Queensland **the Smart State**

Banana root and soil health user's manual

FR02025 Soil and root health for sustainable banana production

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The Department of Primary Industries and Fisheries (DPI&F) seeks to maximise the economic potential of Queensland's primary industries on a sustainable basis.

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Foreword

One of the Queensland Government's priorities is protecting the environment for a sustainable future by

- protecting Queensland's unique environmental and heritage assets
- promoting sustainable development through responsible use of the State's natural resources
- encouraging the development of environmentally sustainable industries and jobs
- protecting Queensland's diverse plants and animals

The DPI&F vision is profitable primary industries for Queensland.

The DPI&F mission is to maximise the economic outcomes for Queensland Primary Industries on a sustainable basis.

The NRW vision is managing Queensland's natural resources... for today and tomorrow.

The role of NRW is to lead Queensland in the effective and responsible management and use of our natural resources.

Horticulture Australia Ltd will: assist industry to grow, and sell their products more profitably.
by: investing in programs that create commercial opportunities for Australian Horticulture producers and their value chain partners. This includes improving production efficiency and sustainability in response to market needs.

The Growcom purpose is to provide influential representation, strong leadership and smart solutions for the success of horticulture businesses.

We do this by: promoting and providing innovative, responsible and commercially-viable business practices; promoting a healthy Australia through championing sustainable farming, and encouraging nutritious eating in the wider community.

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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.

Figure 1.2: Using soil health equipment in the field.

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

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.

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?

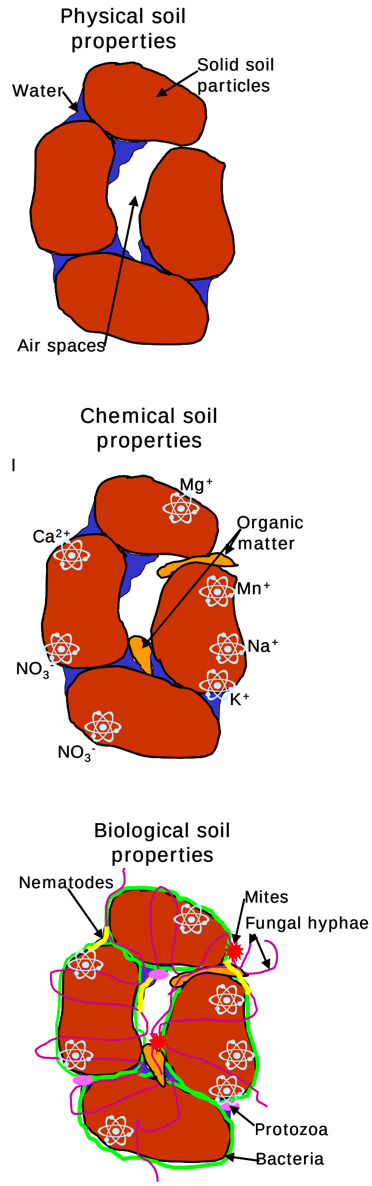

Figure 2.3: Physical, chemical and biological properties of soil interact to determine soil health.

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

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

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.

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.

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.

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.

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).

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.

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

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.

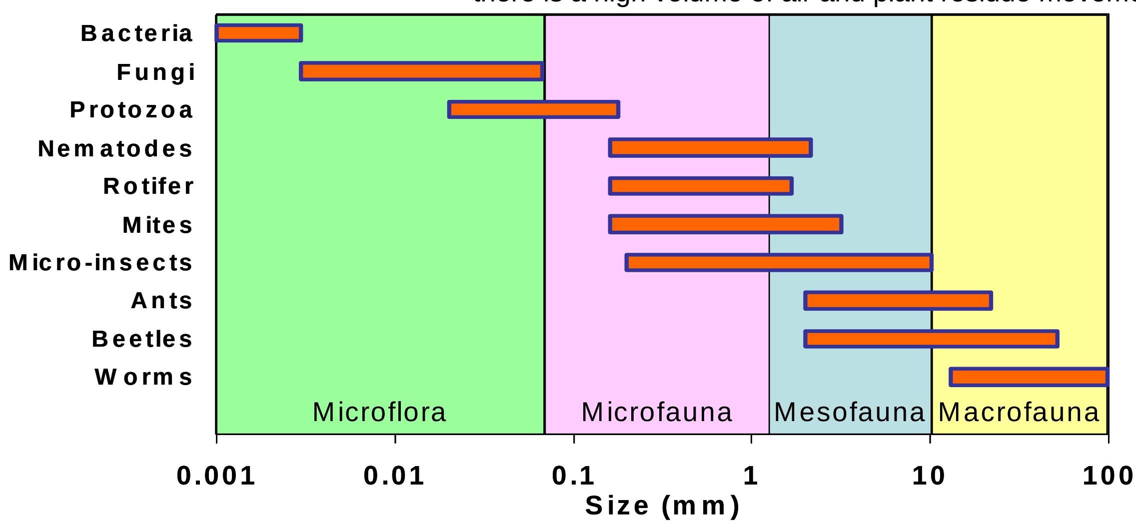

Figure 2.9: Size classifications of some example organisms found in banana soils

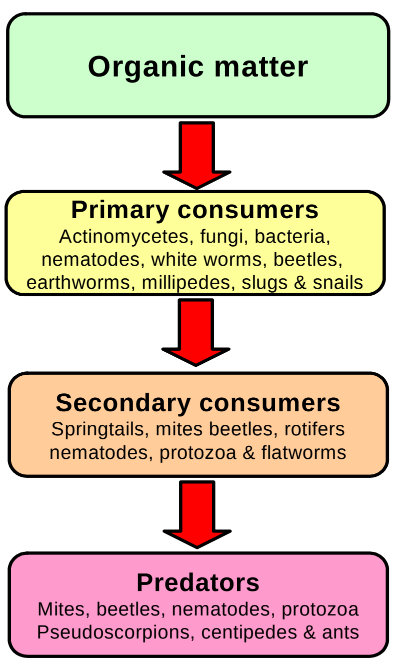

Figure 2.10: Decomposition of organic matter is achieved by different groups of organisms.

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