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Banana root and soil health user's manual

FR02025 Soil and root health for sustainable banana production

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Foreword

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- Mr. Dino De Zen
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Section 1. Introduction

Figure 1.1: Poor soil health from the interrow area of banana plantation.

Figure 1.2: Better soil health from the row area of a banana plantation.

Soils are more than just dirt. Like the natural systems that exist in a coral reef or a rainforest, soil is a complex and diverse ecosystem inhabited by many different types of living creatures performing a range of different tasks. The health of the soil is a major concern for farmers and natural resource managers in most horticultural industries. Issues like soil erosion, decline in soil fertility and biodiversity and management of soil-borne pests and diseases are recognised as serious issues. The health of banana soil determines how well it functions to sustain banana production.

To improve our understanding of banana soils, a project was developed with the Queensland banana industry to investigate the influence of various farm management practices on the chemical, physical and biological properties of the soil. The project aims to identify and develop simple, practical tests to measure soil health and to develop an on-farm testing kit to perform these tests. This testing is designed so that banana producers or agricultural consultants can asses or monitor the health of the soil inexpensively and without the need for a laboratory.

A few threshold values for the tests are described, which suggest whether a soil is healthy or not healthy. Soil health management should be viewed as a continuous improvement process. It is important to monitor key soil properties at regular intervals. To obtain accurate information, banana producers should assess their soil both before and after a new soil management practice. In this way they can determine those practices which have the greatest impact on soil health, and avoid expensive methods that contribute little.

We have tried to incorporate the use of existing tests where possible to prevent duplication. However, we have also given instructions for developing your own soil health kit. The manual and the testing kit described here are products of a banana industry project funded by the Department of Primary Industries and Fisheries, Department of Natural Resources and Water, Growcom and Horticulture Australia Ltd.

1.1. How to use this manual

Figure 1.1: Banana growers examining bulk density tubes at a field day in north Queensland.

This manual guides you through the use of soil health testing kit, which involves some basic instruments and measurements developed particularly for banana producers. The manual has 12 separate sections:

- Section 1 – Introduction. What you need to know about the manual and the project that developed soil health measurements.
- Section 2 – What is soil health? Background information about soils and soil health.
- Section 3 – Key soil health indicators; what are they? Description of soil health indicators and the role they play in soil health.
- Section 4 – How do I measure soil health? Step-by-step instructions on how to conduct each test.
- Section 5 – What does soil health mean? Description of what the implications of the different measurements mean for banana production.
- Section 6 – How can I manage soil health? Description on how soil management can be used to maintain soil health.
- Section 7 – Soils as a system. Integration of the different management components to develop a sustainable banana production system.
- Section 8 – Soil health case studies. How some growers have implemented soil health practices on their farms.
- Section 9 – Soil health recording and calculation sheets. Used to record measurements and calculate soil health measurements.
- Section 10 – My soil health records. Space to record your soil health measurements and monitor changes over time.
- Section 11 – Building a soil health kit for bananas. Description of the items used in soil health and where they may be purchased.
- Section 12 – Reference section. Reference material used to build this manual and some useful web sites for more information.

Figure 1.2: Using soil health equipment in the field.

Figure 1.3: Measuring infiltration rate of water entering the soil.

If you are using the soil health kit for the first time, you should learn about key soil health indicators and why they are important. This information is set out in Sections 2 and 3. Section 4 provides information and step by step instructions on how to conduct each of the 7 soil health tests.

The items required to make the soil health test kit are described in Section 11. Most of these items are readily available from variety stores, hardware stores, electronic suppliers and plumbing suppliers. Our aim was to make use of every day items wherever possible. However, some items are more specific to soils and will need to be purchased from agricultural suppliers or scientific supply companies. Some of the items contained in the test kit are displayed in the pictures at the side (Figure 1.4 and 1.5). If only a few tests are to be conducted each year, you may be able to purchase relatively inexpensive pH and EC meters from agricultural suppliers. However, if you intend to do a lot of samples it may be worth contacting scientific supply companies and purchasing more reliable instruments.

Figure 1.4: As many everyday items as possible are used to construct a soil health kit

Figure 1.5: Some specialised laboratory equipment is required for some soil health measurements.

Blank recording and calculation sheets are provided in Section 9. These sheets should be copied and are used for each field. Instructions for the calculations are provided on each sheet. Some calculations can be done once and the value copied for all other soil measurements using the same piece of equipment. A spreadsheet could also be set up on the computer to do the calculations. Section 10 provides an area to record the measurements, so that you can quickly see any trends or changes in the soil health indicators for your property. If you are comparing two different soil management systems, the records can be placed on the same graph to allow for a quick comparison of differences over time.

Section 5 helps understand what the soil health measurements mean and how these relate to other soil properties and banana production. Section 6 describes how to manage the different soil health properties. However, the soil should be looked at as a system, because a change in soil management may have effects on a number of soil properties, and this is described in Section 7. Section 8 provides some case studies showing how different banana growers have attempted to improve their soil health by setting objectives such as reducing cultivation, managing ground cover, optimising nutrient use or applying amendments. Their experiences and the soil health measurements that they are monitoring are discussed.

Finally, Section 12 is a reference section. It includes some of the resources used to help build this manual and the soil health tests. Other types of soil tests are available, but the information and tests described in this manual are designed specifically for improving soil health in Australian banana production systems while keeping the time and expense of soil health monitoring to a minimum.

Section 2. What is soil health?

Figure 2.1: Poor soil health can lead to soil erosion.

The question "what is soil health?" often provokes emotive discussion. This is because soil health is a difficult concept to define and individuals have differing ideas of what soil health is, depending on their perspectives on soil management. Soil health has also been promoted as being "*the land of milk and honey*"; capable of solving all the problems of modern agriculture, however, we take a more realistic view of soil health. There are many benefits from achieving a healthy soil, but this may require some hard work. There must be continual fine tuning and it may take some time to see the benefits. The definition we are using for soil health is:

"Soil health is the effective functioning of the soil system so that it provides for the growth of plants in a sustainable system".

In our case, we are talking about the soils ability to function sustainably for the production of bananas. We need the soil to support the profitable growth of plants without impacting on the surrounding environment and without degrading the soil resource. This involves developing a balance in inputs that both promote greater profitability and do not harm the environment.

Figure 2.2: Poor soil health can lead to compaction of the soil, resulting in poor anchorage of the banana plant where the corm sits on the soil surface.

Symptoms of unhealthy soils can include;

- poor plant growth
- poor water infiltration
- soil erosion
- continuing plant disease and pest problems

The symptoms of poor soil health not only show themselves in reduced plant yield and fruit quality, but may also show up as poor water quality leaving the farm due to excess sediment and nutrients in water ways. This draws unfavourable attention from the public and environmental regulators, and puts pressure back on agricultural industries to improve management practices.

The concept of soil health requires a holistic view of the soil. That is, we need to look at all the components that make up a living soil, how they interact with one another and how they interact to sustain banana production. The separate components of the soil are physical, chemical and biological soil properties, which have typically been investigated as separate categories, with little regard to their interactions and dependence on one another. Land use and management decisions have a big impact on the interaction of the components that go into making a healthy soil.

2.1. What is soil?

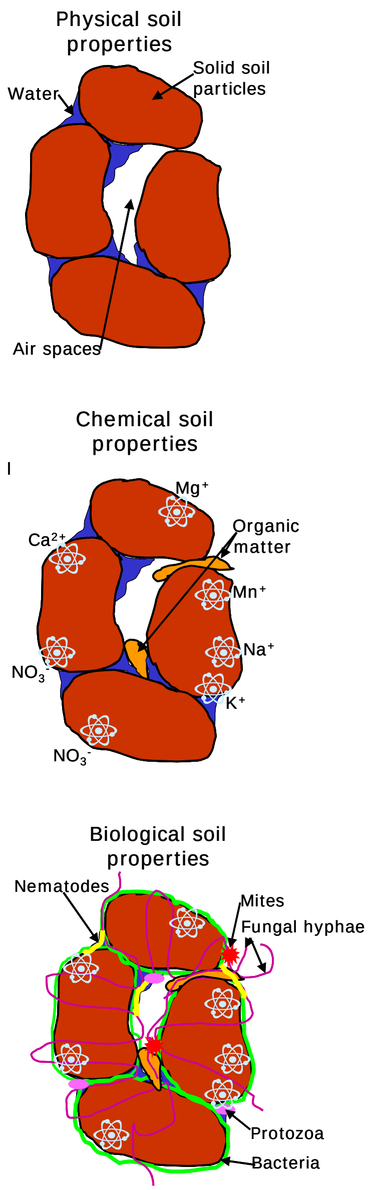


Figure 2.3: Physical, chemical and biological properties of soil interact to determine soil health.

Soil is made up of minerals (~45%), water (~25%), air (~25%) and organic matterial (~5%). The make up of the soil will vary depending on conditions. As soils dry out, there will be less water and more air and conversely, following rain there will be more water and less air.

Soil minerals give soils many of their properties and will determine the soils suitability for agriculture. The minerals in soil are derived from rock, known as the *parent material*. As the rock is weathered down over many years it forms soils. The mineral elements exist in different sizes which can be classified as sand, silt and clay. The proportion of sand, silt and clay fractions in the soil will give the soil its texture. The amount and type of clay minerals in the soil affect its chemical properties. Soils with high clay content are able to hold on to nutrients, much better than sandy soils. Soils with sandy texture are usually better draining than clay soils. The mineral component of soils does not vary with changes in agricultural management.

Water in the soil and the ability of the soil to supply water to the plant is an important property. Very sandy soils will drain very quickly following rain or irrigation and require continual recharging with water to support good plant growth. On the other hand, soils with high clay content are able to hold more water in small pore spaces, but following rainfall it may take a long time for the water to move down into the soil. Water in the soil contains dissolved nutrients that are able to be taken up by plant roots. The supply of water to plants is critical in supporting uninterrupted plant growth.

Air displaces water in the soil as the soil dries out. The air in the soil is found in pore spaces. Connections between pore spaces allow gases such as oxygen to reach organisms and plant roots. The more pore spaces in the soil the greater its capacity for holding water and air, which benefits the plants as well as the animals in the soil. We refer to soils with few pore spaces as "*compacted*"

Organic matter is the smallest component of the soil but it is the most diverse. It affects many soil properties. Soil organic matter is made up of;

- non living organic matter – such as decomposing plant, stable humus, animal and microbial organisms
- living organisms – which can range from microscopic to the size of large earthworms. These include fungi, bacteria, actinomycetes, insects, mites, protozoa, tardigrades, rotifers
- plant roots which interact with the soil to support the growth of the plant.

2.2. Physical soil properties

Physical soil properties deal with the arrangement of soil particles and the movement of air and water in and out of the soil. The physical soil properties can be viewed as the skeleton of the soil. The physical properties are what everything else is built onto. They determine how the chemical and biological properties can be arranged in the soil 3-dimensionally. Good physical soil health provides an optimal supply of air and water to the plant roots. Too much water means that plant roots and soil organisms do not receive enough oxygen. Poor aeration allows the soil to become saturated for a long period of time and plant growth declines. When there is not enough water in the soil the plant needs to work harder to take up water and nutrients, which means the banana plant needs to use more energy extracting nutrients and less energy is going to developing a bunch. In very dry conditions, plants stop transpiring by closing their stomates (pores within the leaf). When this occurs, photosynthesis and plant growth stops.

Figure 2.4: Formation of bog holes is a result of trafficking wet soils.

A soil may become compacted when the soil particles are forced close together. Compaction occurs more readily in wet soil because soil particles are suspended in the water and move easily. When the soil dries the particles have been pushed together in a dense mass. Tillage operations, particularly use of rotary hoes in wet soil, smear the soil particles together, reducing the amount of pore space in the soil. Sometimes, the effects of compaction are not easily seen as compaction occurs below the soil surface and can form a plough layer at a depth of about 30 cm. This means that the ability of roots to efficiently extract water and nutrients is greatly reduced.

The use of heavy machinery in wet conditions can cause subsoil compaction, which can lead to the formation of wheel ruts and bog holes. With increasing soil depth, the compacted soil can spread over a wider area. In wet soil, the compaction forces near the surface are more easily transferred to the subsoil. It may then take years for the soil to correct itself without intervention.

Figure 2.5: Water logged soils reduce the oxygen supply to the roots and cause yellowing of the leaves as the roots are unable to function properly to take up water and nutrients.

When soil particles stick together they form aggregates. Aggregates are the structures or clumps of soil formed when soil minerals and organic matter are bound together. Aggregation in the soil surface is promoted by organic matter. A well aggregated soil, if properly managed, is able to maintain a good balance of air and water, promote nutrient recycling and root development while resisting erosion, surface sealing and other forms of soil degradation. Every time the soil is tilled, the natural soil aggregates break down. Following rainfall, this leads to the soil particles dispersing, resulting in soil surface crusting. The formation of crusts on the soil surface means that more water moves over the soil surface, increasing the chance of soil erosion and nutrient movement in soil particles.

Management practices rarely change soil texture, proportions of sand, silt and clay, but management can have a big impact on the how air and water enter the soil. If physical soil properties are poor, we generally use tillage to improve air movement into the soil or irrigation to supply extra water. We very rarely think about what effects these practices have on the chemical and biological properties in the soil.

2.3. Chemical soil properties

Figure 2.6: Nutrient deficiencies in bananas possibly from an imbalance in nutrients such as induced calcium deficiency (Photo courtesy of E. Serrano CORBANA Costa Rica).

Figure 2.7: Calcium deficiency induced by an imbalance in nutrients caused by excess fertiliser applications (Photo courtesy of E. Serrano CORBANA Costa Rica).

Chemical soil properties deal with the nutrients in the soil and the soil's ability to supply nutrients to the plant. Chemical properties are usually referred to as the fertility of the soil. Soil fertility consists of different nutrients, the balance of these nutrients to one another and the supply of nutrients to growth of the plant. The nutrients exist in a very dilute solution in the soil water, or attached to soil or organic matter particles. Some nutrient fractions are readily available to plants and others are not. If we think soil fertility is low, we add fertiliser to fix the nutrient deficiencies or an amendment, such as lime, to correct a chemical imbalance. It has been common-place to add a little more fertiliser than is required just to make things grow a little better. The addition of fertiliser, however, affects the physical and biological properties of the soil.

The growth of a profitable banana crop requires a constant supply of nutrients to the plant. If the soil does not supply enough nutrients to the roots to support plant growth, production is reduced. However, if the supply of nutrients is more than the plant is able to take up, the nutrients may move off the farm affecting the environment. Some forms of nutrients such as nitrate-nitrogen (NO_3-N) are very water soluble and below the root zone. Other nutrients, such as phosphorus (P), are not water soluble and bind strongly with soil particles. However, they may move with soil particles when soil erosion occurs.

The banana plant needs greater quantities of some nutrients more than others. These are often referred to as macronutrients. The macronutrients required by plants are nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sulphur (S). The banana plant needs these elements in relatively large amounts for optimal plant growth. This is particularly so for N and K. These are usually supplemented in the soil through the addition of fertilisers.

Other nutrients such as iron (Fe), manganese (Mn), copper (Cu), zinc (Zn), molybdenum (Mo), chlorine (Cl) and cobalt (Co) are used by the plants in very small amounts, and are called *micronutrients*. They are still very important for optimal plant growth, but they are only needed in very small amounts. Quite often, the soil is capable of supplying all the micronutrients the plants need. However, with continual removal of fruit over a long period of time, some of the micronutrients may be lacking in the soil.

Toxicity due to excess micronutrients can also occur. Toxicity usually occurs when soil conditions change, making a nutrient more available than it normally would be. Saturated clay soils that have poor aeration often develop Mn nodules in the soil. This excess Mn can be taken up by the plant in levels higher than is needed by the plant, displacing other nutrients and resulting in toxicity symptoms. Quite often, Mn toxicity can develop as a result of the reduced availability of Ca, Mg and Zn in saturated acidic soils.

Another important chemical property is the *reaction* of the soil solution: that is whether it is acidic, neutral or alkaline. Some soil solutions possess an abundance of hydrogen ion (H^+) and are referred to as *acid* soils. This is the most common condition for banana producing soils. Other soils have an abundance of hydroxyl ion (OH^-) and are referred to as *alkaline* soils. Where there is a balance of H^+ and OH^- the soil is said to be *neutral*. The reaction of the soil is determined by measuring the amount of H^+ in the soil solution. This is referred to as the soil pH. Soils with a pH less than 7 are referred to as acidic. Soils with a pH greater than 7 are referred to as alkaline. Soil solutions with a low pH have a high concentration of H^+ in the soil solution.

Figure 2.8: Boron deficiency induced by an imbalance in nutrients caused by excess fertiliser applications (Photo courtesy of E. Serrano CORBANA Costa Rica).

The reaction of the soil affects the availability of nutrients in the soil solution. As soils become more acidic, the availability of aluminium (Al) increases. Excessive Al is toxic to banana plants and has been associated with reduced root growth.

Some soils are able to resist changes in soil pH better than others. This is referred to as the buffering capacity of the soil. As H^+ are removed from the soil solution they are replaced by the reserve acidity. The size of the reserve acidity is the buffering pH capacity of the soil. Soils with low buffering capacity have larger variations in pH. The pH can be altered by management practices, such as liming or fertilising.

It has been suggested that the ratio of nutrients, particularly nutrients that have a positive charge (known as cations) is the key to soil health. This includes nutrients such as Ca, K and Mg. However, the ratio of Ca and Mg in the soil has not been found to influence plant growth, except at extreme values, that are rarely encountered in a normal soil. At extreme ratios, the excess of one cation can cause a deficiency of another. This is because plant roots are able to selectively take up some nutrients from the soil solution and have adapted to variations in the ratios of nutrients in the soil solution.

2.4. Biological soil properties

Biological soil properties deal with the previously living and living component of the soil. The previously living is dead plant and animal material in various states of decay. The living component of the soil is made up of animals and plants. Some biological organisms are large and easily seen with the naked eye, such as earth worms. Others are microscopic and can only be seen with a microscope. Special techniques are required to find these organisms in the soil. The easiest way to classify the soil organisms is based on size (Figure 2.9). The biological component is the most diverse and dynamic component of the soil. Most of the biological activity occurs in the top 10 cm of soil where there is a high volume of air and plant residue movement.

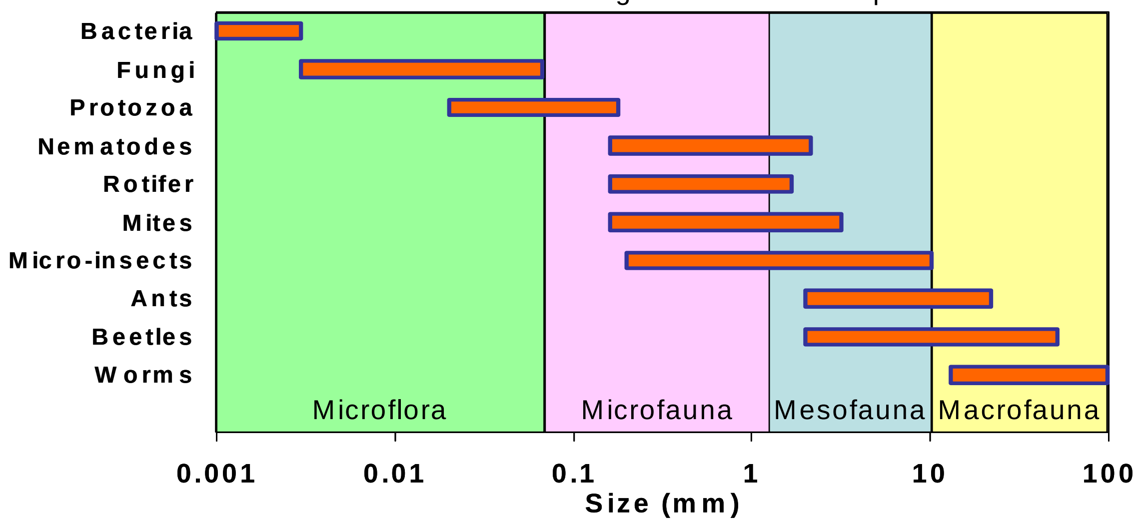


Figure 2.9: Size classifications of some example organisms found in banana soils

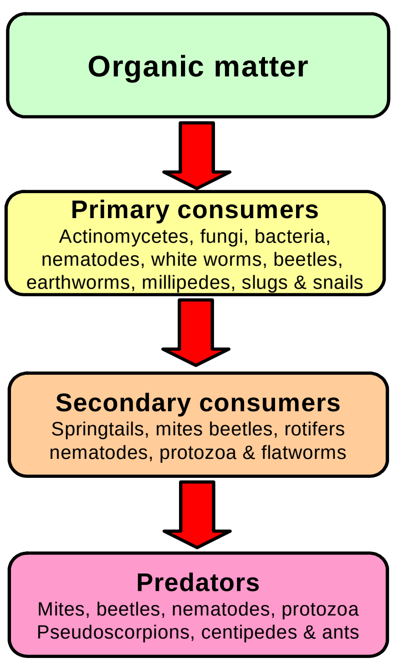
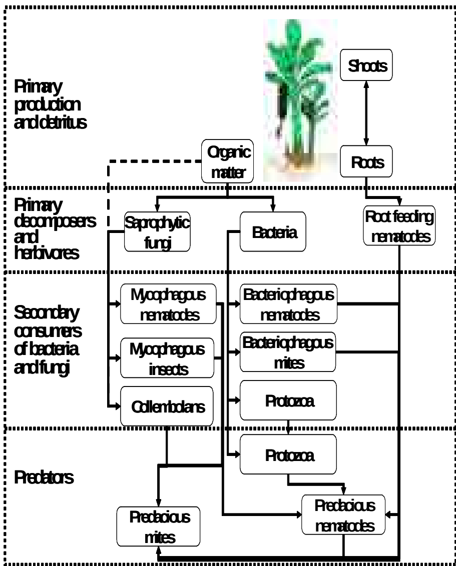


Figure 2.10: Decomposition of organic matter is achieved by different groups of organisms.

Most of our knowledge about the biological component of agricultural soil surrounds important pest and disease-causing organisms. To overcome these pest and disease problems, we have generally applied pesticides, which in turn affect other organisms inhabiting the soil. The application of both pesticides and fertiliser may impact on organisms which have been helping to suppress and prevent pests and diseases.

Many of the soil organisms also promote plant growth by recycling nutrients, improving the structure of the soil and detoxifying the soil by degrading chemicals and preventing them from accumulating.

Nutrient recycling – Organic matter in agricultural soils can contain high levels of nutrients. However, much of this is unavailable to the plant until it undergoes transformation by soil organisms in a process known as mineralisation; converting organic forms of nutrients into mineral forms that can be taken up by plants. Few organisms possess the ability to decompose organic matter by themselves. Instead, there are chains of organisms that decompose the organic matter, ranging from large organisms that shred the organic matter turning it into smaller pieces, to fungi and bacteria that act on specific compounds to release nutrients. This chain of events and the connectivity of organisms is known as the soil food web.



Figures 2.11: Simplified soil food web with examples of organisms responsible at each level for the decomposition of organic matter. Arrows indicate the direction of energy flows in the soil food webs.

Maintaining soil structure – Biological activity has a strong influence on the formation and maintenance of good soil structure. The mucus covering of some organisms in the soil, mix with soil particles, sticking them together to form soil aggregates. Soil fungi not only produce mucus, but the hyphae can act as a net helping to form soil aggregates.

Suppression of plant diseases – Disease suppression is a natural condition that can be found in most agricultural soils. However, agricultural activities can disrupt disease suppression in soils, allowing the pathogens to become dominant. Disease suppression occurs when the disease causing organism is present, but it is not causing symptoms or yield loss. Suppressive soils are thought to result from predator-prey relationships occurring as part of the interactions of organisms in the soil food web.

Soil detoxification – The organisms in the soil act as biofilters, decomposing many of the pollutants and pesticides that are applied to the soil. The organisms in the soil are able to use some pesticides as a food substrate, breaking it down into harmless components. This is referred to as *biodegradation*.

Measuring soil biology

When investigating the biology of soils, we want to know the size of the biological soil component or how active the organisms are, and the diversity of organisms present.

Biological activity can be measured in a number of different ways. Soil biology can be measured either directly or indirectly. Direct measurements of biological activity looks at the organisms, either in the soil, or, once they are extracted from the soil.

Indirect measurements of biological activity rely on measuring chemical substrates produced by the organisms in the soil. One of the easiest ways is to measure the amount of carbon dioxide (CO_2) produced. Other methods look at enzyme activity in the soil. Enzymes are produced by soil organisms for the purpose of breaking down specific compounds.

Biological diversity is the number of different types of organisms present in the soil (a single gram of soil can contain several thousand different species of bacteria alone). Because there are a large number of different type of organisms present in the soil, measurement of diversity usually only looks at certain groups of organisms, which are thought to representative of other soil organisms. As well as the diversity of organisms, we are also interested in the diversity of different functions they perform in the soil. Soils with greater functional diversity tend to be more resilient; that is they are able to recover from disturbance better than soils that have poor functional diversity.

2.5. Holistic soil management

Figure 2.12: Holistic soil management looks at how farm practices impact on physical, chemical and biological soil properties.

Good soil health requires a holistic view of the soil. Holistic soil management is concerned with how the physical, chemical and biological soil components work together to sustain plant growth with minimal impact on the surrounding environment (Figure 2.10). The problems in agricultural production generally arise, due to a focus on single issues within the soil, with little regard to how this will impact on other soil properties over the long term. Because soil properties can be slow to change, we do not fully appreciate the effects that we may be having on the soil and, therefore, continue doing what we have always done.

However, by measuring soil properties and production information, it is possible to develop a set of key indicators for use in soil health monitoring. The soil indicators take into account the physical, chemical and biological soil properties, their interaction with one another and their impact on banana production. This strategy involves measurements of the soil environment and requires understanding of how a soil functions and how management decisions impact on the components of the soil.

Many banana growers have an intuitive knowledge of their land and what makes up a healthy soil, through observation of soil conditions and plant performance. Also, this knowledge can be further developed by carrying out some objective measurements leading to better overall soil management. Comparative soil tests can give banana growers valuable information on soil properties if they are done at a comparable time using the same method. The tests need not be expensive but must integrate physical, chemical and biological soil properties with banana production.

Figure 2.13: Farm practices impact on the physical, chemical and biological soil properties and need to be viewed as a holistic management system.

Section 3. Key soil health indicators: what are they?

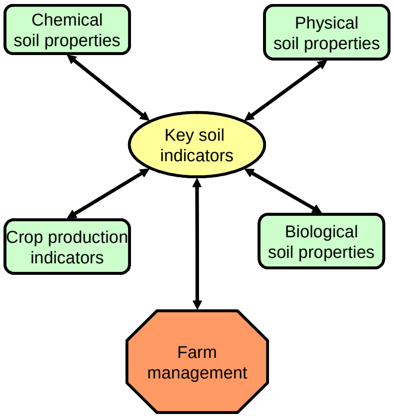


Figure 3.1: Holistic soil health management requires the monitoring of soil physical, chemical and biological properties and their interaction and relationship with farm management practices.

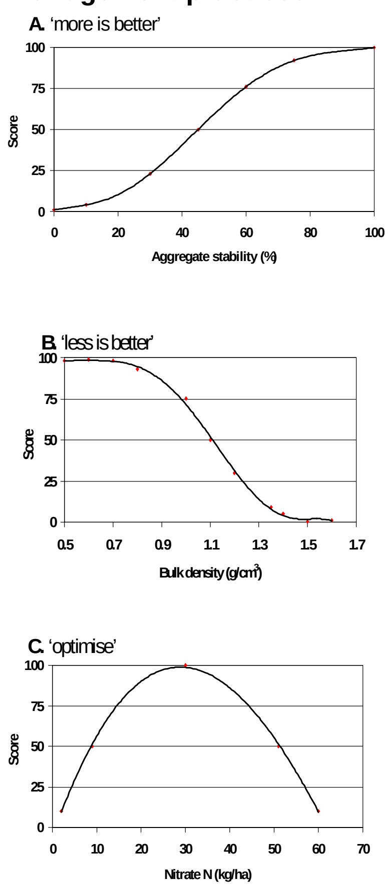


Figure 3.2: Theoretical interpretation methods for soil health indicators, (A) 'more is better', (B) 'less is better' or (C) 'optimum'.

Key soil health indicators are soil measurements that are able to relate changes in soil properties to changes in soil management. Because improper management of the soil can lead to damaging changes in soil function, there is a need for tools and methods to assess and monitor soil health. Soil health measurements are able to indicate to us if there is a problem with the soil. However, they do not tell us exactly what is wrong.

Indicators of soil heath are measurements of soil properties that have the greatest sensitivity to change and, can be related to the functioning of the soil, to provide sustainable banana production. Soil health indicators should:

- capable of detecting changes in physical, chemical and biological soil properties and how they interact with one another
- sensitive to changes in management
- be easy to use by many users
- be reproducible in a range of environments and
- wherever possible be part of existing soil measurements

We want the indicators to be able to tell us how healthy the soil is and what changes, if any, are required in banana crop management. To determine the most sensitive indicators for Australian bananas, a survey was conducted to compare banana plantations with nearby less intensively managed plant systems, such as rainforest and pastures, to determine what soil properties had changed under the cultivation of bananas. The intention of the survey was not to provide values that banana soils should be achieving, as any agricultural activity will inevitably change the soil environment. However, it is useful to know which soil properties are the most sensitive to changes under banana cultivation.

Indicators have been selected and they can be classified into three groups for interpretation;

- more is better – improved soil health with higher levels, poor soil health at low levels e.g. aggregate stability (Figure 3.2 A)
- less is better – improve soil health with lower values, poor soil health with high values e.g. bulk density (Figure 3.2 B)
- optimum – increasing values have a positive effect on soil health up to an optimum value, beyond this point soil health begins to decline e.g. soil nitrate (Figure 3.2 C)

For the Australian banana industry, seven key soil health indicators were chosen as being sensitive to changes in land management (Table 3.1). The seven indicators chosen were measurements of two physical, four chemical and one biological soil property.

Table 3.1: Key soil health indicators for the Australian banana industry that match productivity with sustainability and are responsive to management changes as a result of growing bananas.

Test	Description	Physical, chemical or biological	Sensitivity	Ease of use on farm (1 difficult) (5 easy)	Exists in current soil tests	What is best?
Bulk density	Bulk density is a measure of how compacted a soil is, and if the soil has enough air space for plant roots and organisms to function.	Physical	Slow to change	3 - needs special equipment, takes time and requires calculations	No	Less is best
Water infiltration	Infiltration is a measure of how fast water enters the soil. Water entering too slowly may lead to ponding, water logging and more runoff causing erosion.	Physical	Slow to change	4 – Needs some equipment made but is easy to manufacture	No	More is best
Root mass	A measure of the health of the root system of the banana plant. The weight of roots also helps to interpret the soil respiration results.	Biological	Medium	3 – takes time to wash the soil away from the roots and needs scales	No	More is best
Electrical conductivity (EC)	Electrical conductivity (EC) is a measure of the dissolved salts in the soil. A high soil EC reading can indicate high levels of nutrients from fertilisers.	Chemical	Changes rapidly	3 – requires mixing soil with water and EC meter.	Yes	Less is best
Soil pH	Farm practices affect the level of acidity in the soil. Soil pH measures the level of acidity and can influence nutrient availability and soil biology.	Chemical	Medium	3 – requires mixing soil with water and pH meter.	Yes	Optimise
Soil nitrate (NO_3-N)	A measure of how much of the nitrate form of nitrogen is present in the soil. Not enough nitrate can slow plant growth, too much nitrogen increases risk of losses to the environment.	Chemical	Changes rapidly	3 – requires mixing soil with water, filtering and NO_3-N test strips.	Yes	Optimise
Soil phosphorus	A measure of how much phosphorus is present in the soil. Not enough phosphorus can slow plant growth, too much phosphorus increases risk of losses to the environment.	Chemical	Medium	1 – needs specialised soil laboratory.	Yes	Optimise

3.1. *What is bulk density?*

Figure 3.3: Measuring the height of cylinders used to measure the bulk density of the soil.

Figure 3.4: Measuring the diameter of cylinders to determine the bulk density of the soil.

Bulk density is the determination of how densely the soil particles are packed together. Bulk density is defined as the ratio of the mass of oven dried soil to its volume, which includes the volume of particles and the pore spaces between particles. In other words, it is the weight of soil for a given volume. It is dependent on the density of soil particles (sand, silt, clay and organic matter) and how much air space exists between them. It is the most common method used to measure soil compaction. The greater the density, the greater the compaction and the less pore space for air and water movement as well as root growth.

Bulk density is usually measured using a cylinder which is driven into the soil with minimal disturbance of the soil. The volume of the cylinder is determined by measuring its height (Figure 3.3) and the cylinder's inner diameter (Figure 3.4). The volume of the cylinder can then be calculated using the formula.

$$\text{Volume} = (\textbf{diameter} / 2)^2\ \pi \times \textbf{height}$$

$$= (\textbf{diameter} / 2) \times (\textbf{diameter} / 2) \times 3.14 \times \textbf{height}$$

In the photographs at the side, the height of the cylinder is 7.5 cm and the diameter is 7.4 cm. Therefore, the volume is:

$$\text{Volume} = (7.4 / 2) \times (7.4 / 2) \times 3.14 \times 7.5$$
$$= 3.7 \times 3.7 \times 3.14 \times 7.5$$
$$= 322.4\ \text{cm}^3$$

The bulk density of a soil is changeable and will vary according to structural conditions of the soil. It is altered by cultivation, compression by machinery, people and rainfall. Bulk density increases with increasing soil depth and generally ranges between 1.0 and 1.7 g cm^{-3}

3.2. What is water infiltration?

Figure 3.5: Poor infiltration of water into the soil can lead to waterlogged soils, where a lack of oxygen makes it difficult for banana roots to function.

Water infiltration is a measure of how fast water enters the soil. Infiltration into the soil is a function of the soil type, soil physical condition, such as aggregation and the stability of aggregates, and the water content of the soil. Water entering the soil too slowly may lead to ponding or water running off the surface of the soil which causes erosion. If water enters too quickly into the soil it may be a sign of poor water holding capacity of the soil. The rate of water infiltration is dependent on the condition of the soil surface and the connectivity of the soil pores below the soil surface.

Soils that develop crusts, or soils where the soil particles have dispersed due to poor chemical qualities, do not allow the water to enter as readily as soils with a porous surface with good aggregated structure. In compacted soils, there are fewer pore spaces, which also tend to be smaller. If the connectivity between soil pores is not good, it means it is difficult for the water to move through the soil.

If water is unable to infiltrate into the soil, then it will runoff. When water moves across the soil surface as runoff, it can carry soil particles causing erosion and nutrients. This can result in streams and rivers becoming silted and with excess nutrients also causing environmental problems.

3.3. What is root mass?

Figure 3.6: Toppling of bananas caused by poor root anchorage into the soil

Roots are a vital part of the banana plant. The roots are responsible for anchoring the plant into the soil (Figure 3.6), absorbing and moving water and nutrients to the rest of the plant. The roots of bananas also produce plant growth regulating chemicals and contribute to the development of suckers. Ninety percent of the roots of the banana plant are located within 1 m of the plant, and in general 70% of the root mass is found in the upper 40 cm of the soil.

A banana root grows at a rate of 1.2 to 4.0 cm per day and is functional for about 5 months. This means that banana roots can grow to a length of 2.6 to 7.5 m if they are not impeded by soil compaction, low pH, high water tables, low soil temperatures, oxygen deficiency, nematodes or other root feeding organisms.

The banana plant stop producing roots on the main stem once the bunch emerges. The root mass is reduced by more than 10% following bunch emergence. However, the amount of healthy roots may be reduced by up to 17%. Following bunch emergence, all new root growth occurs on the suckers.

Figure 3.7: Branching of banana roots following the death of the root tip.

Bananas tend to have a low root density in the soil compared to other crops. Bananas tend to have about 1cm of root for each cubic cm of soil. Other agricultural crops tend to have a higher root density, between 4 to 50 cm of root in each cubic cm of soil. This means that there is less banana root present in the soil to take up water and nutrients. Therefore, the banana plant is very sensitive to damage of its root system, making it very important to prevent any impediments to root growth to allow the banana plant to work efficiently extracting water and nutrients from the soil.

Root growth is sensitive to conditions in the soil. Optimal root growth of banana occurs between 22-25 ^{o}C. Lower temperatures will slow root growth. There is no root growth at temperatures below 13 ^{o}C. The roots of banana plants are also very sensitive to oxygen deficiency, which occurs in waterlogged soil (see water infiltration). Waterlogging, resulting in oxygen deficiency for more than 6 hours, is likely to kill root tips. This then results in branching of the roots. Similarly, not enough water will result in reduction in root growth and the death of the root tip. When the roots start to grow again, they have multiple branching, giving a witches broom appearance (Figure 3.7).

3.4. What is soil pH?

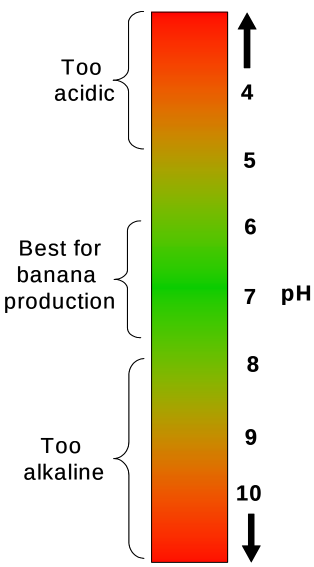


Figure 3.8: Optimum soil pH for banana growth and extreme alkaline and acidic pH values.

Soil pH is a measure of the acidity or alkalinity of a soil, which affects the availability of plant nutrients, activity of micro-organisms and the solubility of soil minerals. pH is a measurement of the amount of hydrogen ions in the soil solution (H^{+}). A pH of 7 is regarded as neutral. A pH value lower than 7 is acidic and higher than 7 is alkaline.

Banana producing soils in north Queensland are naturally acidic. Bananas are able to deal with some acidity. However, low soil pH means that elements such as aluminium or manganese become very soluble in the soil. These can be toxic and have a negative effect on plant growth. This begins to occur when the pH drops below 5.5. Also, a low soil pH means that other nutrients, such as calcium, become less available in the soil.

Soil acidification is a natural process that is accelerated by acids produced in soil by most nitrogen fertilisers. Careful fertiliser management and increased organic matter content of the soil is required to help slow down the acidification process.

3.5. What is electrical conductivity?

Figure 3.9: Fertiliser applied to the soil surface can increase the electrical conductivity (EC) of the soil.

Electrical conductivity (EC) of soil water indicates the amount of salts present in the soil. The electrical conductivity detects the amount of salts in solution. The more salts in the soil solution the better it is at conducting electricity giving a higher EC measurement. All soils contain some salts which are essential for plant growth. However, excess salts can hinder plant growth and impact on the biology of the soil.

In banana growing areas, high salt content (salinity) is rarely a problem as any excess salts are usually leached through the soil with rainfall. However, a high EC reading can indicate that excessive applications of fertiliser have been applied which can have a temporary effect on soil organisms. Some fertilisers have extra salts as well as the nutrients, so large amounts of fertilisers should not be applied in one application. Excessive amounts of salts, such as sodium (Na), can have a negative effect on soil structure, dispersing the clays, which leads to surface crusting and poor water infiltration.

EC in non saline soils can be a very changeable depending on the period from fertiliser application and the amount of rainfall or irrigation that followed application. In general, measurements of electrical conductivity below 0.8 mS/cm are acceptable for plant growth. At levels higher than this, salt intolerant crops start to suffer.

3.6. What is soil nitrate?

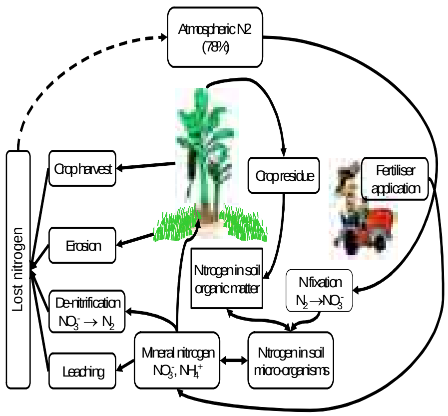


Figure 3.10: Nitrogen cycle within the banana plantation.

Soil nitrate (NO_3^-) is a form of inorganic nitrogen (N) that is available for use by plants. As nitrate is very mobile in the soil, it can be easily leached below the root zone of banana plants and eventually move into waterways. All soils lose a small amount of nitrate to groundwater, including soils under natural vegetation.

Plants need nitrogen to grow, as nitrogen is an important element in carbohydrates, sugars and proteins, which are used to build and fuel the plant. In natural systems, nitrogen is one of the most limiting nutrients commonly deficient in soils, resulting in restricted plant growth. Because nitrate is such a valuable nutrient to plants and micro-organisms, it is continually recycled and redistributed in the soil. This is part of the nitrogen cycle (Figure 3.10). 78% of the air in the atmosphere is nitrogen, but this is not able to be used by plants. It needs to be converted to nitrate or ammonium before it can be absorbed by the plants roots and used to help the plant grow. Some micro-organisms are capable of fixing the nitrogen from the atmosphere and converting it to nitrate. These micro-organisms are usually associated with the roots of leguminous plants and form specialist structures called nodules, where unusable atmospheric nitrogen is converted to usable nitrate. When the plant dies, this nitrate can be made available to other plants after microbes have decomposed the organic matter and died. This process is called *mineralisation*.

Nitrate in banana crops can also come from the addition of fertilisers such as urea, sulphate of ammonia and many blends. These supply the plant with a readily usable form of nitrate. Some of the nitrate added to the soil is taken up by soil organisms. This is called *immobilisation* of nitrogen. Immobilisation is like putting money in the bank. The nitrogen is stored in the micro-organisms and then it is released slowly as the micro-organisms die. If nitrate is not used by the plant or is immobilised, it can be lost from the farm through leaching, erosion or de-nitrification.

Nitrate that is taken up by the plant can also be lost from the farm system through its removal in fruit. The application of nitrogen to the crop should match the growth of the plants and replace any losses through crop removal. However, allowances should also be made for the nitrate that is released from the organic matter of plant residues such as leaf and pseudostem. The application of nitrogen then becomes a balance between supplying enough nitrogen to ensure profitable production, but not too much that excess nitrogen is lost causing problems in the environment.

What is soil phosphorus?

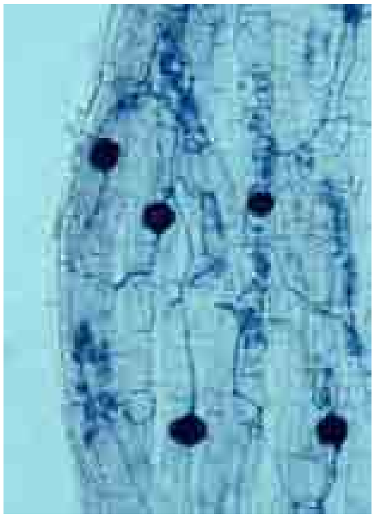


Figure 3.11: Mycorrhiza infecting the roots of banana plants help the plant to acquire phosphorus from the soil.

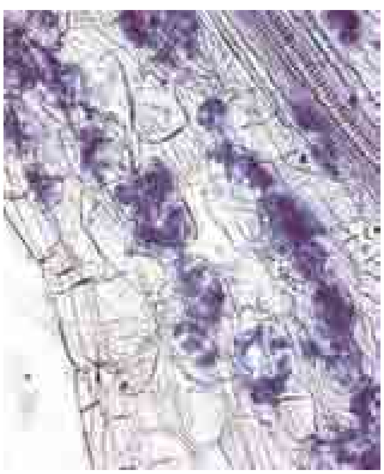


Figure 3.12: Mycorrhiza infecting the roots of banana plants help the plant to acquire phosphorus from the soil.

The banana plant's phosphorus requirements come from the mineral fraction of the soil and from some decomposing organic matter. Unlike nitrogen, phosphorous is relatively immobile in the soil and can be tightly bound to soil particles making it hard for the plant to extract from the soil. The amount of phosphorus in soil solutions is usually quite low. The pH of the soil will greatly affect the amount of phosphorus present in the soil solution. At pH below 6, phosphorus becomes less available in the soil solution. Also, soils with high levels of iron or aluminium oxides will tend to hold onto phosphorus more tightly than other soils. The plant roots absorb soluble phosphorus, mainly as anions from the soil solution.

Phosphorus is used in the plant to ensure proper cell division as the plant grows. Banana plants do not have a high phosphorus requirement and deficiency symptoms are rarely seen in the field. Plants require a steady supply of phosphorus, mostly during early plant growth. A small amount of starter fertiliser at planting usually contains enough phosphorus for the plant's needs. There is very little phosphorus exported off the farm in the fruit.

To help plants extract phosphorus from the minerals component of the soil, many plants, including bananas, form associations between their roots and fungi called *Mycorrhizae*. The plant prvides the fungi somewhere to live and supplies some nutrients, and in exchange the fungus is able to extract from soils, the more immobile nutrients such as phosphorus. The fungus forms structures with the root cells which help the two organisms exchange nutrients (Figure 3.11 and 3.12). Mycorrhiza has also been shown to help protect the plant from other organisms that cause diseases in the plants including other fungi like *Fusarium* spp., and nematodes. However, if there is excess phosphorus in the soil system, the plant no longer needs the fungus to extract the phosphorus from the soil solution as it is able to do this itself. Therefore, the association between the plant and the fungus does not form, leaving the roots of the banana plant more susceptible to attack from soil borne diseases.

Because soil phosphorus is strongly attached to soil particles the main losses of phosphorus from the farm occur with soil erosion. The movement of phosphorus on soil particles can then present problems in waterways by stimulating the growth of algae. As the algae grow they can deplete oxygen in the water and reduce the amount of sunlight that is able to move through the water, causing problems for marine life.

Section 4. How do I measure soil health?

4.1. How do I take soil health measurements?

Figure 4.1: Soil cores from banana fields should be taken randomly across the banana paddock and bulked together.

Figure 4.2: Selection of plants of a uniform age, such as at bract fall, is important.

Figure 4.3: Soil rings should be placed in front of the following sucker at a uniform distance from the plant.

Sampling is probably the most neglected step in soil testing. It is important to choose a representative area for testing, as differences in sampling areas can have a big impact on the results. The following illustrates the importance of proper soil sampling. One hectare of soil, to a depth of 10 cm, weighs about 1 500 tonnes. The total weight of samples taken for testing soil are usually about 0.5 kg or about 0.00003% of the weight of soil in a hectare. This small fraction must be representative of the sampling area.

Two methods of sampling described below. One method requires soil to be collected from a uniform area. The other occurs when tests are conducted in the field and this requires a different sampling approach.

To collect soil samples from a uniform area such as a banana paddock, a minimum of 15 -20 soil cores should be taken across the paddock in a random pattern, usually to a depth of 10 cm. Any parts of the paddock that are obviously different, such as gullies or drainage lines, should be avoided. The soil cores should be bulked together, usually in a bucket, to make a composite sample (Figure 4.1). The soil should be mixed in the bucket and any intact cores should be broken into smaller pieces. Once the larger pieces of soil have been broken down and the soil mixed, a 200 – 500 gram sample is taken and placed in a plastic bag. The bag should be labelled with the name of the paddock and the date and placed inside a foam box or esky to keep it cool. This soil can then be used for soil chemical tests.

The other type of sampling is conducted around the banana plant, and a minimum of five tests should be performed in each paddock. These tests include measuring water infiltration and soil bulk density. It is important to choose a representative area to conduct the tests. Because banana plants in a paddock are often at different development stages in terms of bunch development, it is important to try to standardise the procedure for making the measurements. For example, always choose a plant that has recently bunched (Figure 4.2). Conduct all the soil measurements in front of the following sucker, about 10 cm away from the plant, as this will be the soil that the plant will use for the next ratoon crop and this is the zone of most root activity for the current banana crop (Figure 4.3).

4.2. How do I measure bulk density?

You will need

- 7.5 cm diameter aluminium rings
- rubber mallet
- block of wood
- long-bladed shovel or spade
- paint scraper
- sealable plastic bag

The steps to follow!

- The smaller 7.5cm (or 3 inch) aluminium ring is used to determine the soil bulk density. One end of the ring has a sharpened edge. This is the end that is driven into the ground.
- Determine the volume of the cylinder as described before. It is also helpful to determine the weight of the cylinder. This can be written in permanent marker on the cylinders as this weight is needed later for calculating the amount of dry soil.
- Find a spot no closer than 30 cm from a banana plant, trying to avoid roots. Carefully remove the surface vegetation.
- Using the piece of pine and a rubber mallet, drive in the smaller tube until its top edge is level with the soil surface.
- Carefully dig up the tube. Trim the soil core level to the ring with the scraper and scrape any from the outsides.
- If there are big clods of soil that fall out of the cylinder it will give an underestimation of the soil bulk density. It is important that all the soil from the within the cylinder is retained.
- Very carefully, put the tube and the entire soil core into a labelled plastic bag.
- When you return from the field carefully take the cylinder of soil out of the plastic bag. The soil will still contain the same moisture it had in the field. This is referred to as the wet soil. Determine the wet weight of the soil and the cylinder together. Record this weight on the recording sheet.
- Place the cylinder with the soil core in an oven to dry. Ideally, the soil should be allowed to dry for 3 days at 105^{o}C.
- Once the soil is dry, determine the weight of the cylinder and the soil again. This is the dry weight of the soil, with all the water removed from the pore spaces.

Calculations

Finding the soil moisture content

Before the bulk density can be calculated, it is useful to calculate how much water is present in the soil. This can be used for comparing sites and soils when measured on different occasions.

$$\text{Soil water content (g water / g soil)} = \frac{\text{(Wt. of wet soil \& cylinder - Wt. of dry soil \& cylinder)}}{\text{(Wt. of dry soil \& cylinder – Wt. of cylinder)}}$$

For example:

Weight of sampling cylinder = 54.5 g

Wet weight of the soil and cylinder = 615 g

Dry weight of the soil and cylinder after 3 days at 105 ^{o}C = 425 g.

Then

Soil water (g water / g soil) =

$$\text{Soil water content (g water / g O.D. soil)} = \frac{(615 - 425)}{(425 - 54.5)}$$

$$= \frac{190}{370.5}$$

$$= 0.51$$

This is known as the gravimetric water content with, this soil having a gravimetric water content of 51%. The gravimetric water content will vary according to the soil type and the time since the last rainfall or irrigation event. Clay soils tend to have a higher gravimetric water content as the water is held tighter in the smaller pores. Sandy soils tend to have a lower gravimetric water content as there are a large number of large pore spaces that do not hold onto water very well and drain quickly.

Finding the bulk density

To calculate the soil bulk density we can use the following equation.

$$\text{Soil bulk density (g cm}^{-3}\text{)} = \frac{\text{Weight of oven dry soil (g)}}{\text{Volume of cylinder (cm}^{3}\text{)}}$$

$$\text{Soil bulk density (g cm}^{-3}\text{)} = \frac{\text{Weight of oven dry soil (g) – Weight cylinder (g)}}{\text{Volume of cylinder (cm}^{3}\text{)}}$$

For our example above and using the volume of the sampling tube calculated earlier, the calculation for soil bulk density is:

$$\text{Soil bulk density (g cm}^{-3}\text{)} = \frac{425 - 54.5}{322.4}$$

$$\text{Soil bulk density (g cm}^{-3}\text{)} = \frac{370.5}{322.4}$$

$$\text{Soil bulk density (g cm}^{-3}\text{)} = 1.15 \text{ g cm}^{-3}$$

4.3. How do I measure water infiltration?

What you need!

- 150 mm diameter ring
- rubber mallet
- block of wood
- graduated measuring cylinder
- an electronic timer
- water

The steps to follow!

- Choose a spot for the 150 mm diameter ring to be driven into the ground – a flat area at least 150 mm in diameter and about 100 mm away from a banana plant is ideal (see section on how to take samples). Make sure that the spot chosen is not on the edge of a block, roadway, drain or on top of the irrigation. Do not try to make a spot flat by removing or compressing the soil. It's okay if you can't find spots that are perfectly flat..
- Using the rubber mallet and block of wood, drive the 150 mm ring about two thirds (100 mm) into the soil, leaving one third (50 mm) of the ring above the soil surface.
- An infiltration measurement is taken **twice** in each 150 mm diameter ring.
- Pour 445 ml of water into the graduated cylinder. The best way is to drill a hole into the cylinder at the 445 ml mark. This means that you should not be able to overfill the cylinder.
- Place a plastic sheet inside the 150 mm ring. This protects the soil surface from being disturbed when the water is poured into the ring.
- Gently pour the water evenly over the plastic sheeting inside the ring.
- Remove the plastic sheeting and start the count-up timer as the last of the water is added.
- Observe the water draining into (infiltrating) the soil. Stop the timer and record the time (in minutes and seconds) when no more water is visible at the surface. It may be that the surface is quite uneven and that you will have to make some estimate of when the water would be all gone had the surface been level.
- Repeat the above infiltration measurement procedure immediately using another 445ml of water etc.
- Stop infiltration observation if it reaches 30 minutes. If it's the first infiltration observation at the spot, record 30+ minutes for both observations. If the first observation exceeds 18 minutes, the second measurement will most likely be 30+ minutes.
- You will have two records for infiltration time, one for dry soil and one for wet soil. These can be recorded onto recording sheet (Section 9).

4.4. *How do I measure root mass?*

What you need!	The steps to follow!
• 150 mm diameter rings (still in position from the infiltration measurements) • long-bladed shovel or spade • paint scraper • sealable plastic bag • digital scales 	**In the field** • Once the infiltration measures have finished, drive the ring into the soil until its top is level with the soil surface. • Gently dig up the ring with its soil-root core. With a scraper, trim the soil core so that its level with the bottom of the ring. Scrape away any soil that is sticking on the outside of the ring. • Empty the soil and roots from the ring into a labelled plastic bag.
  	**In the shed** • Carefully wash and discard all the soil from the roots. Be sure to collect the fine roots as well as the cord roots. • Weigh and record the mass of roots from the 150 mm soil core. • The results can be entered on to the recording sheet (Section 9) and calculations made on the density of roots in the soil (g roots per litre of soil).

4.5. How do I measure soil pH?

What you need!	The steps to follow!
• digital scales (accurate to 0.1 gram) • screw top jars • deionised or distilled water • pH meter • soil collected from multiple cores across the paddock mixed together 	• Before starting, calibrate the pH meter according to the manufacturer's instructions. • Weigh a screw top jar and record the weight. • Add 30 g of soil to the jar which can be done on the scales for better accuracy. • Remove the jar from the scales and add 150 ml of distilled water to the jar and screw on the lid. Shake the jar vigorously for 1 minute. • Allow the water to settle for 30 seconds and take a reading from the upper half of the suspension with the pH meter and add the results to recording sheet (section 9). • **Do not throw out the soil-water mixture!** • Rinse the pH meter with distilled water between measurements and store it as directed by the manufacturer when you have completed the final measurements.

4.6. How do I measure EC?

What you need!	The steps to follow!
• digital scales (accurate to 0.1 gram) • screw top jars) • deionised or distilled water • EC meter • soil collected from multiple cores across the paddock mixed together 	• Before starting calibrate the EC meter according to the manufacturer's instructions. • Use the 1:5 soil water mixture from the soil pH measurements. • Take a reading from the upper half of the suspension with the EC meter and add the results to recording sheet (section 9). • **If you did not measure the soil pH** then use the following steps to measure EC • Weigh a screw top jar and record the weight. • Add 30 g of soil to the jar which can be done on the scales for better accuracy. Remove the jar from the scales and add 150 ml of distilled water to the jar and screw on the lid. Shake the jar vigorously for 1 minute. • Allow the water to settle for 30 seconds and take a reading from the upper half of the suspension with the EC meter. • **Do not throw out the soil-water mixture!** • Rinse the EC meter with distilled water between measurements and store it as directed by the manufacturer when you have completed the final measurements.

4.7. *How do I measure soil nitrate?*

Soil nitrate is measured by most reputable soil testing laboratories. The tests indicated below are not meant to replace soil tests conducted by accredited laboratories. The information generated from doing your own soil nitrate tests can be used as a guide to compare changes due to management. Doing your own tests is much cheaper so it is possible to do more of them to supplement information of soil tests from accredited soil laboratories. You could also incorporate the information you get from soil test labs as this would be a more reliable than the method described below.

What you need!

- coffee filter papers
- screw top jars
- funnel
- collecting jar
- soil-water mixtures from EC and pH tests
- nitrate test strips

The steps to follow!

- Use the 1:5 soil water mix that was used for the pH and EC measurements.
- Fold a filter paper in half lengthways and then in half again. Open it out to make a funnel shaped cup. Put the filter paper cup in a funnel that is sitting above a small jar.
- Carefully pour the soil-water mixture into the filter paper cup. Wait until you have enough clear fluid in the jar to perform a nitrate test on the Aquachek® test strips.
- Dip the test strip into the filtrate for 1 second and remove. Do not shake to remove excess water. Leave it on for one minute.
- Compare the colour change with the nitrate scale on the test strip container and record the result. A darker pink colour indicates more NO_3-N in the soil solution.

The test strips measure the amount of NO_3^- in the solution as parts per million (ppm) or micrograms of NO_3^- per g soil ($\mu g\ g^{-1}$). This can be converted to a more useful form, as kilogram per hectare ($kg\ ha^{-1}$), using an equation to account for the dilution (5) of the soil in the 1:5 soil water mix and the bulk density of the soil.

$$NO_3\text{-N } (kg\ ha^{-1}) = 5 \times \text{ppm soil } NO_3^- \times \text{soil bulk density } (g\ cm^{-3})$$

For a soil with a NO_3^- measurement of 15 ppm that was sampled to a depth of 10 cm and had a bulk density 1.20 ($g\ cm^{-3}$) that calculation would be

$$NO_3\text{-N } (kg\ ha^{-1}) = 5 \times 15 \text{ (ppm)} \times 1.20\ (g\ cm^{-3})$$

$$NO_3\text{-N } (kg\ ha^{-1}) = 90$$

4.8. How do I measure soil phosphorus?

Soil phosphorus levels should be measured by an accredited laboratory. Phosphorus is strongly attached to soil particles and requires the use of special solutions to remove the phosphorus from the soil into solutions. There are different methods and each method has a slightly different extraction efficiency. Therefore, it is important to know which method was used to be able to measure and monitor the trends in phosphorus levels in the soil.

Some of the commonly used methods for extracting phosphorus from soil are:

- Colwell
- Bray
- Olsen
- Lactate
- BSES
- Total phosphorus (Kjeldahl)

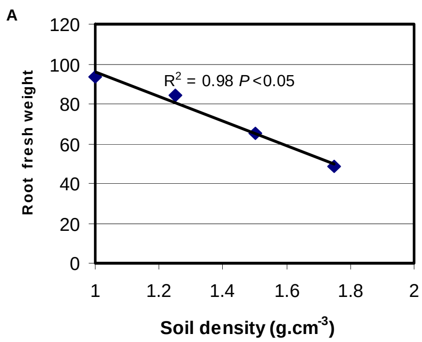
It is important to know which method is being used to test your soil, particularly when you change laboratories, as this may change the results that appear in the nutrient report.

The Colwell method is the method most commonly used for banana soils in Australia. Using this method, the phosphorus level for banana soil in north Queensland should be between 30-60 mg kg^{-1}. Levels higher than this indicate that soil lost due to erosion could contain high levels of phosphorus, which could cause problems in waterways.

It is possible to use test strips similar to NO_3-N testing for phosphorus testing. However, these test strips measure the phosphorus in solution and may not give an accurate estimation of phosphorus in the soil. Therefore, more work is required to develop a test for on-farm soil phosphorus measurement.

Section 5. What does soil health mean?

5.1. What does soil bulk density mean?



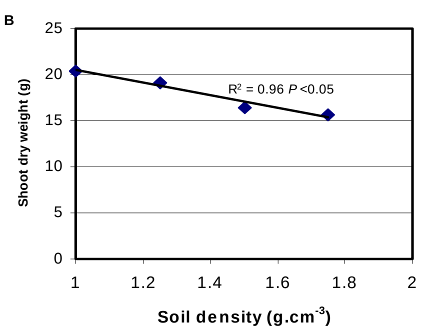


Figure 5.1: Reduced banana root (A) and shoot growth (B) with increasing soil bulk density.

Figure 5.2: Soils with a high bulk density cause the corm of the banana plant to sit on the soil surface making the plant more prone to toppling.

Soil bulk density is a measure of compaction of the soil and how closely together the soil particles are packed. If the soil particles are packed together too closely there are not enough pore spaces in the soil for efficient air and water movement. This means that plant roots need to work harder to be able to grow and to extract water and nutrients from the soil (Figure 5.1). This was shown in a pot experiment where the soil was compacted to different bulk densities and tissue cultured bananas grown in the soil for 12-weeks (Figure 5.1). Plants grown in soil with a high bulk density (1.75 g cm^{-3}) had half the root weight and only 75% of the shoot weight of plants grown in soil that had a low bulk density (1.00 g cm^{-3}).

The roots of banana plants grown in field soil with high bulk density are usually thin and distorted and there tends to be fewer thick cord roots. This was found in a survey of 17 banana fields in north Queensland. Nearly 50% of the variation in the weight of roots greater than 5 mm in diameter could be explained by the bulk density of the soil. The higher the soil bulk density, the fewer roots greater than 5 mm. The thick cord roots are important for supporting the plant as well as for taking up water and nutrients. The thin roots are not as tough as the thicker roots. If they are damaged by nematodes, cane grubs, fertiliser burn or dry out, they more prone to death and breakage.

A compacted soil with a high bulk density also means that the corm of the banana plant is unable to develop properly below the soil surface and is forced to grow on the soil surface (Figure 5.2). When the corm of the banana plant grows on the soil surface, there is reduced anchorage of the plant. It also means that the roots are more critical in the support of the plant. As a result of high bulk density, there are fewer thinner roots. These factors make the plant more prone to toppling.

5.2. What does water infiltration mean?

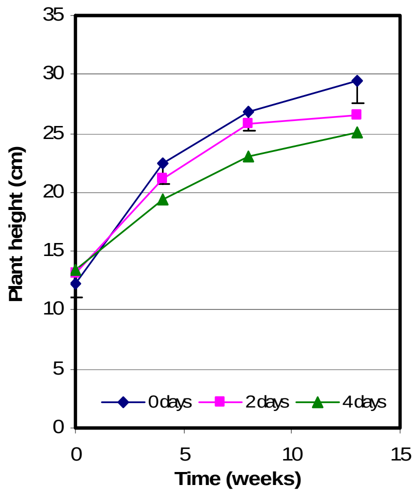


Figure 5.3: Banana plant growth is reduced when the plants are subjected to frequent long periods of waterlogging due to poor infiltration of water into the soil.

Bananas are traditionally grown in areas of high rainfall. In north Queensland, rainfall often exceeds 3 500 mm per year, mostly occurring in heavy rainfall events from January to April. Therefore, the management of the infiltration rate of the soil is an important component of the soil environment. If water is unable to enter and move through the soil, the soil becomes saturated for long periods of time which starves the roots of oxygen. When this occurs, the plant shuts down as it is unable to take up water and nutrients from the soil.

In a pot experiment, the growth of banana plants was reduced when the plants were saturated by placing them in a bucket of water for 4 days per week or 2 days per week compared to plants that remained unsaturated (Figure 5.3). The banana plants that were not saturated were 20% taller than plants that were saturated for 4 days each week over a 13 week period (Figure 5.3). This highlights the importance of banana roots being able to get a good supply of oxygen in order to grow optimally.

5.3. What does root mass mean?

Figure 5.4: Banana roots become distorted when they have to penetrate compacted soil with a high bulk density.

Figure 5.5: The root mass of tissue cultured banana plants is reduced and not as healthy in compacted soil (left) compared to soil with a good soil structure (right).

Figure 5.6: Banana roots showing damage caused by burrowing nematode (*Radopholus similis*)

Many factors affect the root mass of bananas in the soil. The greater the compaction, the higher the bulk density the fewer roots in the soil. Water management is also important. Too much water and the roots die from lack of oxygen and not enough water and the roots suffer drought stress. The amount of water in between too wet and too dry is called the *plant available water*. There is an interaction between the structure of the soil and the optimum soil moisture range for root growth. In compacted soils, or soils with poor structure, the optimum range for soil moisture becomes smaller, which means that water management is more critical than in a well structured soil. In compacted or poorly structured soils, the soil moisture can quickly change from saturated with poor aeration, to dry, causing drought stress for the plants.

Chemical properties also affect the growth of roots. Low soil pH causes a number of elements, such as aluminium (Al) and manganese (Mn), to become excessively available to the plant, leading to toxicity symptoms. However, this usually only occurs in extreme conditions when soil pH is below 5.0. This can cause the roots to burn off. Similarly, fertilisers that have a high salt content may burn roots if applied in large quantities.

Roots are also the hosts to many other organisms, some harmful and some beneficial to the plant. Increasing nematode numbers, particularly the burrowing nematode (*Radopholus similis*), decreases the weight and the capacity of the roots to function properly. The feeding activity of the nematodes causes reddish brown lesions (Figure 5.6). High numbers of nematodes result in a reduction in productivity.

Organisms such as mycorrhizae live within the root but act as a secondary network to help the plants take up nutrients, such as phosphorus (P), which has low mobility in the soil. Mycorrihaze have been associated with a change in the way the banana roots grow in the soil and also associated with increased growth of tissue cultured banana plants. The presence of beneficial organisms in the roots has been found to reduce the damage caused by pathogens such as nematodes and Fusarium wilt.

5.4. *What does soil pH mean?*

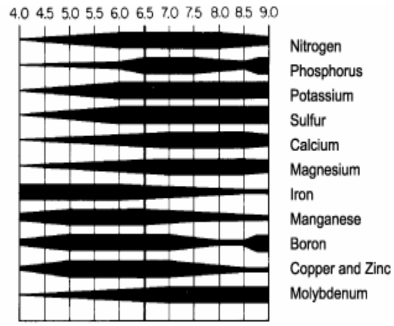


Figure 5.7: Availability of nutrients at different soil pH

A low soil pH means that there are more hydrogen ions (H^+) than hydroxyl ions (OH^-) in the soil solution. This affects the availability of other nutrients to the plant (Figure 5.7).

Results for soil pH and aluminium availability from Costa Rica show how the soil pH decreases (blue line) and aluminium availability increases (pink line) with increasing plantation age (Figure 5.8). This is primarily due to the leaching of nitrogen fertilisers. In this situation, lime was not applied to correct the change in acidity of the soil.

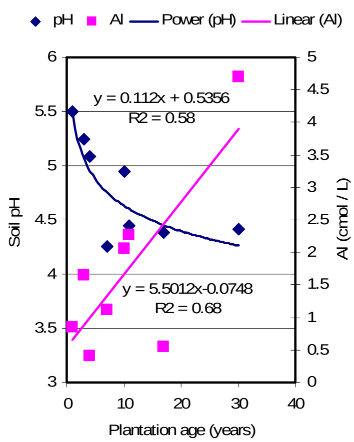


Figure 5.8: Changes in soil pH and available aluminium with increasing plantation age in Costa Rica (data courtesy of E. Serrano, CORBANA, Costa Rica)

The pH of the soil tends to decrease with increasing soil depth. A comparison, made of the soil pH under bananas compared with rainforest, showed a dramatic reduction of soil pH in bananas around 20 cm below the soil surface (Figure 5.9). This again is due to the action of fertilisers applied to the banana crop. It is important to be aware that acidity can develop below the soil surface and that pH at depth should be monitored.

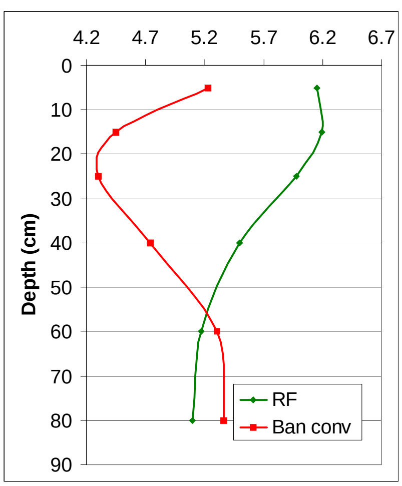


Figure 5.9: Changes in soil pH with increasing soil depth in conventional banana (Ban conv) and nearby rainforest (RF). Subsoil acidity can develop under banana crops with overuse of fertilisers.

5.5. What does EC mean?

Fertilisers are applied to supplement the nutritional needs of banana plants. This increases the electrical conductivity (EC) relative to less intensively managed plant systems such as forest and pastures (Figure 5.10). In Figure 5.10 there is low EC in the organic bananas. However, some organic sources of fertiliser, such as composts, may have a high salt content. It is therefore important to know what the electrical conductivity is of all the inputs applied to the soil to determine if they have a temporary effect raising the salt level in the soil.

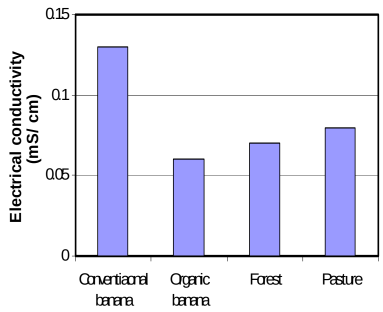


Figure 5.10: Electrical conductivity (EC) in conventional banana soil compared to organic bananas, forest and pastures.

Changes in EC can have a large impact on the biology of the soil. Increasing the EC in the soil was associated with a reduction in the diversity of different types of nematodes. This may be because many of the salts in fertilisers such as NO_3^-, which affect bacterial levels in the soil, then may also affect the organisms that feed on the bacteria such as bacterial feeding nematodes. An increase in the EC tells us there are more salts in the soil. Only specialist organisms can survive in soils with increasing salt content. This has an effect on the soil food web, nutrient recycling and disease suppression.

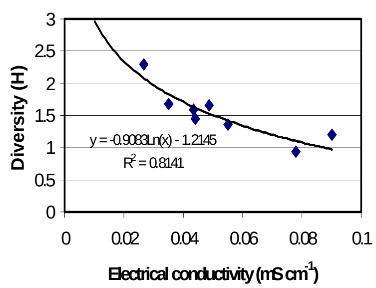


Figure 5.11: Increasing EC in bananas is associated with decreased diversity of nematodes in the soil, possibly due to increased fertiliser usage.

5.6. *What does soil nitrate mean?*

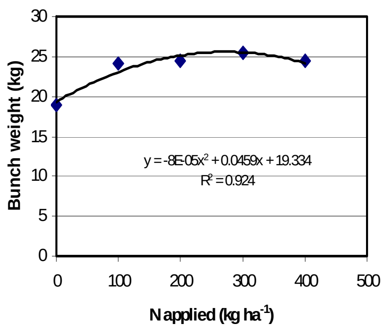


Figure 5.12: Changes in bunch weight of a plant crop of bananas with increasing nitrogen fertiliser application. (courtesy of J. Daniells and J. Armour)

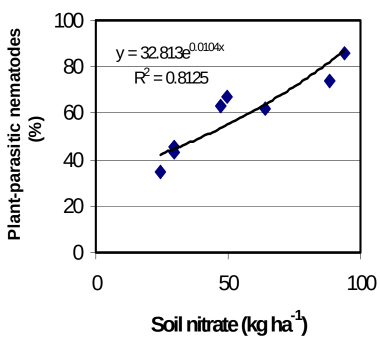


Figure 5.13: Increasing soil nitrate in banana plantations is associated with an increase in the proportion of plant feeding nematodes in the soil.

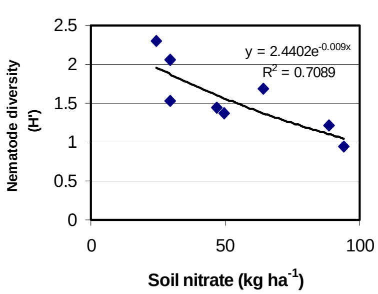


Figure 5.14: Increasing soil nitrate in banana plantations is associated with a decrease in soil nematode diversity of soil nematodes.

Not enough soil nitrate means that plant yields will be reduced. Too much soil nitrate means that there is a high risk that nitrate will move off the farm and into water ways. When nitrate moves into waterways it stimulates the growth of algae. This can have a dramatic effect on the waterways, as the excess growth of algae takes oxygen out of the water making it harder for other organisms to survive.

While nitrogen can increase the growth of the banana plant and the weight of bunch, there is a point when extra applied nitrogen will have no effect on plant growth and can even become toxic; reducing the weight of bunches (Figure 5.12). Before this point is reached, the value of each kg of nitrogen applied starts to diminish. This means that for every extra kg of nitrogen applied there is a smaller increase in bunch weight. If nitrogen is no longer being taken up by the banana plant to increase plant growth and yields, then it is probably causing other problems in the soil and moving off the farm into the environment.

Because nitrogen is usually limiting in soils, addition of extra nitrogen can have a large effect on the biology of the soil. When organic matter is added to the soil, the nutrients contained in the organic matter are released by a variety of micro-organisms that break apart the organic matter, releasing the nutrients. Because a lot of organic matter is of poor quality, many decomposing organisms supplement their nutrition by preying on or parasitising other soil organisms. When easily decomposed organic matter is added to the soil there may be a flush of nutrients which favours quick growing organisms, which dominate the soil biological community. Also, because the organic matter is of higher quality with more nitrogen, decomposing organisms tend to rely less on predatory or parasitic activity to supplement their nutrition. When nitrate becomes available at elevated levels, the quick growing organisms out-compete the slower growing organisms that usually decompose poor quality organic matter. This reduces diversity of the biological community and reduces the suppression of disease causing organisms.

The effects of high soil nitrate levels were illustrated in a survey of banana farms with different management practices. Those having a higher nitrate content in the soil, had more plant parasitic nematodes and less diversity of other types of nematodes (Figures 5.13 and 5.14). The number and type of nematodes in the soil is a good indicator of what is happening in the soil food web. A low diversity of nematodes usually means there is a low diversity of most soil organisms.

5.7. *What does soil phosphorus mean?*

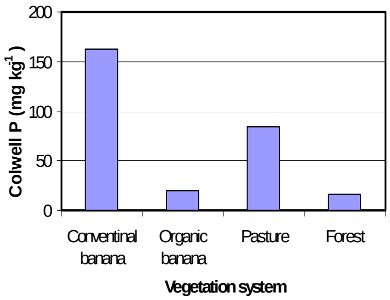


Figure 5.15: Phosphorus levels in conventional banana soils compared to organic bananas, forest and pastures.

About 0.06% of the bunch weight is phosphorus which is exported off the farm. Therefore, for a 30 kg bunch in a plant density of 1700 plant per ha, only about 30 kg of phosphorus is removed each crop cycle. The plant may be able to obtain most of it's phosphorus needs, after the plant crop, by relying on mycorrhizae. It is therefore important to monitor the level of phosphorus in the soil with regular soils tests and ensure that it is not accumulating to high levels.

In a survey comparing bananas in north Queensland to other vegetation systems, including pastures and forest, there was found to be twice as much phosphorus in the soil growing conventional bananas compared to pastures and 8 times more phosphorus in the soil compared to organic banana production and forest soils (Figure 5.15). This suggested that there had been an overuse of phosphorus fertiliser in the banana industry, with more phosphorus being applied than the plant is able to take up. This is expected to reduce the mycorrhizal colonisation of the banana roots, making the plants more susceptible to soil borne diseases.

Section 6. How can I manage soil health?

6.1. How do I manage bulk density?

Figure 6.1: Cultivation of moist soils results in compaction.

Figure 6.2: Use of tracked machinery instead of machinery with tyres may help to slow the development of soil compaction.

Figure 6.3: Wheel ruts developing in banana interrows as a result poor drainage and machinery with narrow tyres moving over wet soil.

Bulk density of the soil can be managed by reducing the amount of tillage, especially in wet conditions. Implements such as rotary hoes have been found to compact the soil more than other implements, particularly in moist conditions. Tillage temporarily reduces bulk density. However, once the soil is wet and settles again, it goes to a more compacted state.

The repair of a compacted soil can take a long time and usually requires crop rotation and addition of organic matter. The roots of grass plants are much finer than the roots of bananas and are able to grow between soil particles and force them apart increasing the amount of pore spaces in the soil. Also, the addition of organic matter provides larger soil organisms, such as earthworms and ants, with a food source. Their movement through the soil moves soil particles and creates larger pores. Therefore, rotating bananas with a grass pasture has a double benefit for the next banana crop. Grasses provide fine roots to help penetrate soil particles and it also provides organic matter encouraging activity of larger soil organisms.

The use of machinery with wide, flotation tyres or tracks instead of narrow tyres may help to reduce soil compaction (Figure 6.2). The load of the machinery is distributed over a greater surface area. This means not as much force is being exerted onto soil particles to create a compaction layer. When the weight of the machinery is concentrated in a small area the force is transferred to the soil. The force being transferred through the tyres can distort the soil particles, especially in wet soils, resulting in wheel ruts and soil compaction (Figure 6.3).

6.2. How do I manage water infiltration?

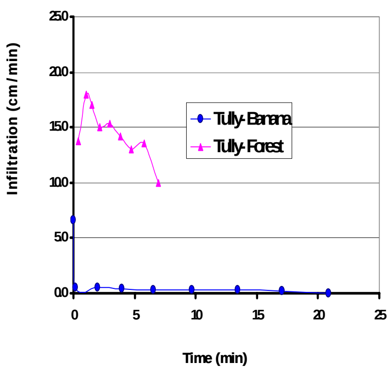


Figure 6.4: Infiltration rate of water in forest soil was faster than nearby banana soils at the Tully.

Maintaining good soil structure is essential to ensure that water can infiltrate into the soil. Soil structure is maintained by retaining crop residues on the soil surface and minimising disturbance of the soil by tillage and traffic. This is highlighted by comparing the infiltration rate of water from undisturbed forest situations with the infiltration rate of water into soil around banana plants. At Tully, more water was able to infiltrate into the soil surface in forest soils than in bananas (Figure 6.4). This is most likely because there is better connectivity between the large pores in the undisturbed forest soil, whereas the connectivity between soil pores has been lost in the banana soils through cultivation and compaction.

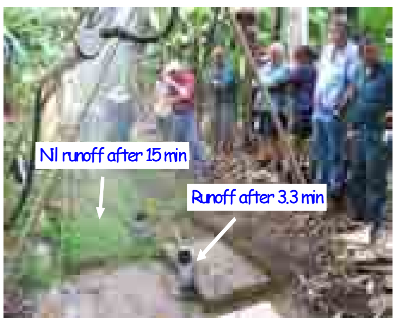


Figure 6.5: Rainfall simulator demonstration measuring the time taken for water to runoff the soil surface in vegetated and non-vegetated areas of a banana interrow.

The use of ground covers such as grassed interrows is able to slow the movement of water across the surface of the soil. The vegetation not only slows the movement of water, but provides root channels and encourages soil organisms, which can make channels in the soil, increasing the infiltration rate of water into the soil. The greater the infiltration rate of water into the soil the lower the risk of erosion from water moving across the soil surface.

The value of vegetated banana interrows was highlighted using a rainfall simulator demonstration, which showed infiltration of water into the bare soil stopping after 3.3 minutes leading to surface water runoff being collected (Figure 6.5). For soil with vegetation growing, no runoff was recorded for 15 minutes when the demonstration was terminated. All of the water applied to the vegetated area had infiltrated into the soil (Figure 6.5).

6.3. How do I manage root mass?

Figure 6.6: Banana roots become distorted when they have to penetrate compacted soil with a high bulk density.

To manage root mass it is important to ensure the plant has optimum physical and chemical conditions with as few pathogens and parasites as possible. Generally, 70% of banana roots are found in the top 40 cm of soil. Therefore, management of the topsoil becomes very critical in maximising the efficiency of roots.

The roots are indicators of good soil health as they integrate the physical, chemical and biological aspects of the soil in order to grow and develop. By managing soil health, you also manage root growth.

6.4. How do I manage soil pH?

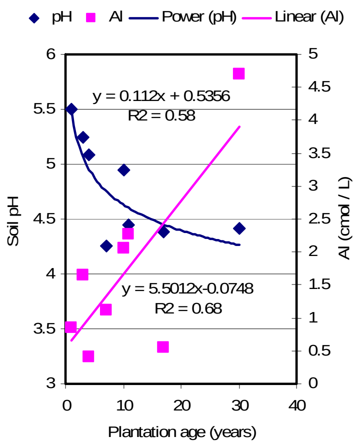


Figure 6.7: Changes in soil pH and available aluminium with increasing plantation age in Costa Rica (data courtesy of E. Serrano CORBANA, Costa Rica).

Increasing the pH of acidic soils is usually accomplished by adding ground or crushed limestone to the soil. Three pieces of information required:

- the current soil pH and target pH are you aiming for
- what is the lime requirement needed to change the pH to the desired level? This will depend on the buffering capacity of the soil. Soils with a higher clay content and organic matter are better buffered than sandy soils and so will resist both increases and decreases in soil pH
- what is the quality of limestone being used? The fineness and the carbonate content of the limestone govern how effective it will be in changing soil pH

As well as managing pH by adding lime, it is also possible to manage the soil pH by managing other soil inputs. The rate of soil acidification can be reduced by;

- choosing less acidifying forms of fertilisers (ammonium based fertilisers are more acidifying than nitrate based fertilisers)
- apply fertiliser to meet plant requirements in frequent, small doses rather than large doses
- schedule irrigation so that over-watering does not occur
- fertigation increases the efficiency of fertiliser use
- return banana organic matter (waste fruit, stalks, leaves and pseudostems) back to the row area around banana plants

Organic matter is also able to buffer the soil from changes in pH. Because organic matter is able to hold onto nutrients, there is less leaching, helping the soil to maintain a stable pH. Organic matter helps to make aluminium less toxic, by preventing the soil pH from becoming acidic. When the soil is acidic, Al is able move into soil solutions to be taken up by plants. Organic matter is also able to tie up the Al in acid soils making it less available to banana plants.

6.5. How do I manage EC?

Electrical conductivity on banana soils in the wet tropics can be managed by careful fertiliser and nutrient application. Because bananas are grown in areas of high rainfall, many of the salts that could build up to cause salinity are leached from the soil. Temporary periods of high electrical conductivity can be avoided using small applications of fertiliser applied frequently, rather than less frequent large applications. This will better match the nutritional requirements of the banana plant.

How do I manage soil nitrate?

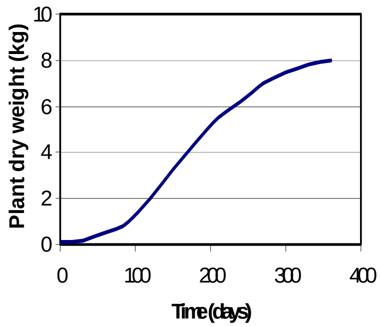


Figure 6.8: Growth of the banana plant can be used to plan fertiliser application so that applications match the need of the banana plant reducing nitrogen losses from the farm.

Good nitrogen fertiliser management relies on a good understanding of nitrogen inputs and outputs for the soil system.

The banana bunch only makes up about 20% of the total weight of the entire plant. However, only about 0.4% of the fresh weight of the banana bunch is made of nitrogen. Therefore, in a 30 kg bunch there is around 120 g (0.12 kg) of nitrogen removed. In a plantation with a density of 1 700 plants per ha, this means that approximately 204 kg of nitrogen per ha is removed with each harvest. This is a simple nutrient budget. A nutrient budget looks at the losses and tries to balance these with the inputs (Box below). The use of regular leaf nutrient tests can help to make nutrient budgets more accurate.

In this example, an extra 30 kg of nitrogen per ha is unaccounted for. Some of this would become bound up in the soil microorganisms, while some will be leached through the soil and end up in waterways. While this is a simplified nutrient budget it can still be used as a guide to fertiliser applications.

Large amounts of nitrogen can be lost by inefficient fertiliser applications. Up to 30% of the nitrogen applied in bananas can be lost through leaching. Another 30% of nitrogen applied can be lost through losses to the atmosphere. To improve the efficiency of fertiliser applications, the amount applied should match the needs of the plant. When the plant is first growing, it requires relatively little nutrients. As the plant increases its growth rate, the amount of nutrients required increases until the bunch is formed (Figure 6.8).

Table 6.1 Simplified nutrient budget for nitrogen use in bananas

Source	**Components**	**Nitrogen lost ($kg\ ha^{-1}$)**		**Nitrogen inputs**	**Components**	**($kg\ ha^{-1}$)**
Removal in fruit	Bunch weight	30 kg		Fertiliser	543 kg urea	
	Nitrogen content of fruit	0.4%			Urea 46% N	
	Plant density / ha	1700		Total N		270
Total nitrogen removed in fruit			204	Plant residue	4400 $kg\ ha^{-1}$ 1.5% nitrogen	66
Uptake in stems & leaves			66			
Leaching		5%	17			
Erosion		1%	2			
Volatilisation and de-nitrification		5%	17			
Total losses			**306**	**Total inputs**		**336**
Difference						**30**

6.6. *How do I manage soil phosphorus?*

Phosphorus can be managed by matching the inputs with the phosphorus being exported in fruit and by reducing soil erosion. Phosphorus behaves differently in the soil in comparison with nitrogen. Therefore, it should not be assumed that because nitrogen is low, then the phosphorus is low. The two nutrients must to be evaluated separately. Relatively small amounts of phosphorus are exported in the fruit of bananas so fertiliser needs are low in comparison to nitrogen and potassium.

Figure 6.9: Soil erosion is the major pathway for phosphorus to move off-farm

The application of phosphorous fertilisers to the soil surface means that the phosphorus is prone to erosion, so ideally, when phosphorous fertilisers are applied they should be incorporated into the soil. This is only easily achievable at planting. Phosphorus, attached to soil particles below the soil surface is not as prone to soil erosion.

Minimising soil erosion is the best method of keeping the phosphorus in the soil on farm (Figure 6.9). Erosion is reduced by maintaining ground cover, especially in periods when heavy rain is expected, reducing tillage, especially when the soil is wet and improving the soil structure through addition of organic matter (Figure 6.10). By establishing vegetation buffer zones, grassed areas around paddocks and sediment ponds, any soil that is lost from the paddock can be trapped before entering waterways. This will reduce the level of phosphorus in waterways.

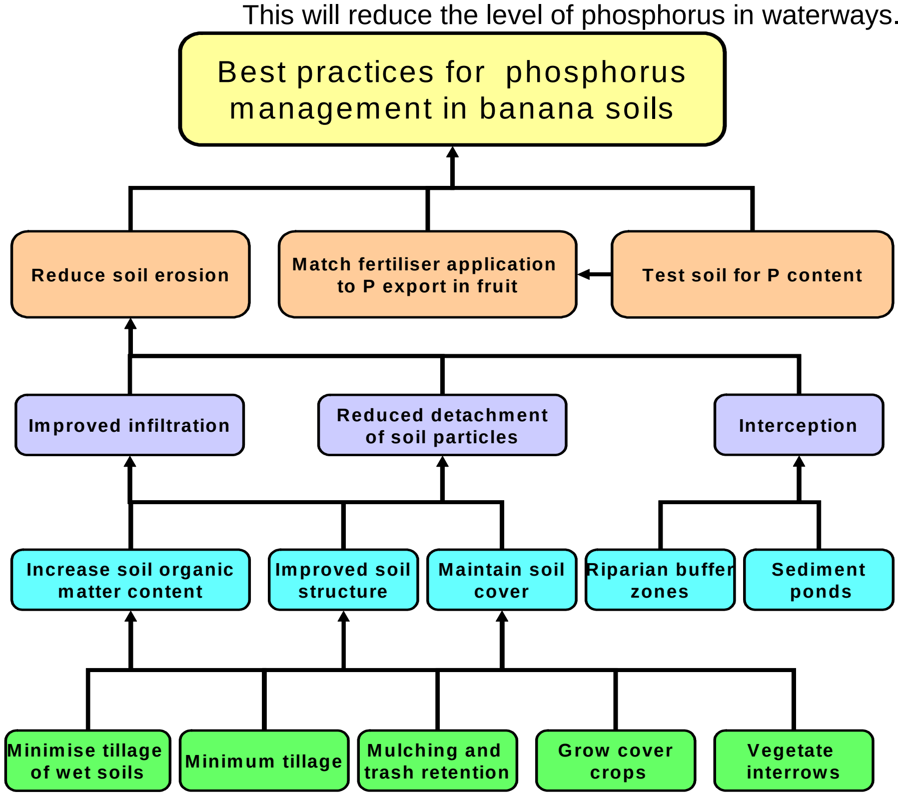


Figure 6.10: Best farm management practice options for managing phosphorus on banana plantations.

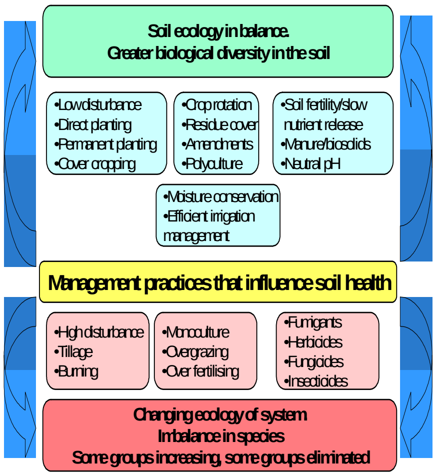


Figure 7.1: Effect of management practices on soil biology and soil health (Kennedy *et al.* 2004).

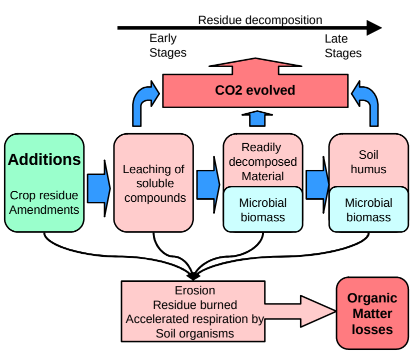


Figure 7.2: Stages of decomposition and losses of organic matter following additions to the soil (Kennedy *et al.* 2004).

Soil health management requires a holistic view of the soil. For a soil to function properly to sustain banana production the physical, chemical and biological components of the soil need to work together. The partnership of these soil components helps soils to resist changes. There are a number of mechanisms in the soil which rely on the interaction of the different soil components, such as biological activity to access nutrients from different nutrients pools or biological activity to maintain the structure of the soil. Activities like these in the soil help to buffer the plant from changes and as a result changes to soil properties occur slowly and often go unnoticed. However, over a long period of time or with severely degrading practices, problems with production and the health of the surrounding environment may begin to occur. Once soils have become degraded, good soil properties can be take a long time to be restored.

It is important to realise what impact management decisions will have on soil health. The improvement of soil health follows some basic principles (Figure 7.1). Management practices that increase the diversity of plant and root systems, and the types of plant residue that are returned to the soil, increase the diversity of organisms in the soil. Increased biological diversity helps to build a healthier soil that is better at sustaining plant growth. There are other benefits with increased biological diversity, such as improved nutrient recycling, improved soil stability and disease suppression.

Management practices that use a lot of inputs and impose large disturbances on the soil environment, such as fertilisers, tillage and pesticides and a reliance on monocultures (single plant species) tend to decrease the diversity of organisms in the soil (Figure 7.1). The continual removal of plant residues degrades the organic matter levels in the soil, which reduces microbial activity and diversity, reducing the health of the soil. Practices that degrade the health of the soil make an agricultural system less sustainable, reducing the viability of the farming operation and degrading the surrounding environment.

Proper organic matter management plays is essential in developing healthy soil systems. Because organic matter is made up of a mixture of compounds, it performs a number of different roles in the soil. However, organic matter is continually being lost from soil as either CO_2 or as particles (Figure 7.2). The activities of organisms in the soil require the carbon in organic matter as an energy source. This activity causes carbon to be lost as CO_2 to the atmosphere. However, soil management decisions can accelerate the losses of organic matter from the soil. Practices such as burning, tillage, erosion and over fertilisation all speed up organic matter loss. Managing the systems to improve soil health requires that carbon be sequestered or saved in the soil as humus or microbial biomass. Therefore, the addition of carbon as organic matter must be greater than losses as CO_2 or as organic particles. However, the process of sequestering carbon may take many years.

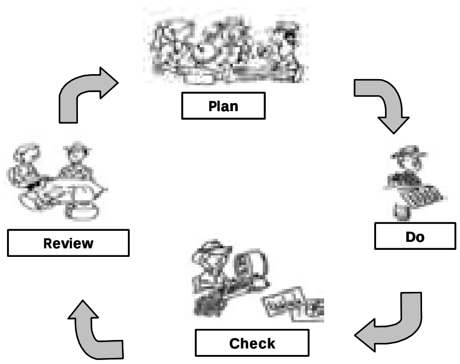


Figure 7.3: Continual improvement process for implementing better systems for managing soil health.

Soil health management is not a one-off treatment, but a process of continually improving and refining management practices. The improvement of soil health through the development of good soil management systems requires a strategic process of planning, implementing, monitoring and reviewing to determine if the changes implemented are working (Figure 7.3).

- The “planning” process requires some definite aims and defined methods for addressing soil problems. The aims and methods must be realistically achievable.
- The “doing” process is the implementation of practices that may vary from what was traditionally done before.
- The “checking” is the monitoring that allows measurements to be obtained for comparisons between new practices and old practices. These do not have to be sophisticated or expensive tests. They can be done with simple on-farm tools.
- The “reviewing” of the practice changes allows a better understanding of what has worked, what has not worked and why. It is also the next stage in the continual improvement cycle and provides information for the next planning stage.

Agricultural practices can have a positive or a negative effect on the health of the soil. It is important to understand how management decisions impact on long-term soil and plant health. Soil health management requires an awareness of how physical, chemical and biological soil properties work together to sustain plant growth. Decision making for the management of soil systems needs to be balanced, integrating the physical, chemical and biological soil properties with plant productivity, while ensuring environmental sustainability.

The management of soil organic matter is an important part of developing healthy soils. A better understanding of how carbon contained within organic matter is continually lost from the soil and what practices can save soil carbon is fundamental to building healthy soils.

Any decisions about developing a “healthier soil system” should be structured with the aim of continually improving soil management and not relying on “one-off” treatments with the expectations that this will fix all soil and production problems. The benefits from healthy soil practices may not occur immediately, and will not solve all production problems, but will eventually result in sustained productivity and environmental protection.

Section 8. Soil health case studies

8.1. Reducing cultivation

Traditionally cultivation in banana production is used to:

- Eradicate old blocks – 3 to 5 passes with large trailing discs to knock down and chop up the crop residue
- Prepare land for planting – 10 to 12 passes to flatten beds, break compaction layers, reform beds and prepare a suitable tilth
- Maintain good surface drainage in the plantation interrows – mostly done late in the year with a v-blade to ensure unimpeded surface drainage and repair "bog holes"

Figure 8.1: Yellowing banana plants as a result of injection with glyphosate.

In recent years banana growers have been investigating methods of reducing the amount of cultivation used in each of these aspects of banana production. Some of these practices are now well established, and provide benefits in reduced cost, more flexibility in timing of operations and reduced environmental impacts.

Figure 8.2: Dying banana plants are allowed to decompose in place.

- **Herbicide crop eradication** – banana crops are being eradicated by injecting or spraying with the systemic herbicide glyphosate. The plants go yellow in about two weeks (Fig 8.1), and progressively die leaving plant residues to decompose in place until conditions are ready to prepare the land for the next crop (Fig 8.2). This method has a number of advantages:
  - Reduced cost as smaller machinery and fewer passes (reduced from about 6 to 2) are required because residue is decomposing
  - Reduced cultivation helps reduce impacts on soil physical, chemical & biological properties
  - Reduced population of pests such as burrowing nematode because very few volunteer plants occur with the herbicide treatment
  - The decomposing crop residue protects the soil surface from erosion during periods of heavy rainfall
  - The beds used in the previous crop can be retained and used for the next crop, reducing the amount of cultivation use in land preparation

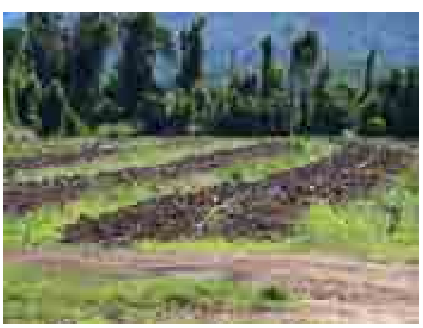


Figure 8.3: Only the bed area is cultivated, leaving the interrows with vegetation.

- **Permanent beds/zonal tillage** – eradicating blocks with glyphosate provides the opportunity to retain the beds from the previous crop, significantly reducing the cultivation needed for land preparation. The advantages of this practice are:
  - Reduced cost because only cultivating the bed area (about 40% of the paddock), and using less cultivation

Figure 8.4 Planting of bananas can take place with minimal disturbance of the soil.

(5 compared to 10-12) by avoiding the need to flatten and reform beds.

- Reduced cultivation helps reduce impacts on soil physical, chemical & biological properties, and compacted soil from the interrow is not mixed into the row area each time a block is replanted.
- Improved flexibility in planting time, particularly if weather conditions are limiting, because fewer cultivations means planting can occur more quickly.
- Fallow crops can still be used by growing in the bed area until it is ready to be planted.
- Ground cover can be maintained in the interrows of plant crops, which is a stage in the crop with a high risk of soil erosion
- Establishing drainage lines and contour banks can be retained, and the retention of grass and other vegetation in the interrow helps to maintain the shape and function for surface.

By implementing these 2 practices growers can reduce the tillage operations needed to eradicate blocks and prepare the land for new banana plantings from 12-15 to less than 7, and:

- Conserve organic matter
- Reduce risk of soil erosion
- Reduce the disturbance of soil biology
- Improve soil structure
- Allow greater flexibility of farm operations
- Save money.

8.2. Managing ground cover

Figure 8.5: Rhodes grass grown as a ground cover to help reduce nematode numbers and add organic matter to the soil.

Ground cover management is an important part of the health of banana soils because ground covers have been shown to:

- slow the speed of water moving across the soil surface,
- reduce the impact of raindrops hitting the soil surface
- provide root channels to assist with the movement of air and water into the soil,
- Increase the organic matter in the soil
- Increase the biological diversity in the soil.

Ground covers may include living plants such as a cover crops during a fallow period (Figure 8.5), interrow ground cover (Figure 8.7) or residues from the banana crop (Figure 8.8).

There are 4 main opportunities in banana production to maintain ground cover to prevent soil erosion and improve the health of the soil. They are:

- **Crop eradication** – the use of glyphosate herbicide to eradicate blocks provides the option to leave the crop residue as ground cover on the soil surface during the wet season when the risk of soil erosion is highest. The crop

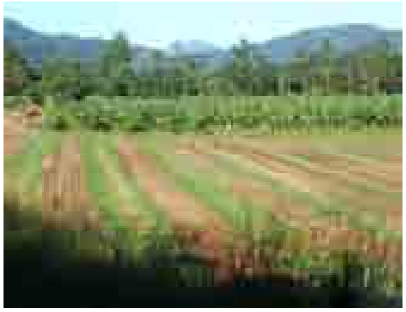


Figure 8.6: Using herbicides to spray only the area to be used for land preparation ensures there is some ground cover even in the plantation establishment phase.

Figure 8.7: Grassed interrows help to protect the soil health in this area from degradation.

Figure 8.8: Retention of crop residue around the banana plant helps protect the soil, recycle nutrients and suppress weeds.

residue is also a valuable source of organic matter and nutrients.

- **Fallow periods** - cover crops can be established in the fallow period between banana crops, and by choosing a cover crop that has some resistance to burrowing nematodes , such as Rhodes grass, it can help will reduce the numbers of the nematode in the soil before the next banana crop is planted (Figure 8.5). Growing a thick cover crop will also help to suppress weeds and put additional organic matter back into the soil. The fine roots of grasses are able to penetrate compacted soil aggregates improving the soil structure. By removing cover crops with herbicides some ground protection can remain in place (Figure 8.6). The dying cover crop is also able to provide a mulch to suppress weeds while the next banana crop is being established.
- **Interrow vegetation** - ground cover in the interrows is able to reduce soil compaction, sediment movement and soil temperatures, and increase water infiltration and biological diversity. (Figure 8.7). Most plantations begin with any natural interrow vegetation that establishes and through slashing or wick application of herbicide will select for low growing species like sour grass (*Paspalum conjugatum*) or blue couch (*Cynodon dactylon*). Records from one NQ producer show that the extra cost in slashing or mowing interrows is offset by the savings made in reduced herbicide application. The use of wick application equipment attached to bagging machines can significantly reduce the amount of slashing required in plantations.
- **Placement of leaf/stem residue** - regular harvest and leaf disease management practices produce leaf and stem residue that is retained in the field. The retention of this crop residue around the base of the banana plant helps to suppress weeds, re-cycle nutrients, provide organic matter, suppress plant-parasitic nematodes, increase soil biological diversity and reduce erosion.

8.3. Optimising nutrient use

For profitable banana production with optimum yields it is necessary to apply nutrients to the crop in the form of fertilisers. However, applying more fertiliser than the crop really requires can have negative impacts on soil health, and on broader environmental issues like water quality. Optimising nutrient use is based on applying only enough nutrient to produce profitable banana yields, and the nutrients are applied in such as way as to reduce impacts on soil health and losses from the farm. Excessive applications of nutrients should be avoided because they can have a negative impact on soil health by reducing biological diversity and making it harder to increase and retain organic matter in the soil.

Figure 8.9: Spreading granular fertiliser in a banana field

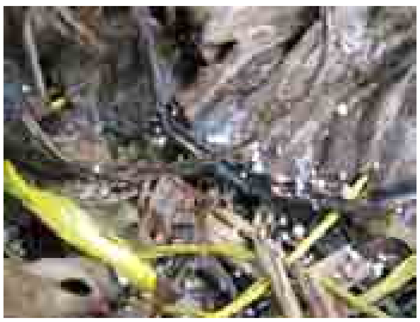


Figure 8.10: Granular fertiliser on the surface of banana residue.

Figure 8.11: Nutrients can be applied by fertigation through the irrigation system.

Producers wanting to optimise their nutrient use can be guided by the basic principles of good nutrient management:

- **Match nutrient inputs to crop needs** – knowing the amount nutrient that the crop needs to grow and produce a profitable bunch allows producers to set target amounts of nutrient that need to be applied. Information on crop removal figures, the amount of nutrient exported from the farm in fruit is also important to refine application rates to replace the lost nutrient. Information is available on crop requirements for nitrogen, phosphorus and potassium under north Queensland production systems.
- **Apply leachable nutrients in small amounts regularly** – this reduces the risk of leaching occurring during periods of heavy rainfall, ensuring more of the total nutrient applied is available for the crop to use. During wet periods when irrigation is not required the use of granular fertilisers spread by machinery is the most common method of application (Figures 8.9 and 8.10). However, during drier periods of the year, the application of fertiliser through the irrigation systems can be much more efficient (Figure 8.11) Reducing leaching can also have an impact on soil health as nitrogen from ammonium-based fertilisers has an acidifying affect on the soil which affects nutrient holding capacity and biological diversity.
- **Maximising crop uptake** – the safest place for nutrients to be is in the crop. Managing factors that reduce crop uptake such as poor irrigation, root and corm damage from pest and disease or soil compaction affecting the plant's root mass, ensure that more of the applied nutrient is available for the crop to use.
- **Monitor nutrient status and plant performance regularly** – the use of regular soil and leaf tissue analysis helps producers know if they need to adjust their target amounts. Optimal ranges for nitrogen and potassium in leaf tissue analysis has been well correlated with yield, allowing

producers to adjust nutrient inputs based on the results. Monitoring plant yields and pack-out figures provides feedback on any effect that changing nutrient inputs might have. Some soil nutrient tests can provide valuable information on key soil health indicators like organic carbon and phosphorus levels over time.

- **Record-keeping to assist farm management** – accurate records of fertiliser applications, yield and pack-out data and results of soil and leaf testing are all part of optimising nutrient use. Good sets of records allow producers to examine yields and pack-out with respect to nutrient inputs and nutrient monitoring (Fig 8.12). Soil test results over time can provide valuable information about trends in key soil health indicators like pH, organic carbon and phosphorus.

Figure 8.12: Electronic recording systems can help schedule better fertiliser applications

By implementing a fertiliser program based on these principles some banana producers in north Queensland have already made savings in fertiliser costs by reducing their application target for some nutrients by 30-50%, while maintaining marketed yields of 51t/ha.

8.4. Using amendments

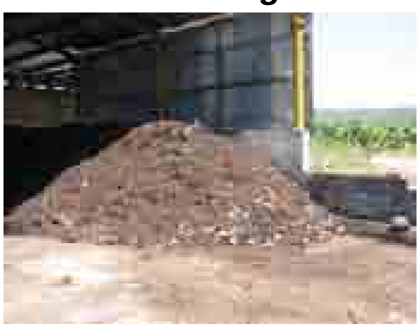


Figure 8.13: Composts can be made on farm from waste organic material.

Figure 8.14: Composted organic matter is partially decomposed and stabilised before being applied to the banana crop.

Different amendments can be applied to the soil to try and correct limiting soil factors. Amendments applied to the soil can be from organic sources or inorganic. Most amendments used in agriculture are waste products, either from other industries or from households.

Careful consideration is needed when deciding to use amendment on bananas. Amendments may be able to correct limiting soil properties in some circumstances, but not all farms are the same so you need to evaluate your own circumstances before applying the amendments. The things you need to consider are;

- What is the limiting soil factor that I am trying to correct by applying an amendment?
- What is the best amendment to use to correct the limiting factor?
- How much will you need to correct the soil properties?
- What are the hazards of applying the amendments such as heavy metals, weeds etc?
- Is it cost effective to use an amendment or is their an alternative?
- How will you evaluate if the amendment is working or not?

While the application of amendments has many benefits it may not be the answer in every circumstance. There are also

Figure 8.15: By products from agricultural industries, such as the ash from sugar mills can be used as amendments for bananas.

Figure 8.16: Amendments such as mill ash are able to change soil properties to improve soil health around bananas.

many different types of amendments that could be used in the banana industry.

Composting organic wastes is a method of stabilising the organic matter and ensuring that no harmful organisms or weeds are passed onto the farm. Because organic amendments are made up of different organic material they can have different nutrient contents which can effect how they work in the soil. However, not all banana farms have the facility to make their own compost or access to waste organic material. If composts need to be brought in they may become expensive if there is large distance between the source of compost and the farm.

Amendments from other industries or waste from packing sheds are available around banana growing areas. Mill ash and mill mud, by-products from processing sugar cane have been used to amend banana soil. However, these products can be difficult to obtain as more agricultural industries realise the value of waste products to supplement

Generally large amounts of amendments are required to have an effect on changing soil properties. If large amounts are needed it may be worth considering using a fallow crop and using cover crops to help improve soil health. Because bananas are grown in warm, wet areas biological activity is usually high. This means that many organic amendments are decomposed rapidly and need to be replaced regularly if they are to have a lasting effect on improving soil health.

Section 9. Soil health recording and calculation sheet

SOIL HEALTH: Data record sheet

Date:	Name:
Farm:	Field:

Large ring (150 mm) in the field:

Sample	Infiltration 1 (min:sec) (A)	Infiltration 1 (secs) B = min x 60 + sec	**Infiltration dry ($cm\ min^{-1}$)** C = 150 / (B)	Infiltration 2 (min:sec) (D)	Infiltration 2 (secs) E = min x 60 + sec	**Infiltration wet ($cm\ min^{-1}$) D = 150 / (C)**
	:			:		
	:			:		
	:			:		
	:			:		
	:			:		

Large ring (150 mm) in the shed:

Sample	Height of sampling tube (cm) (A)	Diameter of sampling tube (cm) (B)	Volume of sampling tube (cm^3) C=(A) x 3.14 $x((B)/2)^2$	Root weight (g) (D)	**Root Mass ($g\ l\ soil^{-1}$)** **E = 1000 x (D)/(C)**

Soil moisture and bulk density:

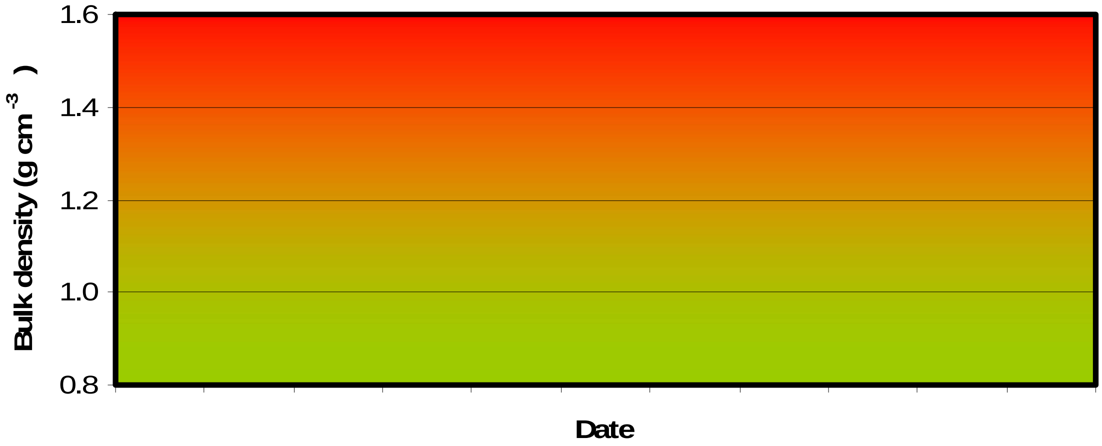
Sample	Weight of sampling tube (g) (A)	Height of sampling tube (cm) (B)	Diameter of sampling tube (cm) (C)	Volume of sampling tube (cm^3) D =(B) x 3.14 $x((C)/2)^2$	Wet soil + sampling tube (g) (E)	Dry soil + sampling tube (g) (F)	**Gravimetric soil moisture ($g\ g^{-1}$)** $G = \frac{(E) - (F)}{(F) - (A)}$	**Bulk density ($g\ cm^{-3}$)** $F = \frac{(F) - (A)}{(D)}$

Soil chemical properties:

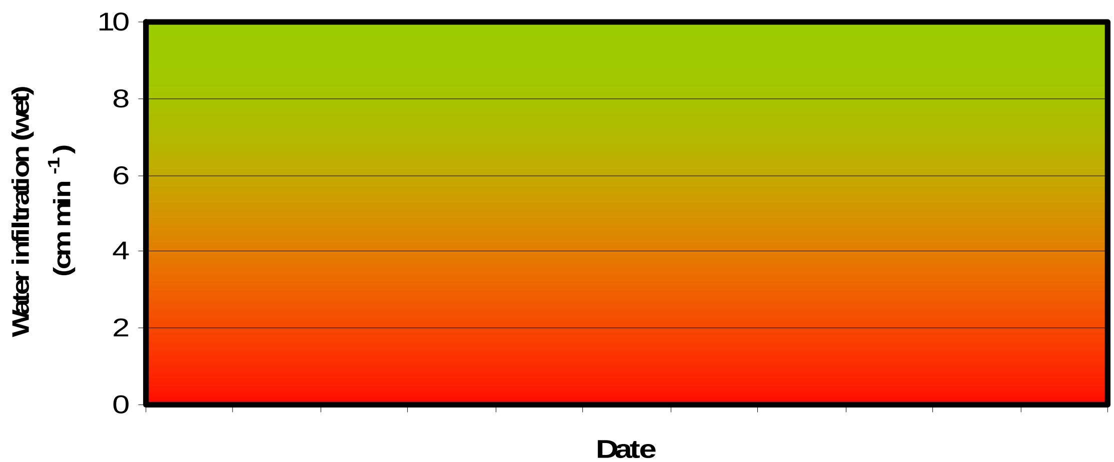
Sample	Sampling depth (cm) (A)	Soil weight (g)	Dilution factor (B)	**EC (mS/cm)**	**pH**	**P ($mg\ kg^{-1}$)** (from soil tests)	Nitrate (ppm) (C)	**Nitrate ($kg\ ha^{-1}$)** $D = \frac{(A) \times (B) \times (C) \text{ bulk density}}{10}$

Section 10. My soil health records

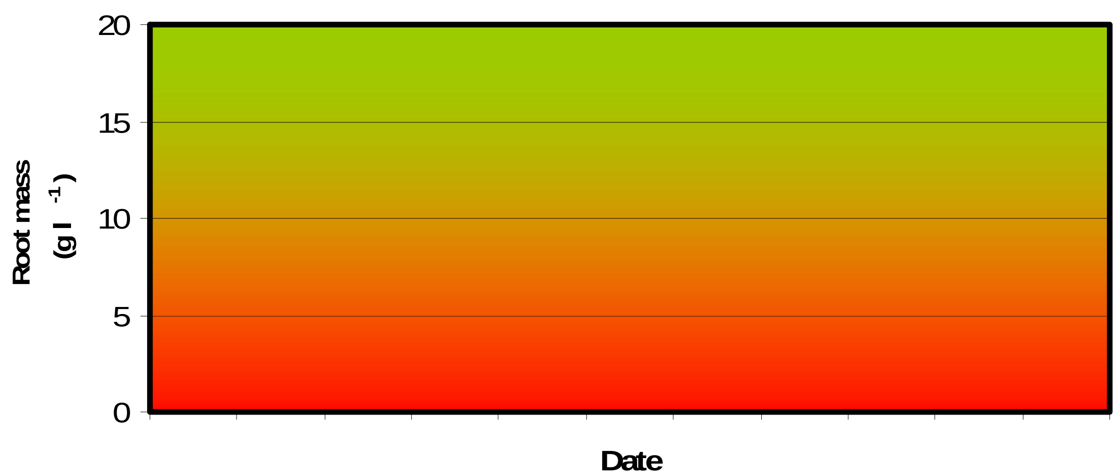
10.1. Bulk density



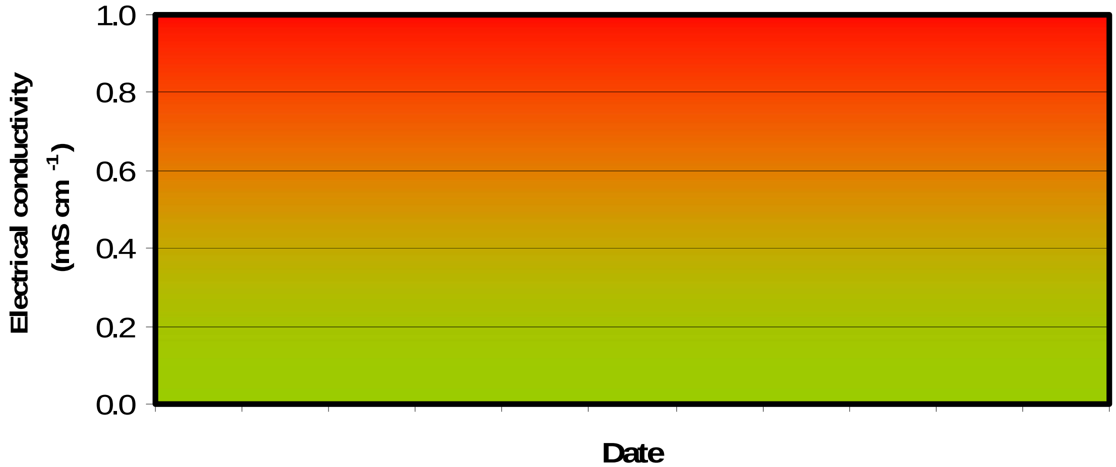
10.2. Water infiltration



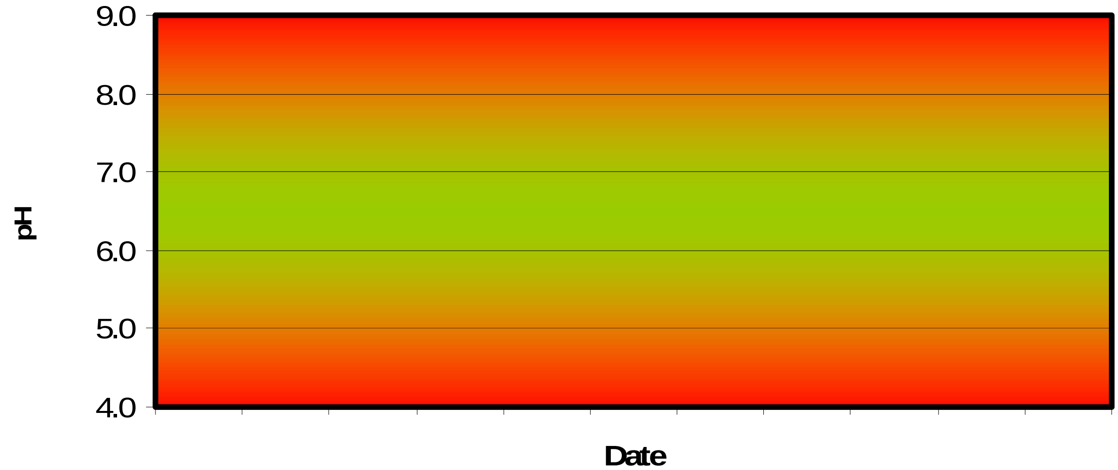
10.3. Root mass



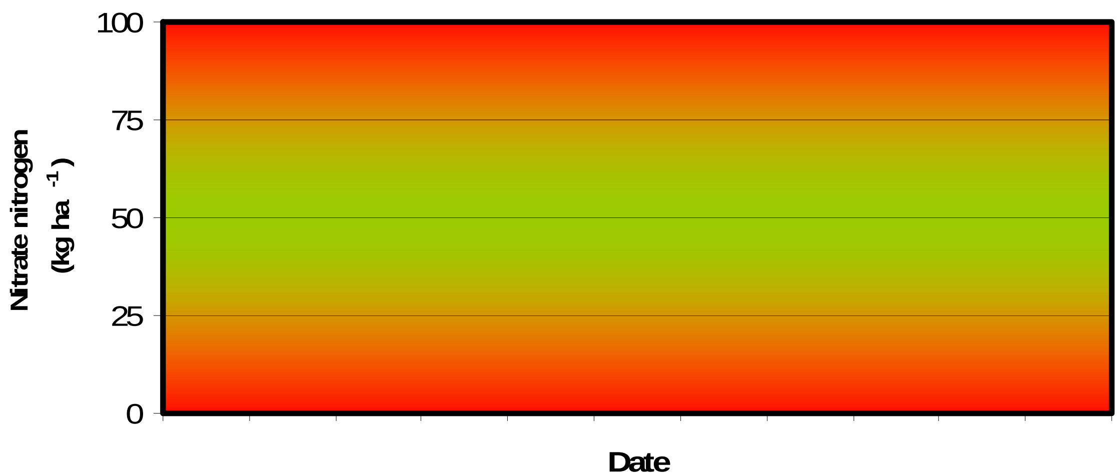
10.4. pH



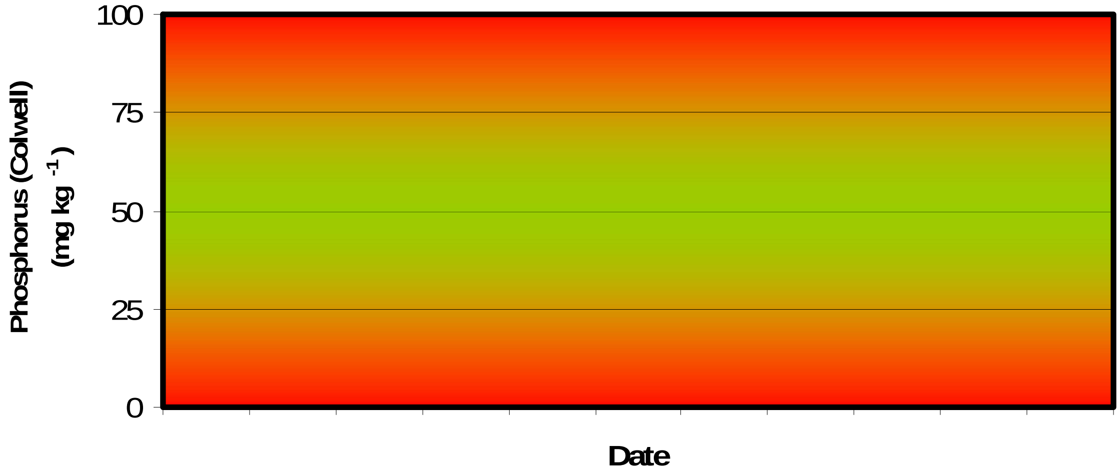
10.5. EC



10.6. NO_3

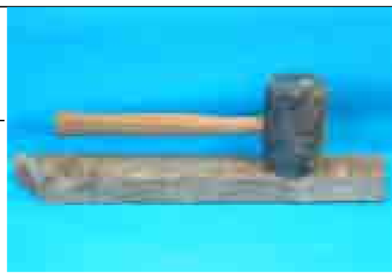


10.7. Phosphorus (Colwell)



Section 11. Building a soil health kit

11.1. Field equipment

Item	Photo	Test	Supplier	Notes
150 mm diameter ring, 125 mm in height		Infiltration Root mass	Irrigation suppliers or plumbing supplies	We used aluminium irrigation pipe, but you could use PVC if soil is not stony. One edge should sharpened to make it easier to go into the soil.
75 mm diameter ring, 75 mm in height		Bulk density	Irrigation suppliers or plumbing supplies	We used aluminium irrigation pipe. One edge should sharpened to make it easier to go into the soil.
Rubber mallet		Infiltration Root mass Bulk density	Hardware store	Drive in measuring rings.
Wood block		Infiltration Root mass Bulk density	Hardware store	Drive in measuring rings.
Paint scraper		Bulk density	Hardware store	It is important to scrape all soil off the sides of the bulk density rings so as not to get extra soil in the sample.
Spade		Bulk density	Hardware store	Used to collect soil samples and dig soil rings out of the soil.
Soil sampling tube		pH, EC, NO_3-N, P	Agricultural supply outlets	

Item	Photo	Test	Supplier	Notes
Plastic bags, clip board, recording sheets, pencil and labels		Root mass Bulk density pH, EC, NO_3-N, P	Super-markets, packaging suppliers	It is important to label and date all samples and record this information.
Electronic timer		Water infiltration	Electronic stores	Count up and count down timers are more useful.
500 ml measuring cylinder		Water infiltration	Agricultural supply outlets	If possible drill a small hole at 445 ml. This makes it easier to add the right amount of water into the water infiltration rings.
10 l jerry can		Water infiltration	Variety stores	
10 l water		Water infiltration	Tap	

11.2. *Shed equipment*

Item	Photo	Test	Supplier	Notes
Electronic timer		Water infiltration	Electronic stores	Count up and count down timers are more useful.
Scales 0.1 g precision		pH EC NO_3-N	Electronic stores	Portable scales with 0.1 g increments usually only weigh to a maximum of 200 g.
Oven 110 C		Bulk density	Variety store	Need to be able adjust the temperature.
pH meter		pH	Nursery, pool chemical or laboratory suppliers (e.g. ProSciTech)	Can be difficult to obtain locally but are available for testing water quality. The quality of the meter will depend on how much testing you want to do.
EC meter		EC	Nursery, pool chemical or laboratory suppliers (e.g. ProSciTech)	Can be difficult to obtain locally but are available for testing water quality. The quality of the meter will depend on how much testing you want to do.

Item	Photo	Test	Supplier	Notes
Nitrate test strips		NO_3-N	Nursery, pool chemical or laboratory suppliers	Can be difficult to obtain locally but are available for testing water quality.
Coffee filters Jars with lids Funnels		NO_3-N pH EC NO_3-N pH EC NO_3-N	Supermarket Variety stores Variety stores	

Section 12. Reference section

12.1. Further reading

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Weil RR and Magdoff F (2004) *Soil Organic Matter in Sustainable Agriculture*. CRC Press: New York, USA.

12.2. Useful soil health web sites

NSW Department of Primary Industries:
http://www.dpi.nsw.gov.au/aboutus/resources/factsheets/soil-biology-basics

United States Department of Agriculture, Natural Resources Conservation Service:
http://soils.usda.gov/sqi/

National Sustainable Agriculture Information Service:
http://www.attra.org/

Australian Banana Growers Council
http://www.abgc.org.au