frequently is the best approach to using these soil types.

The size of a soil's colloid is not only influenced by the amount and type of clay it contains. The size of a soil's colloid is also determined by its organic matter. Humus is a type of stable soil organic matter that is also a colloid. It also contributes to the colloid of the soil system. As humus levels in the soil increase, so do the colloids in a soil.

These two soils are less than half a metre apart but under different management. The soil on the right is mulched regularly for vanilla production. A very thick humus layer has developed. The soil on the left is the grassy inter-row between the vanilla beds. It is mowed regularly. The high humus soil has a much larger colloid because of the increase in humus.

Finally a soil's colloid size can also be influenced by its pH. In some soils that are acidic, the soil colloid size increases as the pH goes up towards neutral. This is due to charge changes on the colloid surface of some soil types as their pH changes.

THE SOIL COLLOID EQUATION

The size of the colloid in any soil is the sum of these three main factors: its clay content and type; the amount of humus in the soil, which is influenced by management; and the soil's pH. Your management can change a soil's colloid to a certain extent. Increasing soil humus content will usually increase it. In some soils, lifting the pH will also increase it somewhat.

The term used to describe the colloidal size in a soil is ***cation exchange capacity*** or ***CEC***. This measures the charge of a soil's colloid surfaces. This charge attracts positively charged soil nutrient elements at their surface. The CEC is measured as part of a soil test done by a laboratory. It describes the capacity of a soil to hold and exchange these positively charged nutrients elements, called cations, that are in a soil.

The CEC measurement is standard on most agricultural soil tests.

The CEC is usually measured as centimoles per kilogram (cmol/kg) of soil. A large CEC soil is not better than a small CEC soil, just different. However, it is important to know your soil's CEC as the size of a soil's charge will influence how to manage it effectively, especially if you are using soil amendments and fertilisers.

ESTIMATED CEC OF VARIOUS TROPICAL AUSTRALIAN SOILS

	1	2	3	4	5	6	7	
	Katherine NT Dry Topics	Dimbulah Qld Dry Tropics	Palmerston Qld Wet Tropics	Mirriwinni Qld Wet Tropics	Collinsville Qld Dry Tropics	Hughenden Qld Dry Tropics	Woopen Creek Qld Wet Tropics	General Range
CEC	1.1	2.5	1.3	2.4	5.6	41	34.6	1 to 60

Soil tests taken from soils across the tropics of Australia. Results provided by EAL, Southern Cross University NSW. All results are from a NATA and ASPAC accredited lab. All measurements are effective CEC in cmol/kg (ppm). Sample depth 0-10cm. Ammonium Acetate Extract.

WHY THE SOIL COLLOID IS IMPORTANT

A soil's CEC is a really important part of the soil system for three key reasons.

1. Nutrient Cycling

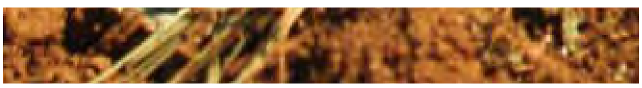
The CEC is a highly active part of the soil where positively charged nutrient elements (***cations***) are held in a stable and yet available form for plants. All soils have a range of cation elements actively exchanging with the colloids in the soil. The most important cations attached to the colloid in soils are calcium, magnesium, potassium, sodium, hydrogen and aluminum.

These positively charged nutrients are attached to the negative charge on the surface of the soil colloid. Held in place, these cations are not readily leached out of the soil but can be replaced by other cations. In this form these nutrients are said to be ***exchangeable***. The CEC is sometimes described as a soil's active "pantry", or "bucket", of nutrients. Nutrient elements held on the colloid can be exchanged or taken up by plant roots. This nutrient exchange process is termed ***cation exchange***.

Not all nutrient elements have a positive charge so only some nutrients, the cations, hang out on the soil colloid. Cations such as potassium, magnesium and calcium can be held on the soil colloid in an exchangeable form when applied as fertilisers. It is important to note that a soil's colloid is not the only important bucket of active nutrients in a soil. A soil's organic matter, the soil minerals, the root biomass and the soil solution are other important parts of the nutrient cycling story in every soil.

2. Chemical Buffering

Because the soil colloid is very active chemically it strongly influences the chemical stability of a soil system. The colloid acts as a stabiliser in a soil, helping to maintain chemical balance in a soil through a process called ***buffering***. The larger a soil's CEC, the more buffering capacity it has. Even soils with a small CEC, usually sandy textured soils, can maintain more chemical stability if they have enough humus to maintain adequate relative buffering capacity for their soil type.



Tropical soils with a light, sandy texture tend to have a low buffering capacity. The best management approach with these soils is to use moderate rates of soil amendments and to apply small rates of soluble fertilisers frequently. They usually respond positively to additions of compost or mill mud.

3. Soil Health

In some situations, the soil colloid can be chemically out of balance due to the proportion of different cations on the colloid. This can lead to poor functioning of the soil. In the Wet Tropics, for example, acidity, high exchangeable aluminium and low calcium on the soil colloid is a common problem in some soils. Fixing this issue requires applying lime or preferably a lime blend with magnesium, depending upon the soil test. How much lime is required depends upon the size of a soil's colloid. The size of a soil's colloid determines how easily it can be modified when you are trying to re-balance it. The larger its buffering capacity the more effort it requires to change its chemical balance.

This coastal sugar cane paddock is being limed to help manage exchangeable aluminium and soil acidity. Both of these soil health issues can limit sugar cane yields.

SOIL COLOUR: THE PALETTE OF SOIL MINERALS

One of the first things you notice when you look at a soil is its colour. There is a wide range of soil colours across the tropics of Australia, from bright red soils to light coloured yellow and white soils through to dark brown, chocolate coloured soils.

The reason different soils have a different colour is often due to their different mineral compositions. However the level of oxygen in a soil, the amount of soil organic matter and the moisture content of a soil also influence its colour.

When it comes to minerals the amount and type of iron minerals in a soil play a large role in shaping soil colour. Soils high in iron, especially where the iron minerals have reacted with oxygen, lead to soils with intense, bright red and brown colours. In situations where the iron minerals in a soil are exposed to low levels of oxygen through previous water-logging, the minerals may be a lighter orange or grey colour.

Other types of minerals also contribute to a soil's colour. Another common mineral in soils is quartz which has a light colour. So soils formed from minerals high in quartz minerals tend to be light grey coloured. Many granite-derived soils are in this category. Other minerals in soils such as those coming from igneous lava flows can give a soil dark brown colours.

The colours of minerals in soils are further influenced by soil organic matter. Humus, the stable, long term form of organic matter, is dark brown to black in colour. Think of a finished compost. It contains high levels of humus. In situations where humus is high in the soil, it will darken the colour of the soil. You can sometimes determine how deep a topsoil is looking at the depth of this darker layer when you dig into a soil.

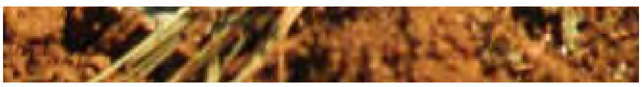
This soil from the Atherton Tablelands of North Queensland is derived from volcanic minerals that are high in iron giving it a rich brown colour.

This sandy orchard soil has a dark brown humus layer on the surface because of regular mulching. The lighter grey colour of the soil minerals can be seen in the lower layer of the sample.

The distinct colouring of calcium deposits can be seen at the bottom of this soil pit.

Finally, the colour of a soil is influenced by the weathering effect of tropical rainfall and temperature. These can transform soil minerals, changing their colour. In areas of high and intense annual rainfall, the rate of weathering will rapidly dissolve and weather minerals that are easily broken down. Once these minerals have been dissolved and weathered away, all that remains are the more resistant minerals like iron or silicate minerals. These resistant minerals are the main reason for the strong colours in many tropical soils.

In some Dry Tropics regions where rainfall is not so intense or only falls seasonally, the dissolution and leaching process is not so strong as in the Wet Tropics. In these areas, in some soil types, you get patches of white or off-white minerals forming where there is an accumulation of certain minerals like calcium carbonate (lime) or calcium sulphate (gypsum) in the soil. In higher rainfall areas these minerals would be completely leached from the soil but in areas of the Dry Tropics the strength of leaching is not so strong. These minerals often remain in a landscape, lower in the soil profile, leaving distinctive white zones.



SOIL HEALTH: A SOIL IN GOOD CONDITION

No matter what type of soil you are managing it needs to be kept in working order if you are to successfully grow pastures, crops or trees. Because plants completely depend on the soil they grow in for nutrients, water and health, it needs to be functioning well for plants to thrive. The term we use for a soil in good condition is ***soil health***.

A handful of healthy orchard soil in the tropics. If you look carefully, you can see mulch, plant feeder roots, fungi breaking down the mulch and the castings of earthworms.

Soil health describes the state of a soil system. It includes a soil's physical, chemical and biological aspects along with how it is functioning. Healthy soils help make farming and grazing businesses more resilient, efficient and profitable in the long term. Well-managed soil leads to better agricultural productivity as well as improved water quality and healthy landscapes in the wider environment.

Soil health is not the same as ***soil fertility***, which refers to the level of nutrient elements in a soil. For example, a soil may have a high level of fertility, but it may be in poor health. When a soil is in poor condition, then plant roots cannot grow well and any nutrients in the soil will not be cycling or available for plant growth. There may also be soil-borne pests and diseases attacking plant roots. A soil with low fertility can support a productive and profitable farm enterprise if it is healthy and the right nutrient strategy is used. However, a highly fertile soil will be unproductive and unprofitable if it is unhealthy. Adding more nutrients will not make it more profitable.

So there are two key aspects to soil management: looking after your soil's health and managing its fertility, the soil nutrients. While the two are interconnected, in agriculture we often focus mainly on managing nutrients for our crops and pastures. A higher priority is to manage soil health well first; otherwise you will be wasting your nutrient dollars. Nutrients cannot be managed effectively if soil function is compromised.

Soil health is a fairly broad term, so we need to get specific about what a soil in good condition actually means. When a soil is healthy it has:

1. Good structure - so that plant roots and soil life can thrive and air and water can flow through the soil.

2. Adequate soil organic matter - this provides energy and nutrients for the soil community and helps maintain soil structure and function.

3. A balanced soil community - this balanced community of microbes, soil insects and plant roots self-organises to regulate pests and diseases, maintain soil structure and cycle nutrients efficiently.

4. Balanced soil chemistry - a healthy soil system maintains a balanced chemical state for important aspects including acidity and cation balances.

5. Low concentrations of toxic compounds such as aluminium, manganese and salt.

The soil health in this sugar cane paddock is being improved with cover crops. Increasing plant diversity by growing sunflowers has improved the diversity of beneficial fungi in the soil.

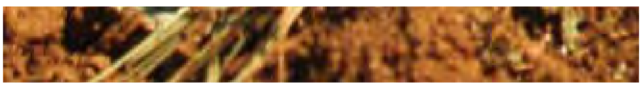
Some key functions occur in all soil systems. In healthy soils these functions occur at their optimum, enhancing agricultural production and maintaining a healthy environment:

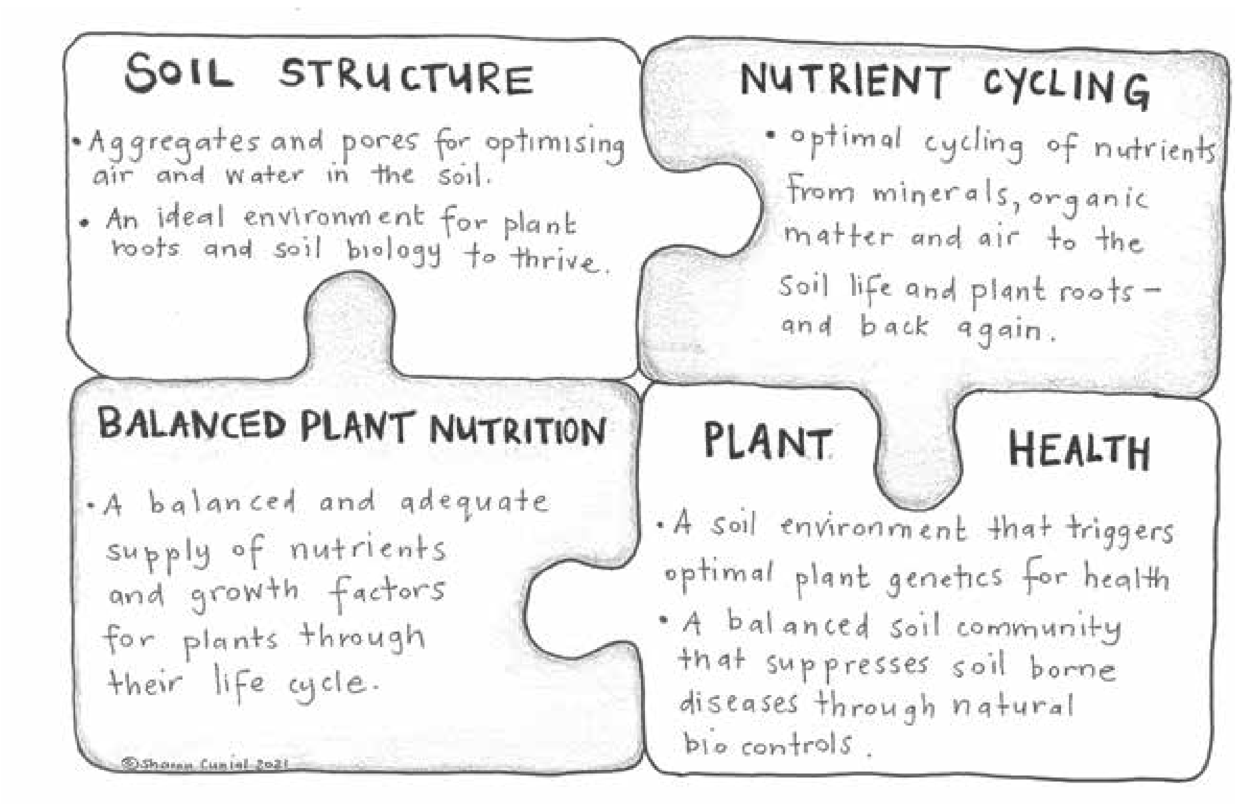
1. Nutrient cycling - nutrients cycle very efficiently in a healthy soil. Limited nutrients leak from the topsoil as the life in the soil and plants tightly exchange nutrients to reduce wastage.

2. Water cycling - rain falling on a healthy soil will easily enter the soil and be stored for plants and the soil community to use. Excessive water in a soil will drain away relatively quickly through the soil pores.

3. Energy flow - the plants growing in a healthy soil will be capturing energy through the process of photosynthesis. There will also be a balanced dynamic in the soil between how this energy is used by the soil system for respiration and for maintaining soil organic matter including humus.

4. Community dynamics - in a healthy soil the plants and soil community self-organise into a chemically, physically and biologically stable system within the constraints of the soil type, climate and vegetation. This leads to regulation of pests and diseases and good plant health.





When a soil is managed well and has achieved a high level of soil health then it results in important benefits for you as a farmer or grazier.

Ground cover is a key tactic to improving soil health. Keeping trash on sugar cane paddocks helps to keep these soils healthy by protecting the soil system from heat and erosion.

SOIL BIOLOGY: THE COMMUNITY OF SOIL LIFE

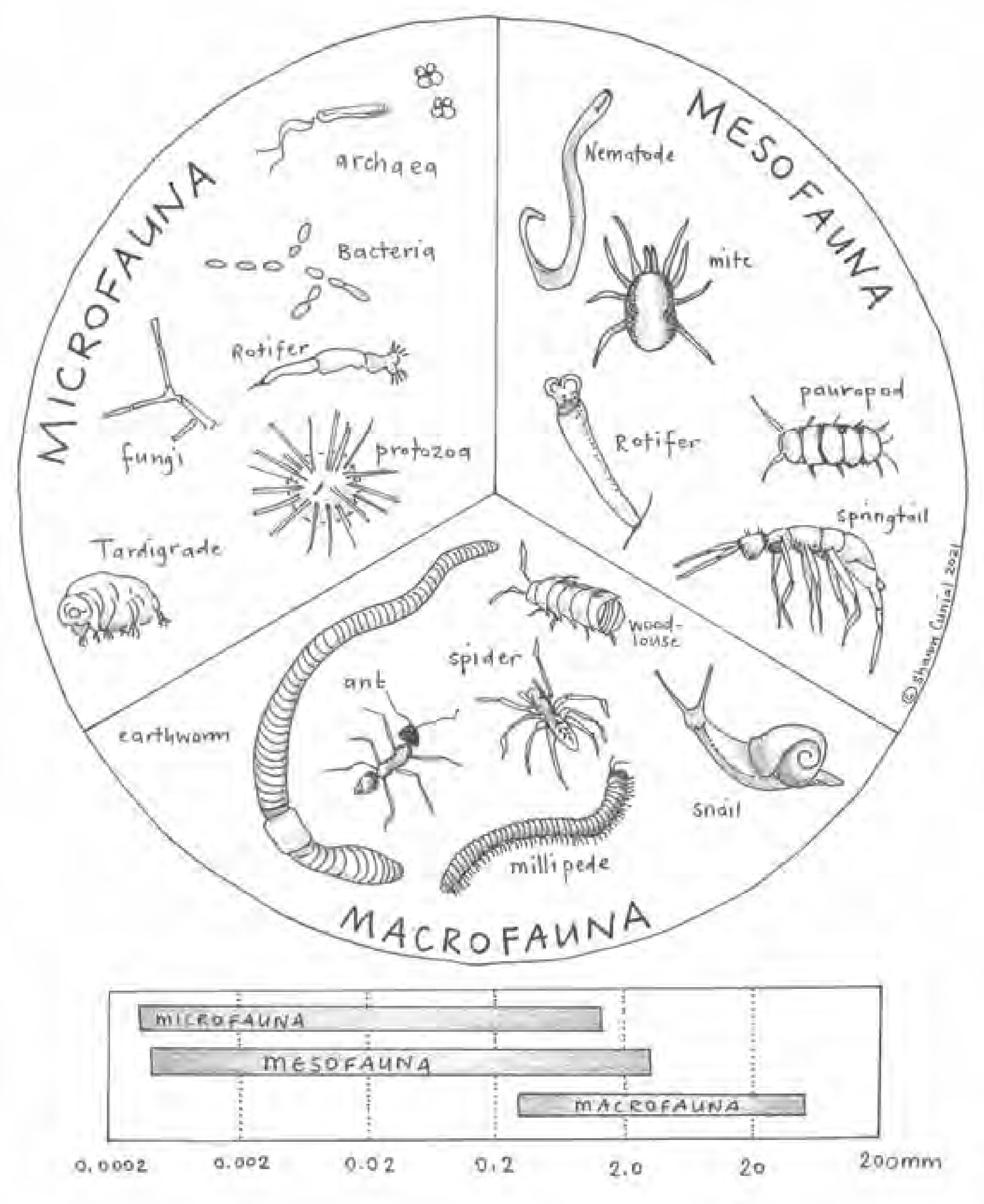
Who's who in the soil community? Soils are living systems and they contain one of the most diverse and complex biological communities of life on the planet. At the heart of this community is a profound relationship between plants and microorganisms that has evolved over millions of years.

In addition, through time, numerous other insects and organisms have joined this community. The diversity of soil life is the driving force that creates topsoil through the various functions of the soil community. We can think of the soil community as a network of relationships between different living things.

One way to look at the members of the soil community is by their size.

Apart from plants there are three main sizes of living things in a soil community:

- **Microfauna**
- **Mesofauna**
- **Macrofauna**



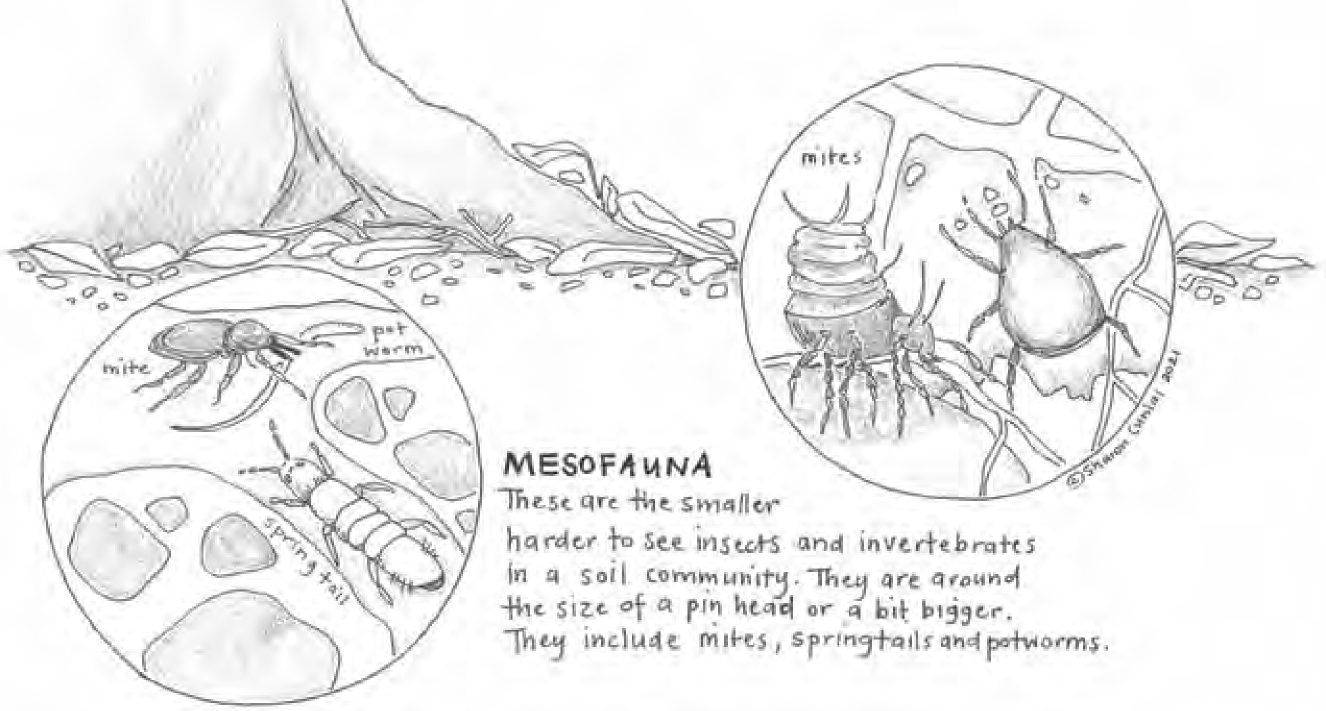
MICROFAUNA & FLORA

These are the microbes! They are the tiny members of the soil community that you cannot see with the naked eye. They include archaea, bacteria, fungi and protozoa. There are billions of bacteria in a handful of soil so the scale and size of the populations of microbes in a soil can be hard to digest. You need a microscope to see these guys.

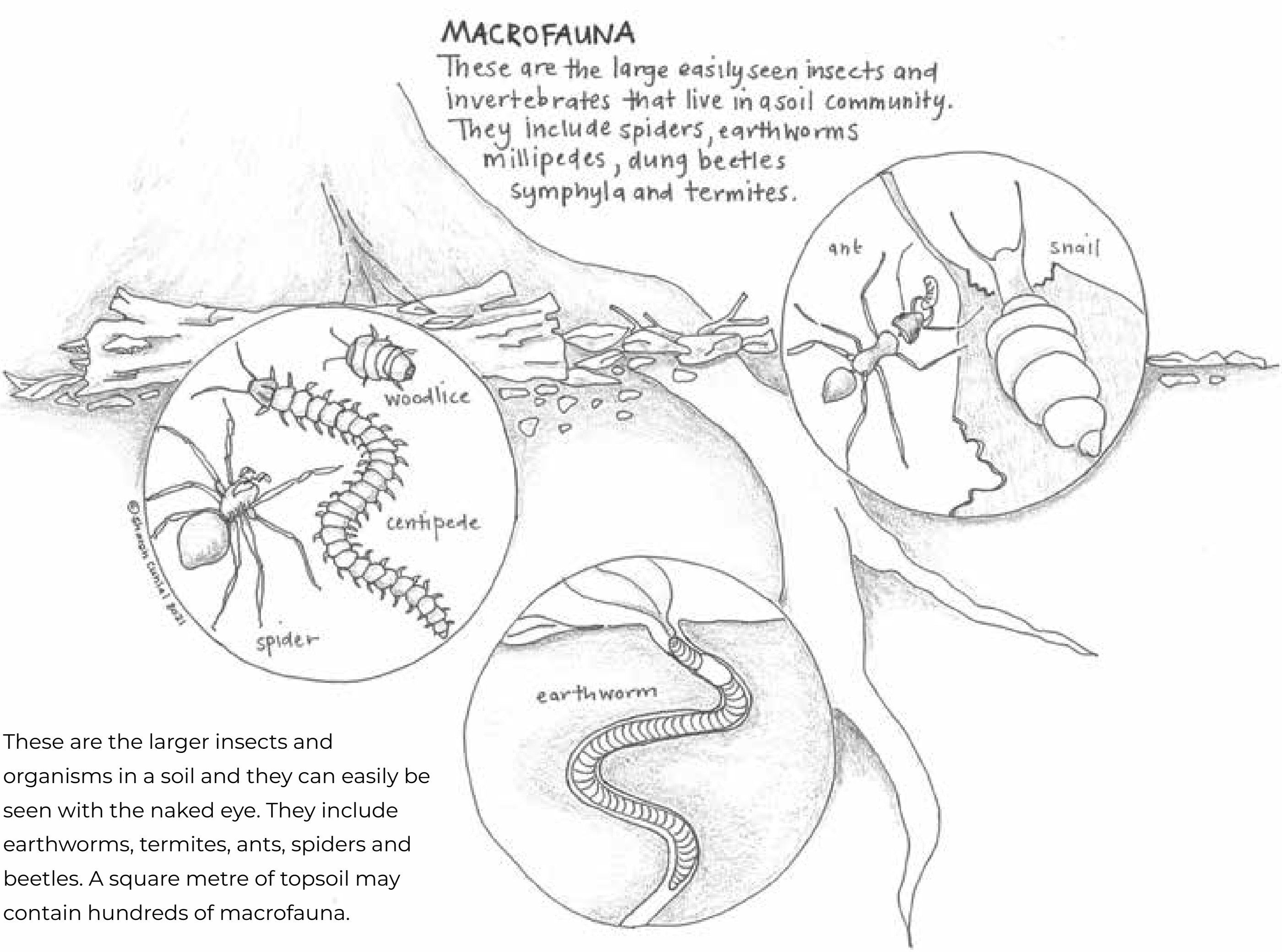
Soil microbes usually cannot be seen by the naked eye. You need a microscope to see them. Fungal hyphae, the white patches in this soil sample, however, can be seen as they feed on organic matter in this soil.

MESOFAUNA

These are medium-sized organisms in a soil. They include many small soil invertebrates including insects like spring tails and mites. They are fairly small and hard to see unless you look carefully. A square metre of topsoil may have thousands of mesofauna living in it.



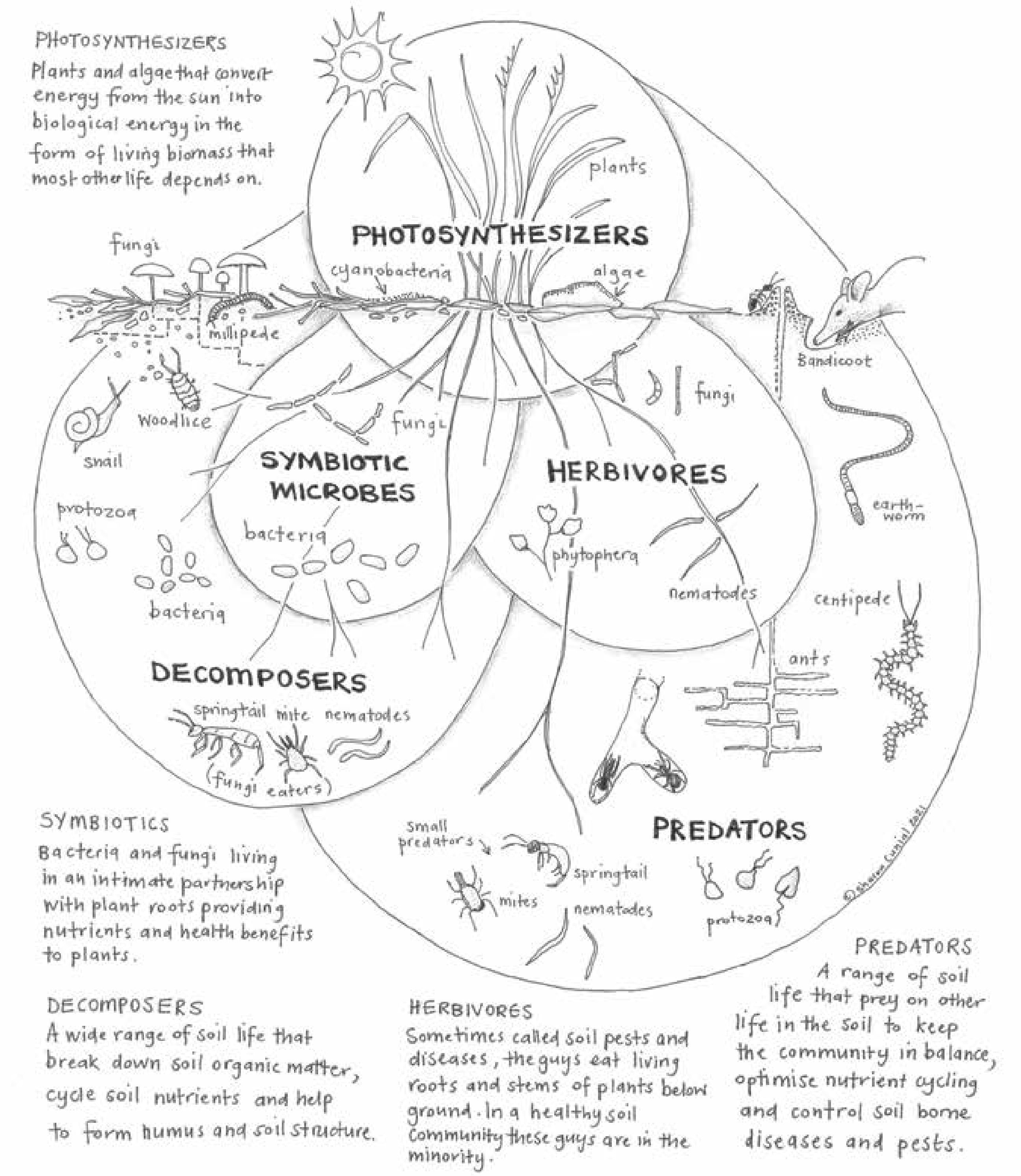
MACROFAUNA



These are the larger insects and organisms in a soil and they can easily be seen with the naked eye. They include earthworms, termites, ants, spiders and beetles. A square metre of topsoil may contain hundreds of macrofauna.

THE SOIL FOOD WEB

The community of life in a soil is sometimes called the ***soil food web***. This is another way to organise the different members of a soil community and the complex network of relationships between them. With the soil food web approach, the community are grouped according to what they do in a soil; the way they get their energy and nutrients. This way of sorting the soil community is called ***functional groups***.

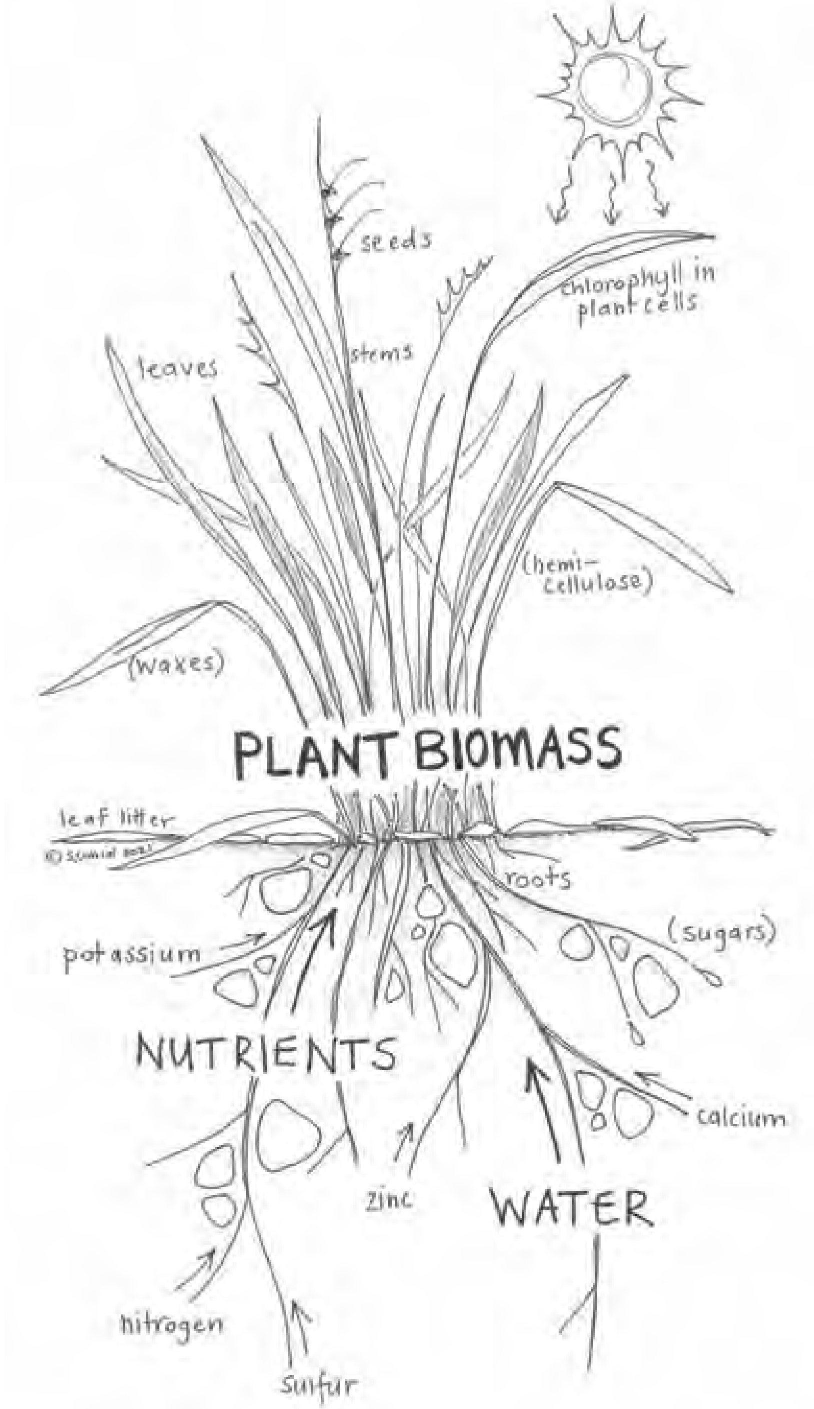


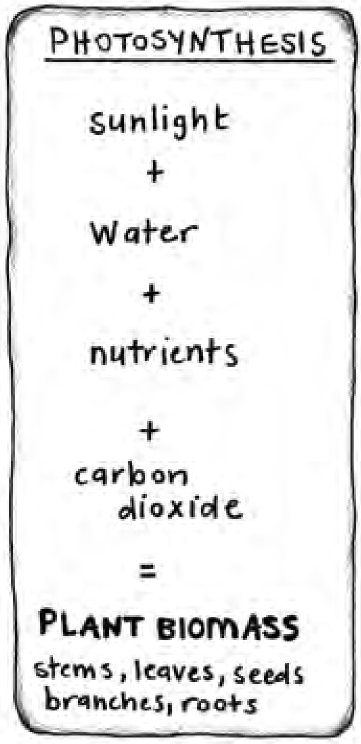
PHOTOSYNTHESISERS

These organisms, mainly plants, create their own energy through the process of ***photosynthesis***. Using the power of the sun they transform the carbon in the air, carbon dioxide gas, into ***carbohydrates***, like sugar and cellulose. Along with plants a few other organisms in the soil also photosynthesise. These include algae and specialised bacteria like cyanobacteria.

While growing, they also take up nutrients and water from the soil. Combining the water, nutrients and carbohydrates they create ***plant biomass*** which contains both carbohydrates (energy compounds made from carbon) and nutrients. Importantly, a lot of this biomass exists under the ground as the roots of growing plants. These roots are alive and fill a critical role in the soil community.

Over time, as plants and these other photosynthesisers live and die, this biomass becomes ***soil organic matter***. While plants are alive they also contribute biomass to the soil organic matter by dropping leaves and stems. Underground they also continually exude sugars from living roots and shed dead roots into the soil system as they grow.





The main photosynthesising organisms in the soil are plants and their roots. They constantly supply organic matter to soils both above ground and below ground through their root systems.

SYMBIOTIC MICROBES

Many bacteria and fungi live in a close, win-win relationship with plant roots. A win-win relationship between two different living things is called ***symbiosis***. In this relationship plants depend on the symbiotic microbes for nutrient supply and disease control. In return the microbes depend on plants to supply them with energy in the form of sugars. This relationship is one of the most important on Earth and has been going on for over 400 million years.

In tropical soils these symbiotic microbes include specialised bacteria called ***rhizobia*** that live in the roots of legume plants. They fix nitrogen from the air and supply this to the plant. Another important symbiotic microbe is the mycorrhizal fungi who partner with the roots of many plants, supplying phosphorus and calcium to their plant partner in return for energy.

The symbiotic bacteria that help legume plants gain nitrogen live in nodules on the surface of the roots.

DECOMPOSERS

Most living things in a soil community survive by decomposing the ***soil organic matter*** provided to the soil by plants as they grow. This includes plant litter on the soil surface as well as dead roots given off by plants underground. Organic matter contains energy and nutrients, so it's a food source for much of life in the soil. Different types of organic matter are broken down by different decomposers in the soil community.

Some organic matter, like bark and stems, is woody and is broken down slowly by fungi living in the soil. Some soil insects like beetles and millipedes also eat woody material, shredding it down into smaller pieces. Other types of soil organic matter, including simple sugars, root exudates and fresh green leaves, are much softer and more easily broken down and usually decomposed quite quickly by bacteria and yeasts.

Many other, larger soil organisms like some insect larvae, spring tails, earthworms and millipedes also help decompose organic matter in a soil. Some live on the surface and others live underground. Without active decomposers in a soil, the organic matter levels will build up over time creating a high organic matter soil. This is how peat soil is created.

Earthworms are one of the most important decomposers in many soils, especially the Wet Tropics. In inland Dry Tropic areas, ants and termites play a similar role in cycling organic matter through the topsoil.

SOIL PREDATORS

A soil community also contains plenty of organisms which prey on the other life in the soil. These can be microscopic protozoa grazing on the billions of bacteria in the root zone, mites preying on other mites, or spiders which consume smaller soil insects. Some soil predators play a crucial role in controlling the populations of soil pests and diseases. Many predatory soil nematodes, for example, eat root-feeding nematodes, keeping their numbers in check and minimising damage to crops. From their role consuming other soil life, soil predators are essential for regulating the soil and keeping a balance in the soil community.

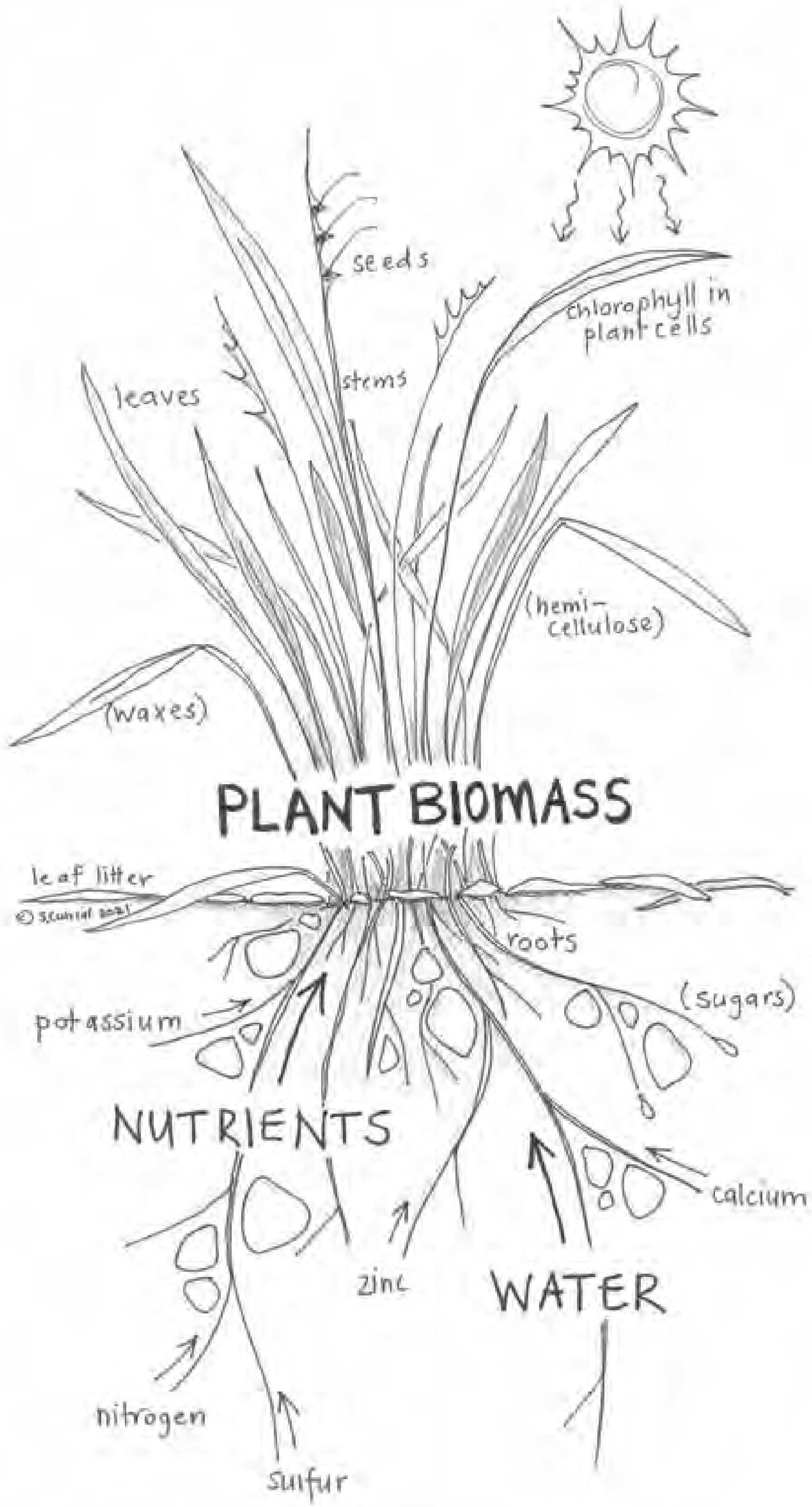
SOIL HERBIVORES

There are some members of the soil community which eat living plant roots to sustain themselves. We often call these soil-borne pests and diseases. Soil microbes that consume living plant roots include bacteria and fungi which infect plant roots in order to obtain their food. One well-known tropical soil-borne disease is phytophthora, a fungus that attacks tree roots and can be a real problem in North Queensland avocado orchards. Other soil organisms that eat living plant roots in tropical soils include nematodes and symphyla, soil invertebrates which can damage sugar cane roots causing major yield losses for the sugar industry.

Root rot in lychee trees near Mareeba, Queensland. In an unbalanced soil community root-feeding pests and diseases can cause great damage to crops and pastures. In a healthy soil with a diverse, balanced biological community, they are usually not as damaging. A wide range of soil predators help to keep their number in check, acting as a biocontrol.

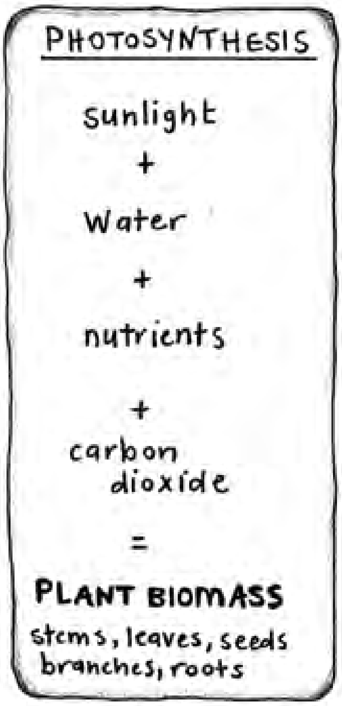
SOIL ORGANIC MATTER: THE HEART OF A HEALTHY SOIL

Where does soil organic matter come from? Soil organic matter is one of the most important parts of a soil system. Without it a soil cannot function in a balanced way.



The origin of soil organic matter in soils is the plants that grow in them. Plants grow through ***photosynthesis***. During this process they convert the carbon from the air to various carbon-based compounds. We call these compounds ***carbohydrates***.

As they grow, plants also take up nutrients and water through their roots. Combining these nutrients with carbohydrates, plants grow, creating ***plant biomass***, both above ground in the form of leaves, stems, branches and seeds, and below the ground, in the form of plant roots. The types of biomass plants create include sugars, cellulose, hemi-cellulose, waxes and fats and lignin. All of these carbon-based compounds make up different parts of plant biomass. Importantly, the nutrients that plants have taken up from their roots, both macro and micro-nutrients, also form part of plant biomass. These have been combined with the carbohydrates by the plant as it is growing.



It is plant biomass that forms the basis for all soil organic matter. Over time, as plants grow and die, some of their biomass enters the soil. Once this plant biomass has entered the soil system we call it ***soil organic matter***. On the surface plants drop leaves and branches to the soil surface. These become part of the ***litter layer*** on the top of a soil. Meanwhile, underground, plants continually exude sugars from living roots and also shed dead roots off into the soil. All of these processes contribute organic matter to the soil system, both on the surface and underground.

In this tropical fruit orchard near Tully the soil is covered in a large amount of biomass that has been created by the plants as they grow. This includes fallen leaves, stems and pruned branches. The roots of all these plants are also supplying the soil with biomass under the ground.

What happens to soil organic matter?

Most plant biomass that becomes soil organic matter gets broken down. This process is called ***decomposition***. Soil organic matter is decomposed by the wide range of life in the soil including bacteria, fungi, soil insects and earthworms. In simple terms, you can think about two main types of un-decomposed soil organic matter: ***greens***, which are the simpler types of material like sugars excreted from plant roots and fresh green leaf material; and ***browns***, which are the more woody fractions of organic matter like dry grass stems and bark from trees. The ***greens*** fraction tends to be broken down quite quickly by soil decomposers like bacteria; the ***browns*** are broken down more slowly, often with soil fungi doing most of the decomposing work. The living and dead remains of soil organisms like worms and beetles, plants and plant roots and the microorganisms also form part of a soil's organic matter.

Cane trash is a key supply of organic matter to cane fields. This materials is usually broken down quite quickly by soil organisms when conditions are moist and warm.

Three essential soil processes happen as soil organic matter breaks down:

NUTRIENT CYCLING

As soil organic matter breaks down, the nutrients in it get cycled. The decomposers in the soil eat the organic matter. In turn they get eaten by soil predators which end up being eaten by larger soil predators. In the soil everything is continually eating either organic matter or each other! At each stage of this process nutrients are excreted into the soil to be taken up by plants or the other life in the soil. This release of nutrients from soil organic matter as it breaks down is called mineralisation and it is one of the key pathways that nutrients cycle through in a soil.

RESPIRATION

The different soil microbes and soil organisms break down organic matter in the soil for energy. Organic matter contains both the energy and nutrients they need to live. Just like us, they need to breathe. For most life in the soil breathing means taking in oxygen and breathing out carbon dioxide. As all the life in the soil is busy decomposing organic matter, much of the carbon that was in that soil organic matter, is breathed back into the air by the soil life through the process of ***respiration***. This is why a pile of leaves in a compost heap tends to shrink as it decomposes. Most of the carbon contained in the pile has been respired as carbon dioxide back into the air. Loss of carbon through respiration is a natural process and explains why it is hard to build up carbon in soil. The breakdown process results in most of the carbon from the organic matter going back into the air as a gas through respiration!

HUMUS FORMATION

Not all of the carbon in a soil's organic matter gets lost to the air through respiration as the material decomposes. Instead some fractions of the decomposing organic material transform into a stable substance and remain in the soil. This stable organic matter is known as ***humus***. Humus is a dark coloured material (think of the colour of compost) and it can form in a soil through different decomposition pathways including by fungal activity on lignin and in the castings of earthworms.

In forest soils a large portion of the soil's organic matter comes from woody material such as leaves and twigs falling to the soil surface from the trees. In the shady, cool and moist environment much of this material can form into humus as it is broken down by fungi and insects. The result is often a distinct layer of dark humus near the surface of a forest soil.

The soil under limes trees near Dimbulah, Queensland. Note the mulch layer on top and the thick humus layer that has developed underneath the mulch. The humus layer is developing down to around 20cm in places. This layer is full of the feeder roots of the lime trees. A similar pattern of soil forms in a forest as the thick layer of litter breaks down.

In pastures or grasslands, humus forms due to the breakdown of the fibrous root biomass of the grasses under the ground. Grassland soils often do not have a distinct "humus layer" in them though they may contain very high levels of humus evenly mixed throughout the top 20-30cm of the soil. The minerals and soil organic matter humus are uniformly mixed together in a grassland topsoil rather than forming layers.

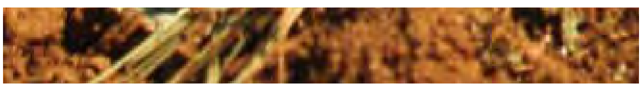
Soils under the influence of grassy vegetation tend not to have distinct layers of organic matter. The humus is more evenly mixed through the topsoil. In this healthy pasture soil the roots, organic matter and soil minerals are thoroughly mixed. It is hard to separate them.

Why soil organic matter is important

Organic matter is a vital part of a soil system. The stable organic matter, humus, improves key aspects of any soil, including its water holding capacity, its structure and its ability to hold onto nutrients. The organic matter that breaks down quickly is also important. As it breaks down, nutrients are released into forms available for plants to take up. This actively decomposing organic matter, known as labile carbon, drives nutrient cycling in soil.

It is important to have enough organic matter in a soil to ensure it stays healthy. It is also important that the soil organic matter is of good quality. A soil can have lots of organic matter in it but if the organic matter is of poor quality then it will not decompose and cycle nutrients very effectively. It may also not maintain humus levels. A soil's organic matter needs to have a good balance of greens and browns.

One way to assess the quality of soil organic matter is to look at its balance of carbon to nitrogen. If the organic matter is high in carbon but low in nitrogen then it will not break down very quickly. On the other hand the organic matter in soils with high levels of nitrogen will break down very quickly. A good balance of carbon to nitrogen is required in soil organic matter to maintain a healthy soil system.



SOIL STRUCTURE: THE BRICKS, MORTAR & WINDOWS

Soil structure: aggregates and pores. Soils physically consist of different sized structures made from soil minerals, organic matter, microbes and fine plant roots arranged together.

These structures are called ***soil aggregates***, or soil crumbs. "Peds" is another term you may hear when talking about soil structure. In between the aggregates in the soil are spaces. These spaces are known as ***soil pores***.

When a soil system is in balance then it naturally forms aggregates and pores. These are the two components of ***soil structure***. The arrangement and size of aggregates and pores in a soil results in different soils having different types of ***soil structure***. As soil aggregates combine, a soil will form clumps. Other terms used to describe soil structure include porosity, tilth and the friability of a soil.

A well structured clump of soil made up of soil aggregates combined together. You can see large pores in this soil that have been created by earthworms. You can also see the internal structure of the clump, the aggregates.

Soils develop aggregates and pores through different processes.

- **Soil microbes** and soil insects mix soil minerals and organic matter together as they go about their daily activities, decomposing organic matter, preying on each other and moving through the soil. Many microbes in the soil also create glue-like compounds that help bind soil aggregates together. Generally the more life there is in soil, the more soil aggregation can occur.
- **Plant roots** give off a range of compounds including sugars and gel-like substances called mucigel into the soil close to their roots. These substances help bind soil minerals and feed soil microbes. They also help drive soil aggregation. In a healthy soil, this soil building process happens at the surface of the dense network of fine roots and root hairs of a plant in the topsoil. The more plant root volume there is in a soil, the more soil aggregation can occur. Therefore, a key goal of soil management is to maximise the volume of roots in a soil.
- **Larger members of the soil community** including earthworms, ants, termites and dung beetles physically shift large amounts of soil as they move around. This is a crucial way that pores and channels are created in the soil. These members of the soil community are also called ***soil engineers*** because of their ability to maintain large pores in a soil.
- **A soil's clay content** contributes to soil structure. The clay in a soil assists with soil structure as the tiny clay particles can bind together with each other or in combination with soil organic matter to form aggregates. Some types of clays aggregate naturally without organic matter, keeping their structure even when they have low levels of organic matter. The high iron soils, known as Ferrosols, are an example of this. Other types of clays can be poor at aggregating due to their colloid properties. Finally the clays in some soil types shrink and swell when wet, and set hard when they are dry. This is often due to the high sodium or magnesium content within the clay minerals.

This spadeful of soil in a sugar cane paddock has a sandy texture. Note the large amount of loose soil material that is not well aggregated. There is not much clay to assist in the aggregation of this soil.

A well-structured soil has a mix of small and large aggregates. Small aggregates are less than 2mm, larger ones being over 5mm to 10mm. These aggregates are arranged in a jumbled fashion in and around each other forming larger clumps. Because of these different sized aggregates and clumps there are also different sized pores in the soil.

The tiny pores, known as ***micro-pores***, are the majority in the soil. The medium-sized pores in a soil are called ***meso-pores***. Finally a soil may contain large pores called ***macro-pores***. Soil pores are essential as they allow air and water to flow into the topsoil. They also ensure water can be stored in the soil. Without air and water a soil system cannot self-organise. You cannot build healthy soil without them. Pores provide space for plant roots to explore the soil, habitat for soil insects and an ideal environment for seeds to germinate.

Good and poor soil structure

In a well-structured soil, when you break apart a large aggregate it breaks into smaller aggregates. If it does not break apart at all and remains as a solid ***clod***, then this indicates poor structure. Alternatively, a poorly structured soil may collapse into loose dust or powder when you break it up. Poorly structured soils have limited large and medium-sized pores in them. This usually results in low water and air penetration of the soil and it also means roots cannot grow easily into and through these soils. ***Bulk density*** refers to how dense or heavy a soil is. A soil with a high bulk density has low pore and air space. Bulk density is another way to talk about soil structure. High bulk density soils are said to be ***compacted***.

In the soil of this grazing paddock you can see plate-like structures, like long thin bricks, stacked on top of each other in the topsoil. This is a sign of poor soil structure.

Soil structure can be lost through excessive tillage, especially tilling the soil when it is too wet, through loss of organic matter and by using heavy machinery on a paddock frequently. It can be rebuilt through adding organic matter and growing cover crops with a large root volume. This feeds the soil life which in turn re-aggregates the soil. In a grassland soil, the fibrous root systems of grasses help drive soil structure. That's why pastures tend to be helpful in maintaining or rebuilding soil structure, along with a lack of cultivation. In a forest a healthy litter layer of organic mulch will help build soil structure.

Aggregate stability refers to the ability of soil aggregates or crumbs to keep their structure when put under stress. To test the strength of a soil aggregate you can place it in water. Soil aggregates that hold together indicate that the soil structure is stable and the soil structure is in good condition. Unstable soil aggregates can either ***slake***, where they fall apart into smaller crumbs, or ***disperse***, where their clay content separates into individual soil clay particles and ends up as a cloudy suspension in the water. Dispersion can sometimes be an indicator of ***soil sodicity***, where high exchangeable sodium in the clay minerals of a soil disrupt soil function.

Aggregate strength test.

A good soil structure is essential for all soil functions. It positively influences plant root growth, water and nutrient cycles and it improves the habitat for soil organisms. A well-structured soil can cope better with agricultural activities like tillage and machinery traffic without soil condition declining too much. So a key aim for all farmers and graziers is to maintain good soil structure.

SOIL AIR & WATER: TURNING ON THE SYSTEM

Air and water are essential for a soil system to function. All life on Earth including plants, soil microbes and soil organisms, needs air and water to thrive. So a key aspect of any soil system is adequate air and water. For a soil to have optimal air and water it needs to be well-structured. In particular, it is the pores in a soil that determine if the air and water balance is optimal. Having a mixture of large, medium and small pores is essential for optimal soil air and water.

SOIL WATER

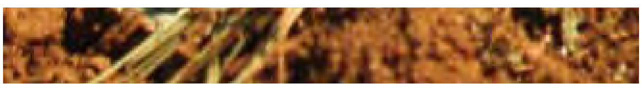
The water in a soil is known as ***soil moisture***. Soils become dormant when there is not enough water available. Many of the microbes and small organisms in a soil actually live in the films of water held in the soil, although many annual plants will die as water dries up in the soil. Perennial plants will go dormant, waiting for soil moisture to increase before regrowing again. Soil microbes and organisms are adapted to dry conditions, going dormant or laying eggs, waiting for soil moisture to come again.

Measuring the infiltration rate of water into your soil is relatively easy and can be done in the paddock with a pipe, water, ruler and a timer. It gives you a good snapshot of how healthy your soil is. In grazing landscapes the infiltration rate of water can dramatically increase when planned grazing is implemented. This leads to less run off and erosion and more grass being grown.

Most of the time the water in a soil originally comes from rainfall or irrigation hitting the soil's surface. The first part of the soil water story is what happens when water hits the soil surface. In a healthy soil this water goes down into the soil through the large soil pores. This is called ***infiltration***. It is the most critical part of the relationship between soils and water. Soils with a good structure tend to capture more water than poorly structured soils as they have more large pores. Soils with a sandy texture also tend to have high infiltration rates as the large sand grains in the soil naturally have large pores between them. Poorly structured soils do not allow much water to infiltrate during rainfall or irrigation events because they have few large pores.

The second part of the soil water story is what happens to water once it is in the soil. Gravity acts as a force on water meaning it tends to flow downwards once it is in the ground. However, the surface tension between the soil aggregate surfaces and water tends to hold some of it in place. The medium-sized pores and small pores are responsible for this process. This water does not drain under gravity but remains in the soil. The name of this water, held against gravity by the soil structure, is called ***capillary water***.

Some of this capillary water is relatively loosely bound to the soil surface and can be used by plants. This pool of soil moisture is often called ***plant available water*** or ***PAW***. It is sometimes called ***RAW***, ***readily available water***. A further portion of this capillary water is very tightly held by the soil surface in the tiny, micro-pores. This water, generally held so tightly that plants cannot access it, is called ***hydroscopic water***.



After water has infiltrated the soil during irrigation the goal is to ensure as much as possible stays in the soil in a plant available form. This means keeping a good soil structure. This will lead to lower pumping costs and better water use efficiency for an irrigation operation like this vegetable enterprise in the Burdekin.

The amount of sand, silt and clay in a soil, its texture, influences how much water will infiltrate a soil as well as how much will be held as capillary and hydroscopic water. However, soil structure is just as important in influencing the soil water story. In poorly structured soils, much less water enters the soil through infiltration and much less is held in the soil in a plant available form.

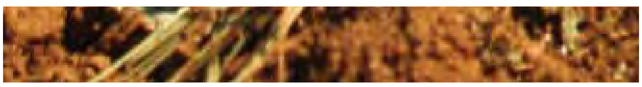
One of the challenges in the Wet Tropics is excessive water leading to water logging and flooding in crops. Drains help move water through the landscape so it does not sit and cause problems. Repairing drains regularly keeps them effective at removing water. Keeping drains well vegetated is also important as it helps to lower nutrient run off from agricultural landscapes.

SOIL AIR

When there is no air flowing into and out of a topsoil then the soil system gets transformed. It changes to a low oxygen state and becomes what we call ***anaerobic***. Most life in the soil needs oxygen to breathe. However, some microbes in the soil are adapted to low oxygen conditions. These are the same bacteria that thrive in wetlands which are naturally low in oxygen. These bacteria can give off strong odours like rotten egg gas.

One of the soil challenges in the tropics is the intense rainfall events that can temporarily saturate soils for days and even a few weeks in a process known as ***water logging***. In this state soils have low oxygen levels. In this condition many plants stop growing and the whole soil system can be thrown out of balance. It is common for many plants to turn yellow during a water logging event as they can no longer take up nutrients. Severely compacted soils, with low porosity also suffer from low oxygen levels. Well-structured soils, with good levels of porosity, tend to bounce back to an oxygen-rich state more quickly after water logging events as the water drains away more quickly through the large pores, returning oxygen to the soil.

In low lying areas like this paddock near Townsville water can sit for weeks leading to low oxygen levels and poor pasture growth. The chemistry of these soils also changes under these conditions.



SOIL CHEMISTRY: THE HIDDEN INFLUENCERS – PH, SALINITY & THE EXCHANGEABLE CATIONS

There are a few important chemical aspects of a soil that strongly influence how it functions. Unseen except by chemical tests, these hidden aspects of soil health include the soil's *pH*, *soil salinity* and the proportion of the different *exchangeable cations* on the soil colloid.

The pattern of this hidden soil chemistry is determined by a few processes. Firstly, the type of minerals a soil contains influences this chemistry. Secondly, climate strongly influences things through the process of weathering of the soil minerals from rainfall. The level of humus and the biological processes of a soil also influence the pattern of this soil chemistry. For example, the colloids in humus can buffer soil pH, stabilising it to some extent. Humus also moderates the influence of soil dispersion that can be caused by high levels of exchangeable sodium. Finally, management activities like using soluble, chemical fertilisers, tillage and irrigation water high in salts may also influence the balance of soil chemistry.

This hidden chemistry of your soil influences soil function and a soil's biological community. It therefore influences plant growth. However, it is a two-way relationship. Plants, including the activity of their living roots and the organic matter they create, along with a soil's biological community also modify soil chemistry. When managing soil chemistry we often focus on fixing it to improve plant growth. However, we can also improve soil chemistry by improving the biological dimension of a soil. By changing management practices, increasing plant diversity and improving soil humus levels we can help maintain the balance of soil chemistry.

SOIL PH

pH is a measure of the overall ***acidity*** or ***alkalinity*** of the soil. It measures the amount of free hydrogen (H) and hydroxyl (OH) ions present in a soil system. The biochemical processes that occur daily in soils always result in a balance of acidity and alkalinity and give a soil its pH. pH is measured as a number from 0 to 14. Seven is ***neutral***, below seven is ***acidic***, and above seven is ***alkaline***. pH levels are influenced primarily by soil type and long-term annual rainfall, but management and farm inputs like nitrogen fertilisers also play a key role.

Soil pH influences many processes in a soil including nutrient cycling and the biological community. Under highly acidic or highly alkaline conditions, some nutrients may become tied up and unavailable for plant uptake. Under acidic conditions in some land types, elements such as aluminium may also get released from the soil minerals. This can create toxic conditions for plant growth. Soil pH also influences the balance of the biological community in the soil.

The main approach to improving soil acidity is applying lime. It lifts the soil pH and adds calcium which improves the exchangeable cation balance in a soil. Here lime is being applied before planting sugar cane.

In tropical landscapes, many plant species present have adapted to the local pH conditions of the area. However, when considering what crops or pastures to grow it is useful to know the pH of the soil as some plants are not suited to extreme pH levels. Keeping the soil pH near the middle when growing crops helps overall soil health as well as crop productivity. When sowing legumes into grazing landscapes it is good to know the soil pH as it will influence your choice of legume to sow.

SOIL SALINITY

All soils naturally contain some salts. A salt is just two elements, one with a positive charge and the other with a negative charge, combined together. For example sodium (Na+) combined with chloride (Cl-) gives common table salt: sodium chloride. So, a salt is a compound made up of positive and negative charged elements. Salts in a soil occur naturally, coming from the soil minerals as they weather and break down, releasing nutrient elements. Salts in a soil can also come from fertilisers added to a soil or from saline irrigation water. ***Soil salinity*** is a measure of how many salts are in the moisture in a soil.

A low level of salts in a soil is normal as these are forms of soluble nutrients. However, excessive salts in the soil cause problems, adversely affecting plant growth. Many plants cannot grow in very salty conditions. The main effects of high levels of soil salinity include preventing plants from taking in water and toxic conditions in the root zone. There are different types of salts in soils including sodium, magnesium and calcium based salts.

High levels of soil salinity are not common in the Wet Tropics as the high amount of rainfall means that the salts in these soils are constantly being leached throughout the year. This prevents a build up of soil salinity over time. An exception is in some coastal soils that can be inundated by seawater at times. However, in the Dry Tropics of northern Australia, with lower rainfall, soil salinity can be quite high on some soil types, especially in areas where the natural minerals are prone to releasing large amounts of salt minerals. In these areas specialised plants, adapted to high levels of salinity, will often grow.

EXCHANGEABLE CATIONS

The soil colloid is the highly active part of a soil where there is an ***electrostatic charge*** on the surface of a soil's clays and humus. Positively charged nutrient elements in the soil are attracted to this charge and are held in a stable and yet available form. Plants and soil microbes can access these nutrients. This colloid charge of the soil is measured on a soil test as the ***cation exchange capacity*** (***CEC***). Different soils have different sized colloid charges. The size of a soil's charge depends upon the clay and humus content of the soil along with its pH. The CEC of soils is usually negative and the positively charged nutrients that attach to it are called ***cations***.

All soils have a range of different cations actively attached to their soil colloid. When these cation nutrients are attached to the colloid they are called ***exchangeable***. This is because the nutrients in this colloid zone can be exchanged by plants and are therefore available. Importantly, the soil colloid is one of the key nutrient buckets in a soil.

The most important cations attached to the colloid in most soils are calcium, magnesium, potassium, sodium, hydrogen and aluminium. Held in place on the colloid, these cations are not readily leached out of the soil but can be replaced by other cations or taken up by plants.

Not only do different soils have different sized colloid charges but they also have different proportions, or ratios, of the various cations exchanging on their soil colloid. For example, in some soils, calcium is the dominant cation exchanging on the soil colloid. In other soils aluminium can make up most of the exchangeable cations attached to the colloid.

Some soils in the Wet Tropics, like on this heliconia farm near Babinda, have a very high proportion of exchangeable aluminium on their colloid. Over 50% aluminium can be present in some soils. Aluminium is a toxic acid cation and high levels is usually a major soil constraint for agriculture. Some tropical crops like tea, sugar cane and heliconias, have adapted to these soils and can grow in the challenging conditions.

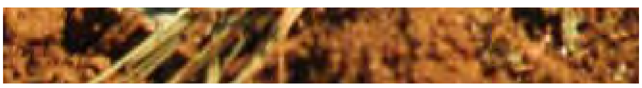
Think of a pub with a mix of fans from different footy teams hanging out at the bar. In one pub you have a lot of one team's fans and a few fans from other teams. In another pub in a different suburb the mix of fans at the bar will be different. Just like the different mix of fans in different pubs, the mix of exchangeable cations is different in different soils. The balance of the cations on a soil's colloid is called the ***exchangeable cation balance*** and this balance can be important for soil health because it can influence how a soil system functions. In some situations the balance of cations on the colloid can lead to soil health issues.

For example, soils with a high proportion of ***exchangeable aluminium*** often have issues with plant growth and nutrient cycling. The high proportion of this cation on the colloid disrupts soil function. In other soils ***exchangeable sodium*** may be relatively high. These soils are called sodic. This can also be disruptive to soil structure and plant growth.

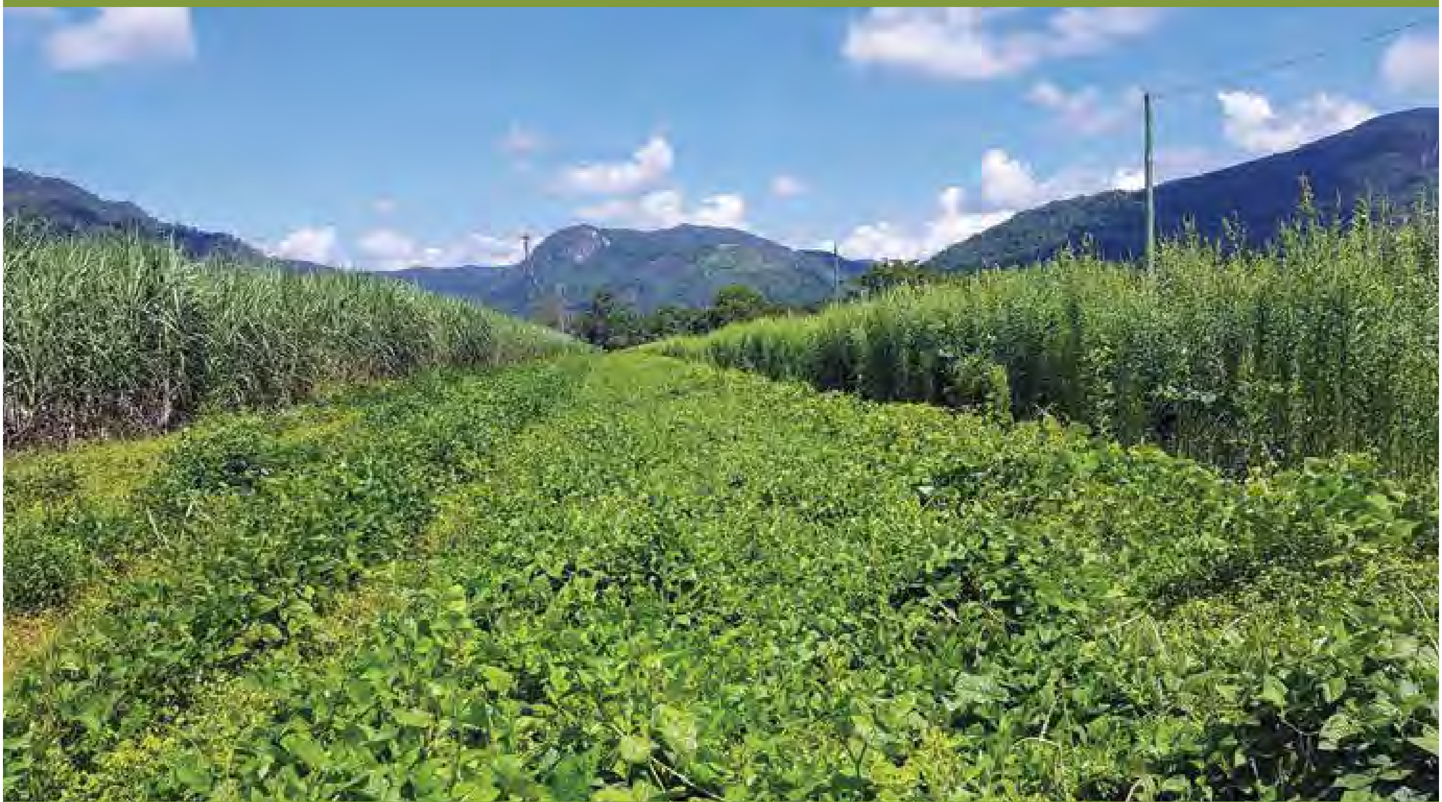
The soil in this irrigated hay paddock near Dimbulah, Queensland, has sodic patches throughout. This disrupts soil function and plant growth. Lower yielding areas within the paddock are symptoms of the sodicity. Another symptom is areas staying waterlogged. Compare the two wheel tracks under the pivot irrigator. Where exchangeable sodium is high, the ground stays waterlogged. In the other areas of the paddock the actively growing grass uses the irrigation water effectively. The wheel tracks are dry.

Managing a soil's exchangeable cation balance can be important for soil health. This balance is usually assessed with a soil test. A decision can then be made as to how a soil colloid can be re-balanced if needed. This usually means adding soil mineral amendments such as lime, dolomite, gypsum or sometimes compost. There are some situations where the cation balance is difficult to achieve due to the soil type and the geography. In other situations it may not be economical to change this balance. In these cases it is often better to focus on biological function and organic matter to help improve soil health. High levels of organic matter and humus help mitigate the soil health impacts of imbalanced exchangeable cations in a soil.

Compost can be an effective way to help manage cation imbalances by buffering the soil colloid. Mixed with lime it can enhance the liming effect. Generally farmers find they need less lime to improve soil acidity when they mix it with compost. It can also be used to address sodic soil situations.



3. GUIDING PRINCIPLES



10 PRINCIPLES OF REGENERATIVE SOIL MANAGEMENT

1. MATCH ENTERPRISE TO SOIL TYPE

The soil you manage comes with certain characteristics that are inherited and not easily changed. These determine soil type and include soil texture, overall soil fertility and the size of a soil's colloid or CEC.

Other aspects of a soil, like organic matter and structure, can be influenced by active management. Matching your enterprise objectives to your soil type is the most effective way to find the profit sweet spot in a farm enterprise. Various soil types are not "good" or "bad", they are just different. However, different soil types are suited to different agricultural activities. Knowing your soil type and its inherent characteristics is important because it influences every farm management decision you will ever make on that area, from tillage to irrigation to fertiliser tactics to your production goals. Matching your farm enterprise goals to the soil type is important as you will spend less effort in trying to "fix" a soil and instead make your enterprise fit the soil's potential. It is easier to work within the limitations of a soil type rather than trying to change a soil type to meet your needs.

THE THREE ENTERPRISE QUESTIONS YOU NEED TO ASK YOURSELF ON ANY SOIL TYPE ARE:

1. **Is this the right enterprise for the soil type?**
2. **Are my production goals realistic for this soil type?**
3. **Are my management decisions appropriate for this soil type?**

MARK SAVINA

800 hectares of sugarcane and legume crops

*Cairns, North Queensland: **Wet Tropics***

Mark manages a large area of sugarcane on the Barron River Delta near Cairns in North Queensland. He continues to heed the words of his father who said 'always leave the land as good as you got it, if not better'. He has to deal with a range of soil types. He has observed that different varieties of cane grow well on different soil types. He targets soil amendments like lime and fertilisers to yield expectations, with some soil types having a lower yield potential than others. By targeting his management to the soil type, he optimises sugar cane yield goals to soil type. This targets farm inputs, reduces costs and positively influences profit. Mark uses GPS and modern mapping to fine tune his approach.

BLUE PERKOWICZ

225 hectares of grazing

*Ravenshoe, North Queensland: **Wet Tropics***

Blue runs a beef operation at over 1000 metres on the Atherton Tablelands of Queensland. There are three main soil types on the property with a high fertility red soil and two different, lower fertility grey soil types. Under the previous set stocking approach cattle preferentially grazed the red soils which led to over grazing of the pastures on these soils and under grazing of the grey soil pastures. Blue has implemented a rotational grazing approach to the property and has subdivided paddocks based partly on soil type. This has allowed him to match grazing management to soil type. He has also targeted the grey soils with lime to address soil acidity and exchangeable aluminium levels. By adjusting his management Blue has been able to target grazing production to soil type. The benefits he has seen include bigger root systems in the grasses and improved pasture quality. Legumes have thrived and he has saved money by applying lime only to areas that need it.

2. MAINTAIN GROUNDCOVER

Groundcover has many benefits for a soil system. Keeping high levels of groundcover on your paddocks is one of the most important things you can do to improve soil health.

The best groundcover is living plants that maintain an active root system but litter, crop trash and mulch are also important types of groundcover. Even cow manure is a form of groundcover! Generally the more groundcover you can maintain on your property the better.

The benefits of groundcover are many, including:

- Protecting soil from being lost through water and wind erosion.
- Preventing soil structure from destruction by the physical impact of rain drops.
- Increasing the infiltration of rain into the soil.
- Moderating the surface temperature of the soil. This reduces evaporation of water and improves the condition for life in the soil.
- Reducing weed germination.
- Adding organic matter for the soil biological community.

David Hampton, grazier, surveying his pastures and groundcover.

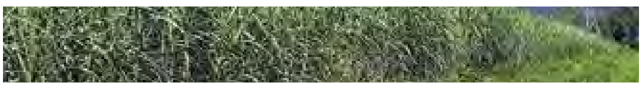
PETER SALLERAS

89 hectares of tropical fruits and rainforest

East Feluga, North Queensland: ***Wet Tropics***

Pete Salleras and his family grow tropical fruits near Mission Beach in Queensland. To manage groundcover they have adopted a “chop and drop” strategy in their plantation where they prune and cut grass and throw it back under the trees. They mulch directly under the tree line which protects the soil from rain and builds up the soil structure. They also bale paddock grass to use later as mulch. In the inter-rows they use cover crops, so there is no bare soil that becomes impervious to water over time, and it also protects the soil biology from the baking temperatures of the sun. The benefits they’ve seen include:

- Less irrigation required, as there is greater water retention.
- A longer growing season and better tree health due to the mulch.
- Better soil structure and reduced erosion.
- Reduced weed pressure which means they can reduce their herbicide and insecticide use.
- Better fruit yield, quality and consistency – which gives them better prices!



DAVID HAMPTON

109 hectares grazing over a number of properties

Atherton Tablelands, Queensland: ***Wet Tropics***

David’s soil strategies are based around maintaining good grass and groundcover all the time, which he has achieved through improved grazing management. This has involved more subdivisions and watering points so he can control the evenness of grazing across the property. This has lifted the soil carbon levels (up from 5.4% to 10.8% at the Malanda farm, and to 9.2% at the Gillies farm). He has also noticed higher water absorbency and the pastures stay greener longer in dry spells as the grass now has a deeper root system. He strategically places water points so that cattle will not make tracks. Tracks greatly increase the risk of erosion in the high rainfall hilly country that David manages.

3. MAXIMISE THE CARBON GROWING SEASON

All soils need a constant supply of energy into the system in the form of carbon. This is the fuel that drives soil function.

This energy is supplied by plants as they photosynthesise, creating carbon compounds called carbohydrates. Living plants are constantly supplying the soil with these carbon compounds including simple sugars from their roots as exudates, along with other forms of organic matter.

The “carbon growing” process of active plants is critical as living roots continually stimulate the soil community. This means that soil functions are maintained or improved while plants are actively growing. To maximise this, it is important to try to keep a living root in the ground for as much of the year as possible.

In the Dry Tropics, with a seasonal non-growing period, maintain a good level of perennial grass to ensure things kick off again when rain comes.

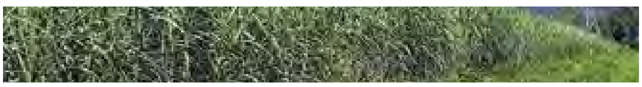
Inspecting a young multi-species cover crop in rotation with sugar cane. This crop is being grown on raised permanent beds near Ingham in Queensland. Using a cover crop instead of a bare fallow increases the carbon growing season, helps reduce soil borne diseases and improves soil structure.

ALAN & JENNY LYNN

200 hectares of sugarcane and cover crops

Ingham, Queensland: ***Wet Tropics***

Alan and Jenny grow sugarcane near Ingham. Part of their soil health strategy is using cover crops. Traditionally during the fallow period the ground was often left bare between cane crops. They now grow multi-species cover crop mixes with a strong focus on legumes on paddocks during the fallow period. This ensures they have living roots in the soil as much as possible in the fallow period. This helps to build soil organic matter and recycle nutrients. By using legumes in their mix, they also get nitrogen fixed into the topsoil for the following crop. Alan also uses a controlled traffic approach and developed a bed renovator to minimise disturbance when turning in cover crops.



O'KANE FAMILY

187 hectares of sugarcane and cover crops

East Feluga, North Queensland: ***Wet Tropics***

Chris and Mick O'Kane and their families grow sugarcane near Tully on a wide range of soil types. The key soil challenges they have are leaching and nutrient run off, compaction and low organic matter. Traditionally they have grown legumes like lab lab and soybeans as cover crops but to increase the carbon growing season they now use multi-species cover crops. This means they have more chance of active root systems in the paddocks no matter what seasonal rainfall conditions they get. Cover crop mixes include soybeans, sorghum, buckwheat, millet, vetch and cereal rye. Depending on the weather conditions Chris slashes the cover crops and allows them to regrow, getting up to six months of active growth, lengthening the carbon growing season. Combined with other practices including controlled traffic and using biofertilisers, the O'Kanes have seen improvements in their soil health. Reducing their nitrogen fertilisers they have also been able to maintain cane production.

4. MAXIMISE PLANT DIVERSITY

A key principle of ecology is diversity. Natural systems, including soils, function more effectively when they have a certain level of diversity.

By increasing plant diversity, soil diversity increases and the key soil functions like nutrient cycling, suppression of soil-borne diseases and soil structure improve. This is due to the synergistic effect that different types of plants often have when growing together. A diversity of plant species in a paddock, either at the same time, or in rotation, improves soil health. A diversity of crops or enterprises also helps a farm business. Having a few different cash crops helps to manage the risks of low prices, poor seasonal conditions or a pest impact on one of your crops.

Ray Zamora inspecting tillage radish in a multispecies cover crop near Tully, Qld.

RAY ZAMORA

130 hectares of sugarcane and cover crops

Tully, Queensland: ***Wet Tropics***

To deal with the problems of monoculture in sugarcane farming systems, Ray has increased diversity in his farming system using mixed species cover crops in fallows. The species selection changes depending on what is growing well. He chooses from a range of cover crop varieties including field brassicas, tillage radish, Japanese millet, kale and Rhodes grass. Using this approach along with minimal tillage and biofertilisers Ray has seen impressive improvements in his soil structure over the last few years. He is also lowering his nitrogen fertiliser applications with no yield loss to date.

SIMON MATTSSON

196 hectares of mixed farming; fruit trees

Marian, Queensland: ***Subtropics***

Initially growing sugarcane and soybeans, Simon explored the potential of introducing more diversity into his farm while on a Nuffield Scholarship. He has grown over 40 different cover crop species and he pioneered the use of multispecies cover crops in the Australian sugarcane industry. Species in his cover crop mixes include sunn hemp, buckwheat and a range of brassicas. He has also successfully grown a simultaneous intercrop of sugarcane and sunflowers. Simon has recently changed enterprises and is currently developing a multispecies orchard of tropical fruits.

5. MAINTAIN SOIL ORGANIC MATTER

Organic matter is essential in soil. As plant material is fed to the soil, either as litter on the surface or as roots dying off underground, it supplies the organic matter to soil that then decomposes. This organic matter contains carbon and nutrients.

The carbon in some of this organic matter becomes stable in the soil over the long term and some actively decomposes each year, disappearing as it does. The stable organic matter, humus, improves the water holding capacity, structure and nutrient cycling ability of a soil. The actively decomposing organic matter, labile organic matter, is also important. As it breaks down, nutrients are released into forms available for plants to take up. The labile organic matter drives nutrient cycling in the soil. For soil health it is essential to supply organic matter to soils constantly and rebuild soil organic matter levels if they are low.

Dereck Devaney with his fermentation compost made on farm. Using compost has helped improve soil structure, soil biology and the health of his bananas near Babinda, Qld.

MAL EVERETT

5.3 hectares of lychees

Mareeba, Queensland: ***Dry Tropics***

Mal grows lychees on a sandy loam soil type with fairly low fertility and low organic matter levels. His soil carbon levels, measured on a soil test to estimate organic matter, were previously around 1.0%. He began mulching and now mulches to 10cm depth annually on all trees. He also encourages the low growing legumes, pinto peanuts and Verano stylo, to grow under the trees as a living mulch. Mal has observed that these tactics have "increased soil biology which breaks down the mulch faster so you have to put more on, but the pinto is growing all the time – building up organic matter without making you work harder". These practices have doubled his organic carbon levels to over 2% in five years. Mal believes increasing organic matter will improve soil moisture retention and increase the cycling of nutrients currently locked up in the soil, making them available to the lychee trees.

DERECK DEVANEY

100 hectares of bananas

Mirriwinni, Queensland: ***Wet Tropics***

Dereck and Stacey farm bananas in one of the wettest parts of Australia. A key soil challenge is to maintain good levels of organic matter in the plantation. Already using best practice of chopping and dropping all excess banana biomass into the rows they were already adding organic matter to the soil. A few years ago they saw an opportunity to go further and add their pack shed waste back to the soil as compost. Using a no turn, fermentation approach they make compost on farm and apply it to the bananas regularly. Dereck has seen improvements in crop growth and soil health from this approach.

6. MINIMISE SOIL DISTURBANCE

Agriculture often involves a fair amount of soil disturbance. The three main types of soil disturbance are physical disturbance, chemical disturbance and fire.

Physical disturbance includes machinery traffic, tillage practices and the impact of animal hooves on the ground. Excessive physical disturbance generally leads to a soil losing its structure and organic matter over time. This then leads to a range of other problems.

Chemicals like herbicides, fungicides and fertilisers can disrupt soil health when too much is added. Small amounts can be assimilated by a soil system but large amounts frequently added can affect soil biological function. Finally, fire can impact on soil by killing soil life and burning off organic matter leaving the soil bare. Scorching fires can even alter the chemistry of a soil.

Some soil disturbance is always going to occur with farming and grazing activities. Applying practices that minimise soil disturbance benefits almost every aspect of soil health. Controlled traffic, minimal and no till, using cool burning only, planned grazing and targeting chemical use are all key ways you can minimise the disturbance of your soil.

Stephen Calcagno checking out the improved soil structure on his cane farm near Bellenden Ker, Qld.

STEPHEN CALCAGNO

185 hectares of sugarcane and cover crops

*Bellenden Ker, North Queensland: **Wet Tropics***

Farming in one the wettest areas of Australia, beneath Bellenden Ker, Stephen has to deal with a range of soil types and high rainfall. Excessive disturbance with machinery and tillage was leading to severe soil compaction across the whole farm. To address this he made big changes to his paddock operations: going to controlled traffic with GPS, minimising tillage and using a long fallow tactic between sugarcane crops. He has seen real benefits from these changes including spending less time on the paddock due to machinery efficiency, better water infiltration into his soils and less wear and tear on equipment. This has positively impacted the farm business. There has also been a noticeable increase in earthworms in the soil.

LAWRENCE DI BELLA

100 hectares of sugarcane, sweet potatoes, pumpkins and cover crops

*Ingham, North Queensland: **Wet Tropics***

Lawrence has focussed on soil health for many years. Noticing how compaction was reducing sugarcane yield he implemented controlled traffic farming over 20 years ago. By combining controlled traffic with minimal tillage he has seen the soil structure and soil biology improve greatly. In the last few years he has also introduced a range of cover crops and cash crops into his system to increase diversity. The benefits of these changes to his farm have been impressive. Running the farm has been more efficient due to reduced paddock operations and he has been able to lower nitrogen fertilisers by around 30%. The soil health benefits include reduced crop damage from nematodes and improved friability in the clay soils. Lawrence knows the soil biology is improving. He is counting nearly 10 times as many earthworms in the cover crop paddocks as in the sugarcane paddocks.

7. OPTIMISE PLANT MANAGEMENT

Whether you manage pastures or crops, optimising the management of vegetation is key to achieving soil health. A key part of farming and grazing is utilising plants for production.

This means balancing the need to harvest biomass from the plants with the need to return some of the plant biomass to the soil as organic matter. You also need to keep plants in an active stage of growth for as long as possible each year to maximise photosynthesis activity.

Over grazing pastures, burning vegetation or stubble too often, not returning some crop biomass to the soil as trash or mulch and turning in crop biomass too early or too late are all examples of poor plant management.

Under grazing pastures, allowing grass to become rank and dormant, is another example which can lead to soil decline in the long term.

To thrive, plants need to be renewed from time to time. Grazing pastures periodically, pruning tree crops effectively and managing crop and cover crop biomass well are all ways to optimise plant biomass. Careful use of cool fires can also help renew vegetation in a landscape.

A cover crop of sunflowers in rotation with sugarcane. Growing sunflowers helps increase soil biological diversity and may lead to improved phosphorous cycling.

BOB HARRIS

2400 hectares of grazing

Bowen, Queensland: ***Dry Tropics***

Bob grazes a large property with a range of landscapes. He has been using a planned grazing approach for over 15 years, rotating mobs of cattle through paddocks and allowing plenty of recovery time for the pastures after each grazing event. A key principle Bob follows is not to over graze the pastures. As he says “another important aspect of rotational or time-controlled grazing is not to let the cattle take the pastures down too far during the growing season, just let them take a bit of the top and then move them on. I like to keep 6 inches of ground cover because once it rains your paddock is ready to go and absorb the rain into the soil profile to be utilised by the plants”.

For rotational grazing, he has 80% of the farm spelled having no cattle on it at all, while the remainder of the farm is intensively grazed over a specific period. “For example, the cattle are only in one paddock for one week or maybe a couple of months but the key factor is to keep them moving along into another paddock. Shifting cattle and thus grazing pressure allows pastures to recover,” he says.

MICHAEL WARING

137 hectares of sugarcane and cover crops

Ingham, North Queensland: ***Wet Tropics***

Growing diverse cover crops is a key part of Michael’s soil management. A key decision when managing cover crops is when to terminate them so the paddock can be prepared for the next cash crop. He aims to keep biomass growing for as long as he can before terminating the cover crop. In deciding when to terminate the crop, rainfall and access to the paddock become key considerations in the Wet Tropics environment. Using strategic herbicide applications he can terminate the cover crop biomass early while still leaving valuable plant biomass in the paddock. A few weeks before he is ready to prepare the ground for the next crop he uses minimal tillage to get the planting beds ready. Using this approach he has reduced his tillage passes from 10 to three. He keeps more plant biomass on the paddock for longer. Fewer weeds, time savings and soil health benefits have all followed.

8. ADDRESS PHYSICAL & CHEMICAL SOIL CONSTRAINTS

By following the first seven principles of regenerative soil management you will go a long way to building soil health.

However, some soils may still have key chemical and physical soil health issues, called ***soil constraints***, that impede them from functioning well. You may need to specifically fix these to really take your soil health forward. Chemical constraints include soil acidity, salinity or high levels of exchangeable aluminium, manganese or sodium. A common soil physical constraint is compaction which limits plant root growth and soil aeration. Using soil amendments like lime or compost or changing grazing management or paddock machinery operations to reduce soil compaction are the ways to address soil constraints. Sometimes ripping or aerating the soil helps to trigger improvement when compaction is present.

Inspecting soil structure on the Attard's farm near Mackay, Qld.

ATTARD FAMILY

53 hectares of sugarcane and cover crops

*Mackay, Queensland: **Subtropics***

Compaction is a major issue on the Attard's property near Mackay. To address it, the Attard brothers use a steel ripper, subsoiling, basically not disturbing the soil too much, just ripping the surface at around 200 mm to oxygenate the soil. They apply it on an as-needed basis to break the compaction and let water infiltrate. They use a ripper with a coulter disc. They do not mix the soil as they see it as important to maintain the three zones of the soil profile and the biology profile each of these zones hosts. John Attard has noted: "As you enhance your biology you find that the microbes are also working their way down into other zones, further aerating the soil, breaking compaction, allowing you to increase the area your crop's root system can explore and thrive in. Anaerobic compacted soils introduce pests and diseases; thus creating a home for your beneficial aerobic microbes is key to soil health."

MICHAEL & PETER OTTONE

228 hectares of sugarcane and pineapples

*Bilyana, Queensland: **Wet Tropics***

The Ottone brothers farm a few different soil types and have a few soil health issues including soil acidity, high exchangeable aluminium and soil borne diseases such as phytophthora. They use lime to improve the acidity of their soils and to lower exchangeable aluminium levels. In the cane they use 1.6 tonne/hectare of lime once in the crop cycle, every five years. Pineapples can handle high aluminium so they tend to plant pineapples in those areas where the exchangeable aluminium is highest. The brothers deal with soil borne diseases in pineapples by using compost teas to improve the beneficial microbiology in their soils. This approach has seen success with notable improvements in pineapple health and soil conditions.

9. MANAGE NUTRIENTS BIOLOGICALLY

It is the soil biological community and plant root systems that are critical for cycling soil nutrients efficiently. This includes any fertiliser nutrients that are applied to the soil.

So it is important to work with the soil community, not against it. It is also important to maintain a large volume of roots in the soil. Anything that reduces the volume of plant roots in a topsoil limits your ability to use fertiliser effectively.

When using fertilisers, aim to maximise the microbial processes in the soil at the same time. This is achieved by keeping high levels of soil organic matter, maintaining soil structure and maximising plant root volume in a soil. Not using too much fertiliser at any one time is also important. Finally, if you are applying soluble chemical fertilisers, then one option is to add some carbon and/or microbes at the same time to assist the soil system in absorbing and cycling the fertiliser nutrients efficiently.

The Rossi family's compost operation near Cairns. Using compost has helped them lower nitrogen fertiliser rates and improve soil carbon.

ROSSI FAMILY

220 hectares of sugarcane

Aloomba, Queensland: ***Wet Tropics***

With very low organic carbon in the soil and high rainfall, the Rossi brothers have been trying to improve their soil's health and the efficiency of their nitrogen fertiliser applications. To achieve this they use a combination of compost and mixed species of fallow crops. They have been making and using compost for four years. They add it at 35 tonne/ha into plant cane, into the drill and mounded over. It stays there, where it is also available to the following ratoon crops. To make the compost, they add a combination of biosolids, green council waste, forage excess from the mixed species crops, cane trash, mill mud, timber sawdust, molasses - it all depends on what is available at the time.

"Our compost system has seen us reduce inorganic nitrogen fertiliser from 130kg/ha to 80kg/ha – it has removed our reliance on inorganic nitrogen. Our organic carbon is increasing, and the sunflowers in the fallow mix have an association with mycorrhizal fungi, which makes the phosphorus in the soil available to the plant and this has reduced the amount of phosphorus we need to apply," says Tony Rossi.

CAAMANO FAMILY

70 hectares of limes and pomelos

Mareeba, Queensland: ***Dry Tropics***

The Caamano family has been working to reduce soluble fertiliser rates for some years. Taking a holistic approach they regularly use compost, mulch and biofertilisers made on farm to get the balance right between production and soil health. The result is consistently high quality limes and healthy trees. They see this approach as being profitable.

As Debbie Caamano says: "We've been able to reduce our inorganic fertiliser use. Our limes have better colour and shelf life. The production is almost the same, but the fruit is healthier. And the soil used to be very dead and compacted. Now it's crumbly and aerated and we see increased soil biology. We see worms the whole time now. We save money in both fertilisers and production costs."

10. MONITOR YOUR SOIL

Soil monitoring is usually last on the list of soil management priorities, but it is one of the most important principles of soil management.

You need to set targets and actively monitor your soil's condition to see if it is meeting those targets and how soil health is affecting your farm enterprises. The two ways you can monitor soil health is through field assessment and with a soil test. The best approach is to use both. Farmers who are serious about soil health carry a shovel with them and regularly check what's happening below ground. It is easy to assess many aspects of your soil's quality in the paddock with simple tools and equipment. Looking at the surface of the soil, digging a sample of soil with a spade to assess soil health in the field through visual assessment is not difficult. Have a monitoring plan. Know what you will monitor and how often you will do your monitoring.

Vanilla grower Fiona George assessing the soil on her vanilla farm at Woopen Creek, Qld. Fiona tracks the condition of the soils regularly both in the field and with a soil test to monitor soil health and fertility.

BOB HARRIS

Grazier, Bowen: Dry Tropics

"The time-controlled grazing approach is constantly monitored and adjusted, where the grazing duration is determined by the forage capacity (feed availability) of individual paddocks on your farm. Observation of your ground cover, ensuring you maintain at least six inches and to not overgraze, is key. Photos can be helpful to observe a change. I undertake my own soil assessment on the farm to understand my soil condition and its health using the RASH (Rapid Assessment of Soil Health) monitoring strategies."

LAWRENCE DI BELLA

Sugarcane and horticulture, Ingham: Wet Tropics

"In the cane, I test the soil once each crop cycle and do a leaf test when I think it's needed. We regularly take soil pathogen tests to diagnose soil pest and disease issues in our cane and horticulture crops. I always have the shovel handy, checking the soil structure, root development, worm numbers and the biological activity. I've seen that my cover crops definitely have more biological activity."

CLINT REYNOLDS

Sugarcane, Lower Daintree: Wet Tropics

"I monitor with full annual soil testing, including exchangeable cation percentages. I have also trialled measuring CO2 respiration in the soil as an indicator of soil biology activity. I participated in a farm soil management course and many other soil extension activities. I'd seen CEC and the cations on the soil tests, but not realised how important they are and how connected to so many other things on the test results. Now I have the knowledge to understand my soil tests and not have to rely on someone else to tell me what they mean and what I need to do."

FIONA GEORGE & MATT ALLEN

Vanilla, Woopen Creek: Wet Tropics

"We spend a lot of time scrabbling in the dirt. We are looking for fungal hyphae which indicates good mineral cycling. We have high carbon now, so we need to be careful we maintain a good carbon to nitrogen ratio. If the soil is sodden, it indicates perhaps that the C:N ratio is too high and we have to ease back on the mulch layer."

PAUL RODGERS

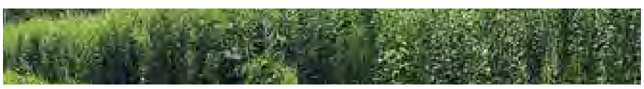
Sugarcane and cattle, Proserpine: Dry Tropics

"We sample soil every fallow. Annually between December and January we undertake leaf sample testing. This assists us in understanding how our nutrient management plan is tracking and our efforts in reducing nitrogen and phosphorus costs. On the farm we look out for worms as they are a good indicator that our soil health is improving. We counted 200 while just having a dig in the paddock. Normally you don't see worms in a cane paddock."

MICHAEL & PETER OTTONE

Sugarcane and pineapples, Bilyana: Wet Tropics

"We take regular soil and leaf tests and have also done soil biological tests a few times. We do a lot of visual observations: we dig up plants and look at roots, looking for pests and diseases like red spider mites."



4. STEPS TO SOIL HEALTH SUCCESS

PATHWAYS TO HEALTHY, PRODUCTIVE SOILS

TROPICAL PERENNIAL CROPS

There is no single recipe for building soil health in perennial crops like limes, avocados, mangoes, tropical fruits, vanilla, cacao and bananas. Each farm is unique in its soil type, family situation and location. However, there are some simple steps to use as a guide to help you adopt changes and, if followed, they may help lead to soil health success.

THREE ESSENTIAL STEPS

1. Mulch your trees

Trees need a covered, high humus topsoil layer for their feeder roots to thrive. Keep the canopy zone always mulched to promote this layer. Use a mix of mulch materials if you can. Using low growing, shade tolerant living mulches like pinto peanut is also an option sometimes.

2. Address physical and chemical soil constraints

Step 1 will help with organic matter and soil biology. You may still have some major soil constraints like soil acidity, soil salinity or exchangeable aluminium. You will need to address these before your soil health can really move ahead.

3. Reduce the herbicides

The fewer the better. They impact on the soil community. Use mulches, living and dead, as the main strategy to minimise weed pressure. Herbicides should complement a mulch strategy, not replace it.

A well mulched lime orchard near Dimbulah, North Queensland. Mulching has reduced weeds as well as irrigation water needs. Other benefits include increasing organic matter, even tree growth, lower irrigation costs, more efficient fertiliser use and the need for fewer herbicides.

THREE OPTIONAL EXTRAS

4. Use your inter-row

It is a resource for the soil and trees. Grow diverse plants in your inter-row and put this biomass under trees using a side-throw mower, hay baler or forage harvester. This will build a litter and humus layer which trees feeder roots need to thrive. Keep some areas of the inter-row high and messy, creating habitat for beneficial insects. It also allows plants to reseed and keeps plant diversity in the orchard. Try doing this seasonally and rotate it around the block. Consider the fire risk as well.

5. Stimulate the crop-soil system

Sometimes you need to stimulate the system. Biological inputs may help here. Adding biostimulants and/or inoculants to your program may help to minimise stress on trees, prime root activity or enhance the breakdown of mulch. If using biological products it is worth doing a trial on farm to observe the effects they may have on your enterprise.

6. Balance and target fertiliser use

Manage your fertility holistically. It is about adequate and balanced plant nutrition. It is your soil's biological community that drives the nutrient cycles in the soil. Work with this community, not against it. Ensure the soil biology has adequate organic carbon, not just nutrients. Without carbon the soil community cannot stabilise and cycle fertiliser nutrients. Consider adding a soluble carbon like molasses or humates with fertiliser nutrients where possible.

The planning for this new avocado orchard has included using the inter-row to grow grass to mulch the trees. The added benefit is the improved habitat for beneficial insects that the long grass provides.

TROPICAL CROPPING

There is no single recipe for building soil health in cropping enterprises like sugar cane, vegetables, maize and fodder crops. Each farm is unique in its soil type, family situation and location. However, there are some simple steps to use as a guide to help you adopt changes and, if followed, they may help lead to soil health success.

FIVE ESSENTIAL STEPS

1. Control your traffic

The community of life in your soil doesn't like being smashed with the heavy weight of machinery. Decide on wheel spacing and stick with it. ***Always***. Permanent beds help, too.

2. Minimise your tillage

Soil organisms and aggregates don't like being sliced up by steel. Many get killed and the survivors have nightmares about food processors for weeks afterwards! Use non-aggressive tillage equipment like bed renovators and wavy discs where possible.

3. Minimise bare fallows

A bare soil is a dead soil. Mulch is good; living roots are better. Prepare ground for planting as close to crop sowing as possible.

4. Diversify your crops

A diversity of plants leads to improved soil function. The science is clear: planting cover crops and crop rotation is your only option. The more diverse the better. Grow cover crops for as long as possible in between your cash crops.

5. Address physical and chemical soil constraints

The first four steps will improve soil structure and soil biology. You may still have some major soil constraints like soil acidity, compacted soil layers, soil salinity or exchangeable aluminium. You will need to address these before your soil health will really move ahead.

Using a bed renovator to prepare the paddock for planting. Unlike a rotary hoe, this implement is not aggressive on soil structure. It will still break down trash and prepare the ground for the next crop.

THREE OPTIONAL EXTRAS

6. Reduce the herbicides

The fewer the better. They impact the soil-plant community. Use cover crops as the main strategy to minimise weed pressure. Herbicides should complement a cover crop strategy, not replace it.

7. Stimulate the crop-soil system

Sometimes you need to stimulate the system. Biological inputs may help here. Adding biostimulants and/or inoculants to your program may help to minimise stress on trees, prime root activity or enhance the breakdown of mulch. If using biological products it is worth doing a trial on farm to observe the effects they may have on your enterprise.

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Manage your fertility holistically. It is about adequate and balanced plant nutrition. It is your soil's biological community that drives the nutrient cycles in the soil. Work with this community, not against it. Ensure the soil biology has adequate organic carbon, not just nutrients. Without carbon the soil community cannot stabilise and cycle fertiliser nutrients. Consider adding a soluble carbon like molasses or humates with fertiliser nutrients where possible.

Checking out a cane crop in the Ingham district of North Qld.

TROPICAL GRAZING

There is no single recipe for building soil health in grazing enterprises. Each property is unique in its soil types, family situation and location. However, there are some simple steps to use as a guide to help you adopt changes and, if followed, may help lead to soil health success.

FIVE ESSENTIAL STEPS

1. Maintain high groundcover at all times

The more groundcover you can leave, the better your soil's health will be. Aim for as close to 100% groundcover at all times if possible. In the Dry Tropics never go under 70% groundcover, especially at the end of the dry season. In the Wet Tropics maintain 100% ground-cover all year round.

2. Graze to an optimal utilisation rate

This means grazing the correct proportion of pasture on offer each season. During grazing events, always leave some plant biomass for the grasses to recover quickly and some for litter to protect the ground. Never over-graze a perennial pasture to the point that it declines in the long term. The preferred perennials then persist, maintaining the land's long-term optimal carrying capacity and soil health.

During active growing seasons, leave some intact leaves after each grazing event. This allows the quick regrowth of the grass. It also means that the grass maintains a large root volume and helps maintain soil health. It is possible to occasionally graze pastures more heavily but these events should be the exception, not the norm, and be part of a long-term strategy.

In the Dry Tropics utilising between 30% and 50% of herbage mass grown annually is a general, long-term rule of thumb. In the Wet Tropics aim for using around 65% of herbage mass as a general, long-term rule of thumb. The lighter the soil type and lower the rainfall, the less percentage of pasture should be utilised. Due to high rates of pasture growth, a common problem in the Wet Tropics is not getting enough grazing pressure on pastures at times. This under-utilisation can lead to lower pasture productivity as rank grass starts to dominate a paddock, changing the soil system.

In areas with a distinct non growing season like the Dry Tropics it is important never to graze below a minimum level so that at the end of the dry season there is still groundcover and still a good proportion of intact perennial grass in the landscape, ready to regrow when the wet season comes.

3. Aim for even grazing pressure

Use subdivisions, watering points, attractants, self-herding and stock density tactics to ensure animals graze evenly across all areas of each paddock and the whole landscape. Otherwise, grazing impact is concentrated in certain areas only. This can lead to bare areas, erosion and woody weeds.

4. Allow adequate pasture recovery periods

Having a good number of subdivisions (10 to 15 paddocks per mob is a rough rule of thumb) and using planned rotational grazing will allow you to strategically rest areas. In pastoral areas low, conservative stocking rates or self-herding tactics are another way to achieve this. During the recovery period pasture and forage plants can recover adequately, rebuilding their root reserves and growing new biomass. The length of the recovery period will depend on the grazing pressure, plant species, season and rainfall.

5. Apply adequate stock density

Use subdivisions, watering points, attractants and/or mob size to ensure adequate stock density over grazed areas. Stock density is the level of herbivore disturbance in an area during any grazing event. Grazing animals impact on landscapes as they graze. This is called animal impact. It includes manure and urine and physical trampling. This animal impact can positively stimulate soil function. A general stock density rule of thumb for positive soil/pasture impact is to aim for at around 30 Animal Equivalents (AEs) (or 250 Dry Sheep Equivalents) per hectare during each grazing event most of the time. There are times when a higher or lower density may be useful. For example, if you are trying to stabilise an erosion site you may use an ultra-high stock density tactic for a short period.

Planned grazing allows you to manage pastures and landscapes for long term optimal production. This management team near Mataranka in the NT are doing their daily grazing planning meeting.

Assessing groundcover is a key part of grazing management for soil health. Good groundcover is essential for water infiltration and nutrient cycling in grazing landscapes.

FURTHER RESOURCES

VIDEOS

Terrain NRM - Soil Health Youtube Playlist

https://www.youtube.com/user/terrainnrm

Reef Catchments - Youtube Channel

www.youtube.com/user/ReefCatchments/videos

Northern Gulf NRM - Youtube Channel

www.youtube.com/c/NortherngulfAu/videos

NQ Dry Tropics - Youtube Channel

www.youtube.com/c/NQDryTropicsNRM/playlists

Soil Knowledge Network- Youtube Channel

www.youtube.com/channel/UCYR2Z1c1kEO2hUJs7PHuiuw/videos

Soil Land Food - Youtube Channel

www.youtube.com/channel/UCqoI46R3EqGaLklPSsNzAcg/videos

Soils for Life - Youtube Channel

www.youtube.com/user/SoilsforLife/videos

Soil Wealth - RM Consulting Youtube Channel

www.youtube.com/user/RMGroupConsultants/videos

READING

Grazing Land Management - Technical Manual (2005) DPI & MLA

Planned Grazing Management Fact sheet (2007) Land & Water Australia

Soil Health, Soil Biology, Soil Borne Diseases & Sustainable Agriculture: A guide (2016) Stirling et al.

Soil health for vegetable production in Australia (2010) Queensland Government

NQ Dry Tropics RASH Manual (2019) David Hardwick, NQ Dry Tropics

Herbert Cane Productivity Services - www.hcpsl.com