Sub tropical banana nutrition –

matching nutrition requirements to growth demands

Matt Weinert & Melinda Simpson

www.dpi.nsw.gov.au

Subtropical banana nutrition – matching nutrition requirements to growth demands

Matt Weinert
Development officer – Bananas
NSW Department of Primary industries

Melinda Simpson
Development officer – Blueberries
NSW Department of Primary industries

Published by NSW Department of Primary Industries, a part of NSW Department of Industry, Skills and Regional Development

First published September 2016

ISBN 978-1-74256-984-0

Job: 13882; 13841

The authors

Matt Weinert and Melinda Simpson
NSW Department of Primary Industries
1243 Bruxner Highway, Wollongbar NSW 2477
Phone (02) 6626 1200, Fax (02) 6628 1744

Cover photo: Leeane Cheal-Gentle

Disclaimer (NSW DPI)

The information contained in this publication is based on knowledge and understanding at the time of writing (September 2016). However, because of advances in knowledge, users are reminded of the need to ensure that the information upon which they rely is up to date and to check the currency of the information with the appropriate officer of the NSW Department of Primary Industries or the user's independent adviser.

The product trade names in this publication are supplied on the understanding that no preference between equivalent products is intended and that the inclusion of a product name does not imply endorsement by the department over any equivalent product from another manufacturer.

Recognising that some of the information in this document is provided by third parties, the State of New South Wales, the author and the publisher take no responsibility for the accuracy, currency, reliability or correctness of any information included in the document provided by third parties.

Disclaimer (Hort Innovation)

Horticulture Innovation Australia Limited (Hort Innovation) makes no representations and expressly disclaims all warranties (to the extent permitted by law) about the accuracy, completeness, or currency of information in the *Subtropical banana nutrition –matching nutrition requirements to growth demands.* Reliance on any information provided by Hort Innovation is entirely at your own risk. Hort Innovation is not responsible for, and will not be liable for, any loss, damage, claim, expense, cost (including legal costs) or other liability arising in any way (including from Hort Innovation or any other person's negligence or otherwise) from your use or non-use of the *Subtropical banana nutrition –matching nutrition requirements to growth demands* or from reliance on information contained in the material or that Hort Innovation provides to you by any other means

Always read the label

Users of agricultural chemical products must always read the label and any permit before using the product and strictly comply with the directions on the label and the conditions of any permit. Users are not absolved from any compliance with the directions on the label or the conditions of the permit by reason of any statement made or omitted to be made in this publication.

Acknowledgments

This manual has been produced as part of the National Banana Development and Extension Program funded by Horticulture Innovation Australia Limited using the banana industry levy, co investment from Queensland Department of Agriculture and Fisheries, NSW DPI and funds from the Australian Government.

David Turner, John Armour, Tegan Kukulies, John Robinson, Stewart Lindsay, Jeff Daniells, Mark Hickey and Ted Winston provided very useful input, discussions and comments on the book and/or the workshop that was the genesis of this book.

The NSW banana IDO project reference group, Jay Anderson, Bianca Cairns, David Perry, David Pike, Peter Molenaar, Paul Shoker, Stephen Spear and the Coffs Harbour Banana Growers Association are thanked for their continual support for and input to the project and this booklet.

Carey Martin is thanked for her excellent editing of the book.

The International Plant Nutrition Institute is thanked for providing the majority of deficiency images.

Contents

1 Foreword

2 Introduction

3 What is phenology?
- 3 Leaf emergence rate
- 4 Flowering and bunch development
- 4 Root extension
- 5 Combined phenology

6 Healthy soils
- 7 Healthy roots
- 8 Soil pH

9 Chemical elements
- 9 Essential elements
- 10 Nutrient limitation and sufficiency
- 10 Nutrient interaction
- 11 Where are the different chemical elements in banana plants?

12 Key banana elements – their role and deficiencies
- 12 Nitrogen (N)
- 14 Phosphorus (P)
- 15 Potassium (K)
- 16 Calcium (Ca)
- 18 Magnesium (Mg)
- 18 Boron (B)
- 20 Sulfur (S)
- 21 Zinc (Zn)

22 Designing a banana nutrition program
- 22 Nutrient recycling in bananas
- 23 Matching application to demand – the 4Rs of plant nutrition
- 23 Nutrient loss
- 24 Leaf and soil sampling
- 24 Nutrient standards
- 26 Fertiliser placement
- 26 Adjusting soil pH
- 27 Fertiliser timing
- 28 Online resources

28 References and further reading

Foreword

Fertilising, like many activities in banana plantations, is where science and practice meet.

Science provides descriptions of plant growth and development throughout the season, the capacity of soils to support production, and the chemistry and symptoms of nutrient deficiencies and excesses. It also tells us how climate affects plant growth, development and production and therefore the demand for nutrients. When these components come together in an ecological framework, benefits flow to growers, soils, plants and the broader environment.

This book combines plant phenology, soils, chemistry and symptoms and applies them to the basics of designing and undertaking a fertiliser program for bananas in the subtropics. The target is banana production in the subtropical regions of eastern Australia, although the principles used here are more widely applicable. Subtropical banana production has a unique set of opportunities and challenges that are reflected in fertiliser practice.

What to apply, how much and when, are fundamental questions that need answers if an appropriate fertiliser program is to be designed and used. This book helps you answer these questions for your situation, making it a valuable tool in working towards plantation practices that lead to sustainable production.

Good luck!

David Turner
Honorary Research Fellow
School of Plant Biology, Faculty of Science
The University of Western Australia
Crawley, WA.

Introduction

Bananas are a tropical crop that theoretically performs best within 20° of the equator, with small fluctuations in night and daytime temperatures. In some aspects, the general subtropical climate might be more suitable, as heat stress during summer and leaf disease pressure are less in the subtropics. When water is not limiting, growth is determined by temperature. Grown along the wetter, coastal fringe in Australia, the ocean's warming influence allows bananas to be grown within subtropical climates – 20° to 30° south of the equator – although growth does slow significantly during winter.

The study of the effect of climate on plant growth and development is called phenology. Understanding phenology allows growers to intensify plantation management to coincide with the highest development rates in warmer weather, and reduce inputs as growth slows in cooler weather. Understanding the nutrient demands of the different growth stages or phenological events, allows growers to fine-tune their nutrition program to optimise production and maximise fertiliser efficiency.

With consumers now demanding better environmental stewardship from growers, it is important that growers strive to reduce soil and nutrient losses into the environment in the areas surrounding subtropical banana production. It also makes better economic sense as fertiliser lost to water run-off and leaching is wasted money.

As every farm is different and growers have different production aims, this guide is descriptive, not prescriptive. The images will allow you to become familiar with, and identify, banana nutrient deficiencies you might see on your farm. Once these deficiencies are evident, production has already been lost so it is important that monitoring, through leaf and soil tests, is used to plan and implement your nutrition program.

Subtropical banana phenology determines fertiliser application times and amounts. The fertiliser removed from your farm in fruit and estimated fertiliser losses, yield history and leaf and soil analysis will allow you to calculate the amounts of fertiliser required for your farm. The suggested application percentages throughout the year will then help to develop a nutrition management program to apply this more effectively.

As with all management decisions and inputs on your farm – if you aren't measuring, you are only guessing.

What is phenology?

Phenology is the study of the growth and development cycles of a plant as determined by climate. Cultivar and management practices also influence these cycles. The most obvious growth and development events for bananas are leaf emergence rate, flowering time and the bunch development period. Root growth and development is harder to monitor, but simple root windows, hessian bags placed on the ground under trash and inspected regularly, allow root extension rate and root health monitoring.

Understanding banana phenological cycles allows growers to intensify their management and inputs when developmental rates and nutritional demands are at their highest – during warmer weather – and scale back management when these slow in cooler weather. It also lets growers plan their planting dates and timing of sucker selection in order to harvest during higher market prices, and deleaf to manage leaf diseases when leaf production rates are highest.

Average monthly temperatures for the Coffs Harbour region were used to develop the growth curves in the following graphs, but these curves should be similar for all Australian subtropical banana-growing areas.

Leaf emergence rate

Leaf emergence rate is the most visible banana phenological event and is closely related to temperature. Leaf emergence rate (Figure 1) is higher during warmer periods and slows significantly during cooler periods. Competition between plants in a ratoon crop also slows the leaf emergence rate compared with a plant crop. Leaf emergence rate is important in the subtropics as it tells the grower when management practices such as fertilisation, desuckering and deleafing should occur. Summer leaf emergence rates are reduced if management inputs are lacking or poorly timed. Water stress also reduces the leaf emergence rate.

Reduced leaf emergence rates during winter make it difficult for subtropical banana growers to manage leaf diseases through deleafing as, under high disease pressure, leaf replacement rates might not be high enough. Growers should aim to have plantations deleafed and clean before the spring months when increasing temperatures and rainfall promote spore release and germination to start the next disease cycle.

Figure 1. Monthly leaf emergence rate for subtropical bananas over a 12-month period. Drawn from Robinson and Galán Saúco (2010).

Flowering and bunch development

Leaves produce the carbohydrates that fill the bunch. As leaf emergence rate slows (Figure 1) the rate of production of carbohydrates for fruit development also slows, leading to slower bunch development (Figure 2) and lighter bunches. This is not directly correlated as the optimum temperature for leaf emergence and crop cycling is 32 °C and the optimum temperature for carbohydrate production and bunch filling is 22 °C. The optimum mean temperature for growth and development is approximately 27 °C and because of this, high carbohydrate production rates continue well into autumn.

Pruning hands from bunches to increase fruit size in winter is an example of phenological management – the reduced number of hands on a bunch is filled more rapidly by the reduced carbohydrate production in winter.

Root extension

Root extension, like leaf emergence, is closely related to temperature (Figure 3). Soil temperature changes are slower than air temperature changes. Therefore, in autumn reduced root extension lags behind reduced leaf emergence and, as temperatures warm in spring, root extension lags behind leaf emergence.

The rate of banana root extension is greatest above 20 °C, with lower temperatures slowing root extension, which then stops when soil temperatures drop below 11 °C.

Fine feeder roots, or root hairs, are produced on the thicker secondary roots, which are produced on the primary roots that originate from the corm. The production of the fine roots that take up nutrients depends upon the extension rate of the primary and secondary roots. These fine feeder roots only remain functional for about three weeks. Reduced major root emergence and extension affects the uptake of some nutrients and can lead to deficiency symptoms including the flag-leaf calcium deficiency symptom (Figure 18). As root emergence and extension slows significantly, and fewer feeder roots are produced, fertiliser applications can be reduced or stopped in winter depending on variety, see Fertiliser timing.

Figure 2. Approximate number of days from flowering to harvest for subtropical bananas over a 12-month period. Time period is for bunches emerging during the indicated month. Drawn from Robinson and Galán Saúco (2010).

Combined phenology

The combined phenological events (Figure 4) show how climate affects banana developmental processes. As air temperatures fall in winter the number of leaves emerging per month falls. As the rate of leaf area development and extension decline and carbohydrate production drops when temperatures fall below the optimum mean temperature (27 °C) for growth and development, fruit growth slows, increasing the time from flowering to harvest.

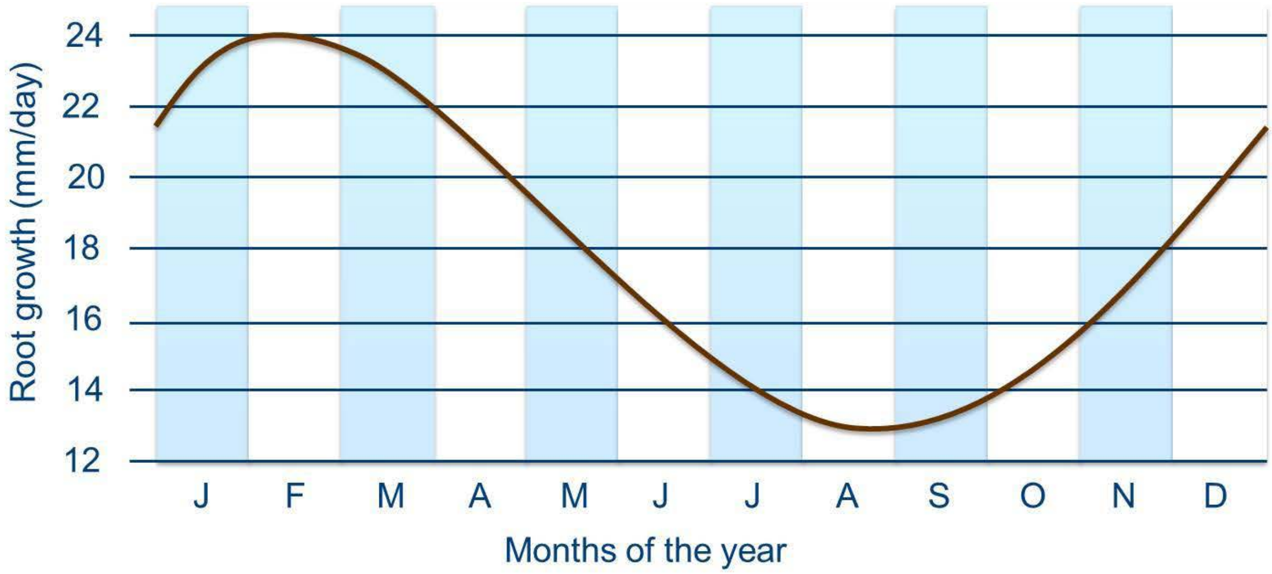

Figure 3. Root extension in mm/day of major roots in subtropical bananas over a 12-month period. Drawn from Robinson and Galán Saúco (2010).

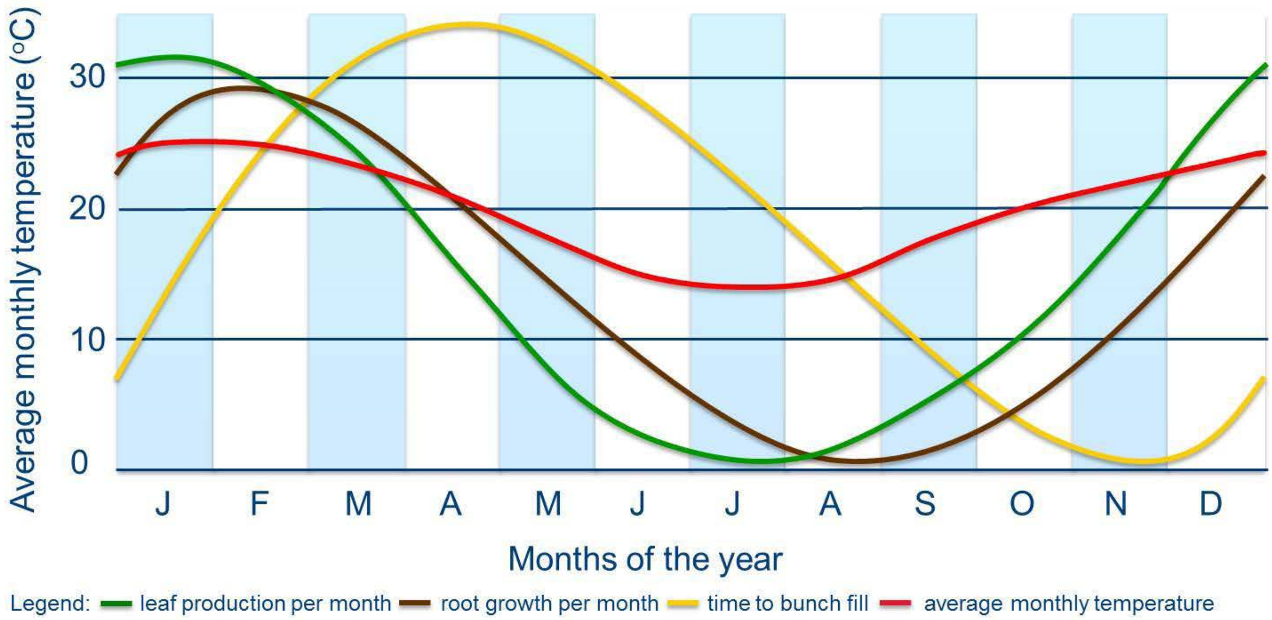

Figure 4. Combined phenological events for subtropical bananas over a 12-month period plotted against average monthly temperature for Coffs Harbour. Axis scales for the growth curves are as for figures 1 to 3. Drawn from Robinson and Galán Saúco (2010).

What is phenology

Healthy soils

Healthy soils are not a simple solution for increased production, but function to sustain productivity, store and cycle water and nutrients, decompose organic matter and suppress pathogens. Having a healthy soil reduces extremes of water and nutrient availability and will increase and stabilise production and improve fruit quality.

Healthy soils function through balanced interactions between mineral, biological, physical and chemical soil components. The mineral component of a soil consists of sand, silt and clay particles; the biological component consists of roots, insects, invertebrates and microorganisms; the physical and chemical components are composed of the texture, structure, porosity and permeability and pH and inorganic compounds.

> Soil health is the effective functioning of the soil system so it provides for the growth of plants in a sustainable system' (Pattison & Lindsay, 2006)

Soil physical properties are the skeleton of the soil – the structure that everything else is built on. Good soil structure provides the right amount of air and water to the banana roots.

Compaction from agricultural practices such as tillage and vehicle movements during wet weather pushes soil particles closer together. Compaction can increase water logging by not allowing soils to drain properly and limiting the ability of plant roots to penetrate the soil. Plant roots and soil microorganisms all require oxygen to function properly; waterlogging and compaction affect the banana plant's ability to access sufficient oxygen, reducing plant growth.

If soils are too dry, the plant has to use more energy to extract sufficient water and nutrients, also reducing plant growth.

Chemical components of the soil are often referred to as the soil fertility. This includes the soil's ability to supply essential nutrients, and soil water in adequate amounts and proportions for plant growth and reproduction, in the absence of toxic substances that can inhibit plant growth. The growth of a banana crop requires a continuous supply of nutrients in sufficient quantities to grow profitably. Excess nutrients, applied when the plant does not need them or where it cannot access them, can be lost, affecting the environment but also costing growers money. They can even outcompete other nutrients leading to imbalances in the plant.

Biological soil properties include the living and previously living components of the soil. These range from large organisms that are easily seen – earthworms, beetles and ants – down to microscopic fungi and bacteria. Most biological activity occurs in the top 10 cm of the soil where plant residues being broken down are made available to plants for growth. Substances produced by soil organisms and strands of growing fungi, called hyphae, help bind soil together and improve soil structure. Tunnels produced by soil organisms including worms and beetles can help aerate the soil and help water to infiltrate, reducing erosion. Soils with greater biological diversity tend to be able to recover from disturbances better and can supress pest nematodes and diseases.

A soil with a high level of organic matter will provide many benefits to the soil, including improved soil structure and drainage, and the slow release of nutrients such as nitrogen, phosphorus and sulfur. In addition, large quantities of nutrients such as calcium, magnesium and potassium are attracted and held until the plants need them. Organic matter also holds water in the soil. Increased organic matter increases the amount of water a soil can hold, which is one way growers without irrigation can maximise water availability.

> As well as holding nutrients and increasing soil health, improving soil organic matter holds more water. An increase of 1% in organic matter in the top 30 cm of soil will hold an extra 62,000 L of water per hectare.

Soils low in organic matter, with poor structure and biological diversity can result in poor plant growth, poor water infiltration, soil erosion, plant pathogens and pest problems. Soil-borne plant pathogens and beneficial organisms are key factors that determine crop health and productivity. The mechanisms that keep these organisms in check are influenced by environmental conditions and by the cropping practices used. Plants grown on infertile soils or those with low organic matter, poor soil porosity and oxygenation, poor soil structure and inadequate drainage, are more susceptible to plant parasitic nematodes, root rots and other diseases.

Healthy roots

Healthy roots are important to productivity as they absorb water and nutrients from the soil and move them to the actively growing plant parts. Banana plants have fewer roots compared with other horticultural crops, making banana plants very sensitive to root damage. Growers must work to prevent root damage in order to maximise the water and nutrients the banana plant can absorb from the soil. Managing nematodes to maintain healthy roots is particularly important (figures 5 and 6).

Banana plants are also sensitive to oxygen deficiency, which can occur in waterlogged soils. Root tips begin to die if they are waterlogged for more than six hours.

Figure 5. Healthy white roots from planting tissue culture plants into nematode-free healthy soils. (Image courtesy of the International Plant Nutrition Institute, Georgia, USA.)

Figure 6. Roots attacked by nematodes from a planting of infested bits and suckers or planting tissue culture plants into soil infested with nematodes. Damage shows as sunken black lesions on the thick primary roots. (Image courtesy of the International Plant Nutrition Institute, Georgia, USA.)

Soil pH

Soil pH is the measure of the acidity or alkalinity of a soil, which affects the availability of plant nutrients, microorganism activity and the soil mineral solubility.

Soil pH can be measured by two methods:

1. in water
2. in calcium chloride ($CaCl_2$).

Readings for pH from the $CaCl_2$ test are approximately 0.5–1 units lower than water, so it is important to know to which test the result refers.

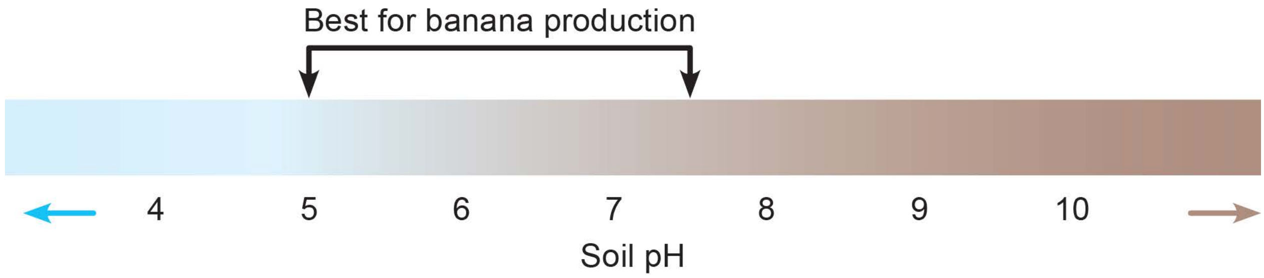

Figure 7. Soil pH (in water) and suitability to grow bananas.

Bananas can tolerate some soil acidity, however a pH below 5.0 means that elements such as aluminium and manganese become very soluble in the soil and their toxicity can reduce plant growth. Aluminium is particularly toxic to plant roots. Low soil pH also means that nutrients such as calcium become less available in the soil.

Soil acidification occurs naturally, but is accelerated by acid produced in the soil by most nitrogen fertilisers. Nitrate fertilisers, while expensive, can increase pH to a depth of 60 cm. The effect of liming products is limited to the surface 20 cm. Careful fertiliser management, liming and increasing organic matter content in the soil will help to slow down the acidification process.

Chemical elements

Essential elements

Nutrients are classified as either **anions** or **cations**. An anion is a nutrient that, in its natural state, has a negative charge, indicated by a minus sign (–). A cation, indicated by a plus sign (+), is a nutrient that, in its natural state, has a positive charge.

Most soil particles have a negative charge; the amount of negative charge is directly related to soil particle size. Generally course textured soils – sands – have a low negative charge and fine textured soils – clays – have a high negative charge. High levels of soil organic matter also increase the amount of negative charge of a soil.

Table 1. Elements essential for plant growth, the form occurring in the soil and taken up by the plant, and their relative mobility in the soil.

Element type	Element (symbol)	Form taken up by the plant	Mobility in the soil
Macronutrients	Nitrogen (N)	$(NH_4)^+$ Ammonium form $(NO_3)^-$ Nitrate form	Somewhat immobile Mobile
	Phosphorus (P)	$(H_2PO_4)^-$, $(HPO_4)^{-2}$, PO^{-3}	Immobile
	Potassium (K)	K^+	Somewhat mobile
	Calcium (Ca)	Ca^{++}	Somewhat mobile
	Magnesium (Mg)	Mg^{+2}	Somewhat mobile
Micronutrients	Sulfur (S)	$(SO_4)^{-2}$	Mobile
	Chlorine (Cl)	Cl^-	Mobile
	Iron (Fe)	Fe^{+2}	Immobile
	Boron (B)	$(BO_3)^-$	Mobile
	Manganese (Mn)	Mn^{+2}	Immobile
	Zinc (Zn)	Zn^{+2}	Immobile
	Molybdenum (Mo)	$(MoO_4)^-$	Mobile

The ability of a soil to hold and release cations is called the **cation exchange capacity** or **CEC**. The amount of negative charge a soil has will influence the CEC. Negatively charged particles and anions attract, adsorb and hold the positively charged cations in the soil. The CEC is the measure of how many negatively-charged sites are available in a soil.

This is critical to the supply of nutrients to plants as it influences the ability of the soil to hold onto the important plant cations: calcium, magnesium and potassium, preventing them from washing through the soil (leaching) or from the plantation (erosion).

A cation exchange capacity below 5 cmol (+)/kg limits banana production while a range of 10–25 cmol (+)/kg is optimal. Soil acidity affects cation exchange capacity, making cations such as aluminium and manganese more available. These are toxic and can reduce root and shoot growth.

Soils with a high cation exchange capacity (CEC) can hold greater amounts of important cations including calcium, magnesium and potassium.

Nutrient limitation and sufficiency

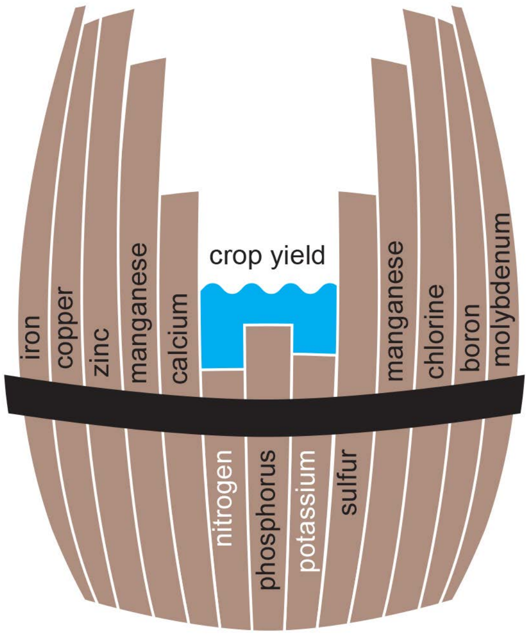

Figure 8. Illustration of nutrient limiting factors.

The law of limiting factors is the concept that a crop requires an adequate supply of all elements (nutrients) at the correct time for optimum growth. If more than one element is in short supply, growth is determined by the one that is in the lowest supply. The barrel in Figure 8 illustrates this concept. The water level in the barrel represents the potential crop yield and, in this case, is limited by the most limiting nutrient i.e. nitrogen. If nitrogen is added, the next most limiting factor is potassium. Multiple deficiencies can occur if several nutrients are in short supply. All elements need to be applied in the sufficient amounts at the correct time for optimum production.

The **sufficiency level concep**t follows on from the law of limiting factors. It states that there are definable levels of individual elements in the soil below which plants will respond to added fertilisers and above which they probably will not respond. Once an element is present in sufficient quantity, plant growth will be maximal across a range of concentrations before growth decreases when levels become toxic.

These two concepts combined illustrate fertilising to the plant's needs, the right fertiliser in the right amount and at the right time and place. This is fertilising according to phenology.

In rain-fed banana production, water is often the limiting production factor, as nutrients cannot be taken up without available soil moisture, making it difficult to fully achieve fertilising to phenology. However, ensuring adequate amounts of nutrients are present in the soil, or fertilising when rain does fall, can help overcome this limitation.

Nutrient interaction

It is important to consider the interactions between elements when deciding how much fertiliser to apply. The balance between elements in the soil and the plant demonstrate the effects that elements have on overall nutrient availability. Some elements interfere with the availability or uptake of another, called antagonism, while other elements can stimulate the uptake or increase the availability of another. It is important to understand these relationships so fertiliser applications can provide a balanced nutrition program.

Nutrient antagonism is where one element interferes with the uptake or availability of other elements. Understanding nutrient antagonism is important to understand when developing fertiliser programs.

» Excess phosphorus applications will reduce the availability of iron, calcium, potassium, copper and zinc.

» High nitrogen fertilisation can reduce the availability of potassium, boron and copper.

» Increased levels of soil potassium can increase potassium and phosphorus uptake, but reduce the uptake of calcium, magnesium and zinc.

Where are the different chemical elements in banana plants?

The concentration of the different elements varies between the different parts of the plant. Levels can also vary within a leaf, particularly if the elements are mobile within the plant. The levels of the different elements can drop in the leaf between flowering and harvest as they move from the leaf into the fruit.

Temperature also plays a role in levels in plant parts. Levels drop with temperatures below 29 °C during the day and 23 °C at night. The nutrients with highest concentrations in the different parts of the banana plant are shown in Figure 9, giving an indication of the phenological nutritional demands of the different parts of the banana plant.

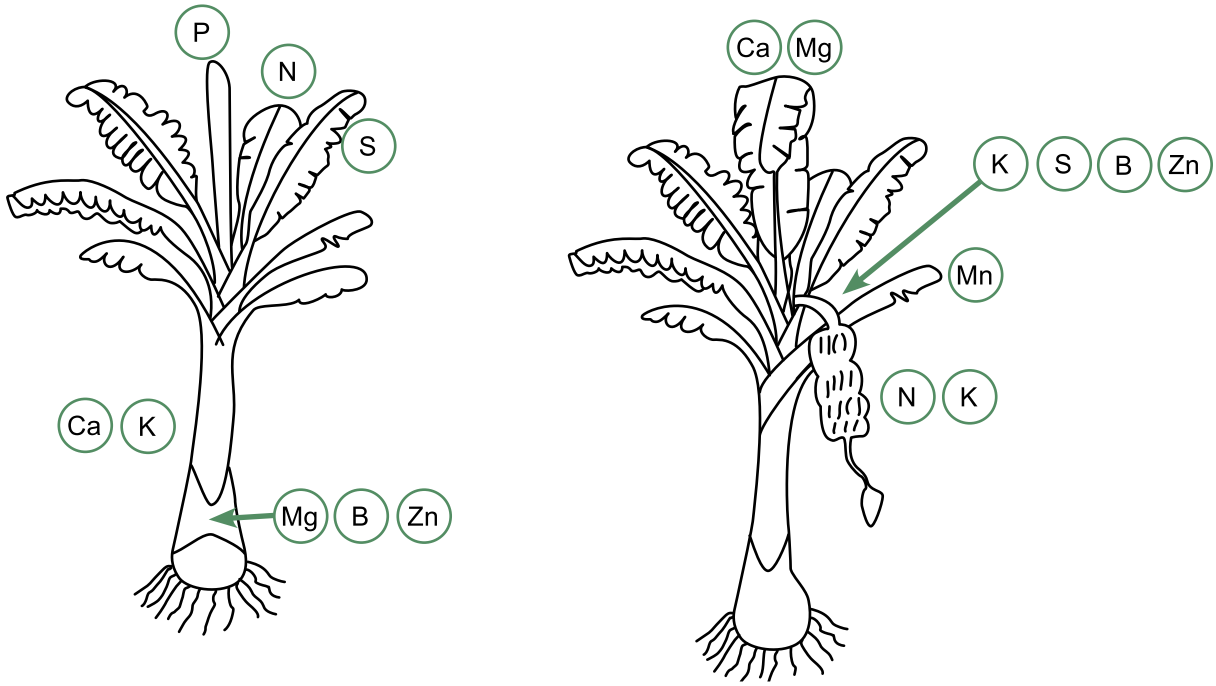

Figure 9. **Elements with the greatest concentration in the different parts of a banana are listed next to the respective part. Drawn from Lahav and Turner (1989).**

Table 2. Summary of deficienty symptoms (Lahav & Turner 1989)

Age of leaf	Symptoms on blades	Additional symptoms	Element
All ages	Uniform paleness	Pink petioles	N
		Midrib curving (weeping, dropping)	Cu
Young leaves only	Whole leaf yellow-white		Fe
		Thickening of secondary veins	S
	Streaks across veins	Leaves deformed (blade incomplete)	B
	Stripes along veins	Reddish colour on lower side of youngest leaves	Zn
	Marginal chlorosis	Thickening veins. Necrosis from margins inward	Ca
Old leaves only	Sawtooth marginal chlorosis	Petiole breaking. Bluish-bronze colour of young leaves	P
	Chlorosis in midblade, midrib and margins remain green	Chlorosis limit not clear. Pseudostem disintegrating	Mg
	Blade dirty yellow green		Mn
	Yellow-orange chlorosis	Leaf bending. Quick leaf dessication	K

Key banana elements – their role and deficiencies

At least 14 elements or nutrients are required for plant growth. For bananas, the key nutrients are nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), boron (B) and zinc (Zn). A summary of nutrient deficiency symptoms in bananas is shown in Table 2.

Nitrogen (N)

Nitrogen drives plant growth. Nitrogen is:

- essential for manufacturing chlorophyll, which in turn produces the carbohydrates required for plant growth and development
- also important for yield and fruit quality.

Bananas have a large nitrogen requirement and deficiencies are often evident when root health is poor, water supply is limited or the plants are waterlogged. Yellowing leaves is the most common symptom of nitrogen deficiency, resulting from reduced chlorophyll (Figure 10). The yellowing normally starts in the older leaves and then affects younger leaves as the deficiency increases. In younger plants, nitrogen deficiency often shows as pink or red colouring of the wings on the petioles or leaf stalk that may also progress down the petiole (Figure 11).

The greatest demand for nitrogen in bananas is during leaf growth. Nitrogen also helps to increase the fruit size and number of hands. Nitrogen should be applied frequently on lighter soils and the rate should be adjusted during the year to match the crop growth rate.

Excess nitrogen leads to rapid growth and poor pseudostem strength, which can cause stems to buckle or bend under the weight of the bunch (Figure 12), delays flowering, produces small bunches and reduces fruit shelf life.

Figure 10. Nitrogen deficiency – poor growth and yellowing in the older leaves. In subtropical regions, this can also be confused with potassium deficiency. (Image courtesy of the International Plant Nutrition Institute, Georgia, USA.)

Figure 11. Nitrogen deficiency – red or pink colouring on the wings (left) that can extend down the base of the petiole – leaf stalk (right).

Figure 12. Buckling and poor stem strength can be caused by excess nitrogen.

Key banana elements

Phosphorus (P)

Bananas have a low requirement for phosphorus, however it still is an important nutrient.

Phosphorus:

» helps in cell division and development of new tissue
» is involved in forming and moving sugars.

Phosphorus is required in high concentrations at the growing points of roots and shoots, making adequate phosphorus levels especially important during times of active growth. During the first five months after planting, the banana plant rapidly takes up phosphorus.

Phosphorus binds with other minerals in the top few centimetres of soil and becomes insoluble, making it unavailable to plants or easily lost through erosion. Fungi, which form beneficial relationships with plant roots (mycorrhizae), increase phosphorus uptake. If soil phosphorus levels are too high, bananas do not form relationships with the mycorrhizae and roots become more susceptible to soil disease and nematodes. Refer to the Nutrient standards section of this booklet to learn how to monitor soil phosphorus.

Phosphorus is mobile within the plant and moves from older mature tissues to younger, actively growing tissues. Deficiency symptoms are first seen in older leaves. These leaves become dark green with purple/brown flecks and 'sawtooth' cell death on the leaf edges (figures 13 and 14). Other symptoms include reduced growth of both mother and daughter plants and shorter leaves.

Figure 13. Phosphorus deficiency – cell death on the leaf edges in older leaves. (Image courtesy of the International Plant Nutrition Institute, Georgia, USA.)

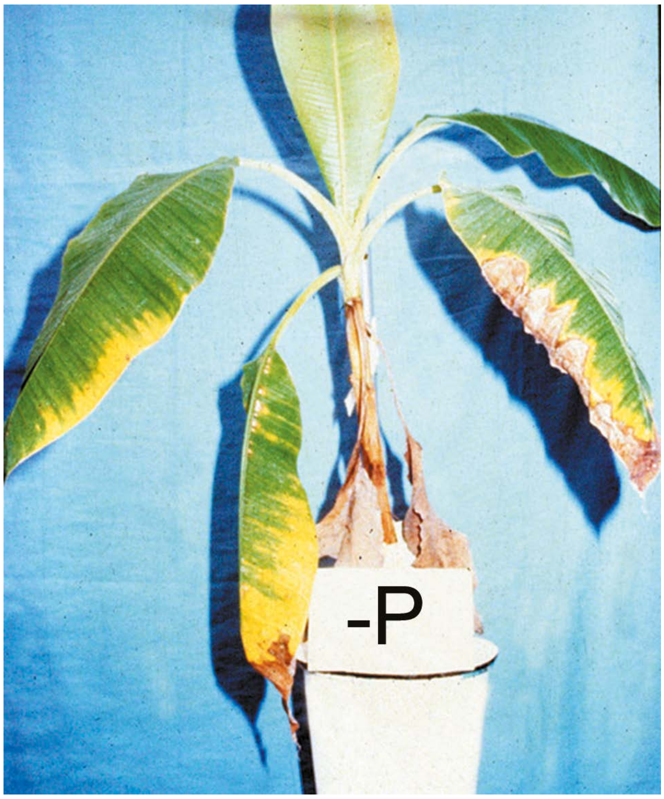

Figure 14. Phosphorus deficiency – 'sawtooth' cell death on the leaf edges on the bottom leaf on the right. (Image courtesy of the International Plant Nutrition Institute, Georgia, USA.)

Potassium (K)

Potassium is the most important element in banana production and has several important roles.

Potassium:

» is required for cell division and expansion during all growth, but particularly during fruit development. Cell division and expansion are key processes that determine fruit size

» controls water uptake, and therefore the uptake of other nutrients, by regulating the opening and closing of the stomates. Stomates are the structures on the leaves that allow gas exchange for photosynthesis and the movement of water from the roots to the leaves

» helps to move sugars from the leaves to the fruit.

The greatest need for potassium is during fruit development. In the soil and the plant, potassium is very mobile and is absorbed during the later vegetative growth stages, just before bunching. Potassium absorption is reduced after bunching. Potassium leaches easily and should be applied more frequently to lighter soils. Other cations such as calcium, sodium and magnesium compete with potassium for uptake.

The most common characteristic of potassium deficiency symptom is the yellowing of older leaves or leaf tips, leading to premature leaf death (Figure 15). In areas protected from wind, potassium deficiency shows as the leaf tip curling downwards and an orange-yellow colouring of the leaf (Figure 16). Other symptoms can include reduced bunch and fruit size, caused by the reduction in photosynthesis and sugar transportation.

Figure 15. Potassium deficiency – general yellowing and death of older leaves. See also nitrogen deficiency, Figure 10 (Image courtesy of Qld DAF.)

Figure 16. Potassium deficiency – in plantations protected from the wind, mild potassium deficiency shows as curling and yellowing at the leaf tip. (Image courtesy of the International Plant Nutrition Institute, Georgia, USA.)

Calcium (Ca)

Calcium in plants is essential for good strength and structure.

Calcium:

- » plays an important role in cell division and growth in leaves, fruit and root tips
- » strengthens plant cell walls, helping to protect against heat stress and diseases
- » helps in the uptake of other nutrients.

Calcium binds with boron in cell walls and does not readily move within the plant, remaining in the old tissues. Calcium uptake is by young roots and roots tips, and is passive. The soil must be moist for uptake to occur. Calcium is held more strongly in the soil than potassium, magnesium or sodium, which can outcompete calcium for uptake.

Calcium is difficult to get into the fruit and uptake speed depends on its particle size; smaller particle sizes ensure quicker uptake. As calcium is important for all growth events, it needs to be available all year round. Levels of calcium in the leaf indicate the total amount of calcium in the soil and the balance with the other cations: magnesium and potassium. Low leaf calcium levels can indicate an excess of these two other minerals.

Calcium deficiency symptoms appear in the young leaves due to its low mobility within the plant. If deficiency is severe, leaves are completely deformed, with serrated edges or with little or no leaf blade (figures 17 and 18). These symptoms are most likely seen in rapidly growing plants in early summer after the spring flush or after high potassium applications. Other symptoms of calcium deficiency include short, thick, rotted roots that can be easily confused with nematode damage (Figure 6), deformed fruit (Figure 19), poor fruit quality and skin splitting.

Figure 17. Calcium deficiency – overgrown secondary veins causing leaf blade to curl. (Image courtesy of the International Plant Nutrition Institute, Georgia, USA.)

The appropriate calcium form to apply depends on soil pH. Lime and dolomite help neutralise soil acidity, but these only act in the top 20 cm of the soil. Dolomite can be used to supply calcium where magnesium is also deficient. Gypsum supplies both Ca and S, but does not change soil pH.

Moisture and root growth are required for calcium uptake. The majority should be applied near the end of the wettest period with smaller amounts included in fertiliser blends spread throughout the year.

Figure 18. Calcium deficiency – 'flag-leaf' deficiency, where the leaf blade is tattered and fails to form, is usually seen in spring. (Image courtesy of the Qld DAF.)

Figure 19. Calcium deficiency – deformed fruit, which can also be a symptom of boron deficiency. (Image courtesy of Qld DAF.)

Magnesium (Mg)

Magnesium is the central component in chlorophyll – the molecule that converts sunlight into carbohydrates in plants. It is the most common deficiency, after nitrogen and potassium, in sub-tropical banana plantations.

Magnesium:

» regulates the uptake of other nutrients

» plays a role in drought and disease resistance.

Large applications of potassium reduce the amount of magnesium available to the plant and can induce magnesium deficiency. Magnesium deficiencies usually occur in old plantations. Light textured and highly weathered soils with low CEC tend to have low magnesium content. Acid soils can reduce magnesium availability and uptake.

The most common visual symptom of magnesium deficiency is yellowing in the middle of the leaf blade. In older leaves, the margins and near the petiole stay green and the leaf blade in between yellows (Figure 20). As the deficient leaf matures, the yellowing becomes more intense and these areas turn brown and die.

Another magnesium deficiency symptom is petioles coloured bluish-purple. Magnesium deficiency also increases leaf disease susceptibility.

Figure 20. Magnesium deficiency – leaf margins and midrib stay green and the leaf blade between them yellows. (Image courtesy of Qld DAF.)

Boron (B)

Boron has several important roles in plant nutrition.

Boron is:

» required for all new cell growth and division as it affects plant hormone and carbohydrate movement

» essential for fruit set, size and shape

» a structural component of cell walls in conjunction with calcium, helping it move to the cell walls.

Boron is highly soluble and is very easily leached from soils, but is bound in the cell walls and not mobile within the plant. Small amounts are required during all growth phases, but the majority is required during early fruit development. As boron is needed in small quantities, it is easy to go from deficiency to toxicity.

Symptoms of boron deficiency include yellow lines at right angles to the veins on new leaves (Figure 21). Newly emerging, boron deficient leaves do not fully expand and, in severe deficiency, the main vein with the leaf will emerge with little or no leaf blade, often with dead margins (Figure 22).

In bunches, a mild deficiency will affect the shape and quality of fruit, but severe boron deficiency can result in serious bunch deformation (Figure 23). Fruit from boron-deficient plants are much thinner at the tip, with a hard brown central core (Figure 24).

Figure 21. Boron deficiency – yellow lines in the leaf blade at a right angle to the main veins. (Image courtesy of the International Plant Nutrition Institute, Georgia, USA.)

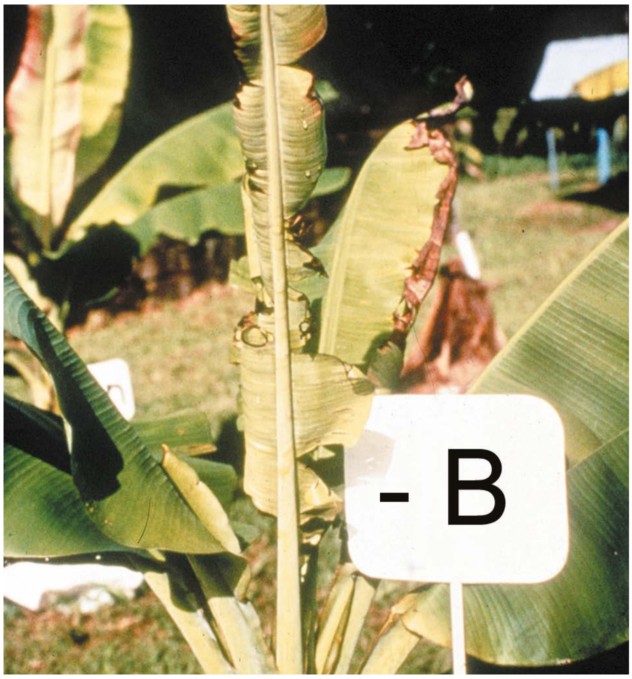

Figure 22. Boron deficiency – deformed, unexpanded leaves with dead margins. Symptoms can resemble calcium deficiency. (Image courtesy of the International Plant Nutrition Institute, Georgia, USA.)

Figure 23. Boron deficiency – severe bunch deformation. (Image courtesy of the International Plant Nutrition Institute, Georgia, USA.)

Figure 24. Calcium deficiency – external pinching of fruit tip and internal brown, hard core in Ladyfinger fruit is linked to calcium and boron deficiency. (Image courtesy of Qld DAF.)

Sulfur (S)

Sulphur has several important roles in banana nutrition. Sulfur:

» is used in amino acids, proteins and oils
» is necessary for chlorophyll formation
» helps to efficiently use inorganic forms of nitrogen.

Symptoms of sulfur deficiency show as yellowish-white colouration in young leaves (Figure 25) as it has limited movement from mature to younger leaves. If the deficiency is severe, the leaf margins become necrotic and develop a slight thickening of the veins. Plants can also appear stunted with small or choked bunches.

The most rapid uptake of sulfur occurs between sucker selection and bunching, after which uptake is reduced and the sulfur needed for fruit development comes from the leaves and pseudostem.

Figure 25. Sulphur deficiency – a light yellow colouring in a young leaf. (Image courtesy of the International Plant Nutrition Institute, Georgia, USA.)

Zinc (Zn)

Zinc is the most important trace element in bananas and the most reported micronutrient deficiency in banana plantations.

Zinc:

» is important for leaf expansion and growth
» increases fruit length and diameter
» increases bunch stem elongation and bunch expansion.

Zinc deficiency typically shows as smaller, thinner, young leaves appearing with a spearhead shape. The leaves can have alternating white and green bands, which can be confused with virus symptoms (Figure 26). As the deficiency progresses, emerging leaves appear with a reddish coloration on the back of the leaves. Bunches produced on zinc deficient plants are small and deformed (Figure 27). Limited zinc availability shortens the distance between hands, giving the bunch a compact appearance. A red pigment, called anthocyanin, can be seen on the back of young, zinc deficient leaves (Figure 28).

Zinc availability is reduced with increasing soil alkalinity. High soil phosphorus can induce zinc deficiency. Zinc can be retained in soil clays and therefore becomes relatively unavailable to plants.

Figure 26. Zinc deficiency – green and white bands on the leaf blade. (Image courtesy of Qld DAF.)

Figure 27. Zinc deficiency – poorly developed bunch in a horizontal position. (Image courtesy of the International Plant Nutrition Institute, Georgia, USA.)

Figure 28. Zinc deficiency – reddening caused by anthocyanin pigmentation on the back of the leaf. (Image courtesy of the International Plant Nutrition Institute, Georgia, USA.)

Key banana elements

Designing a banana nutrition program

Nutrient recycling in bananas

Subtropical banana plantations always have plants of different ages and sizes growing in the one block; the relationships between these plants are important for banana nutrition. Nutrients are recycled from the harvested standing pseudostems to suckers as they grow. By six weeks after harvest 50–60% of nitrogen and phosphorus in the mother plant moves to the growing sucker and after 10 weeks, 40% of the total nutrients needed for the sucker to mature are obtained from the mother plant. Smaller amounts of potassium, sulfur, iron, zinc and boron also move to the sucker, the less mobile calcium and magnesium remain in the mother plant.

As well as direct movement from the harvested standing mother to the sucker, nutrients are recycled through banana trash breakdown in the plantation. Nine weeks after harvest, over 70% of the nitrogen, potassium and magnesium in the banana trash is released into the soil through this breakdown, making it available for the growing sucker (Figure 29).

This recycling is important for planning a nutrition program. Nutrient recycling does not occur in a new planting and all the required nutrients must be supplied for plant crop and the early growth of the first ratoon. Plant and bunch sizes are bigger in the first ratoon crop when recycled nutrient levels are limited, so must be considered as part of a nutrition program. Fertiliser inputs can be reduced for the second ratoon, as recycled nutrient levels are higher.

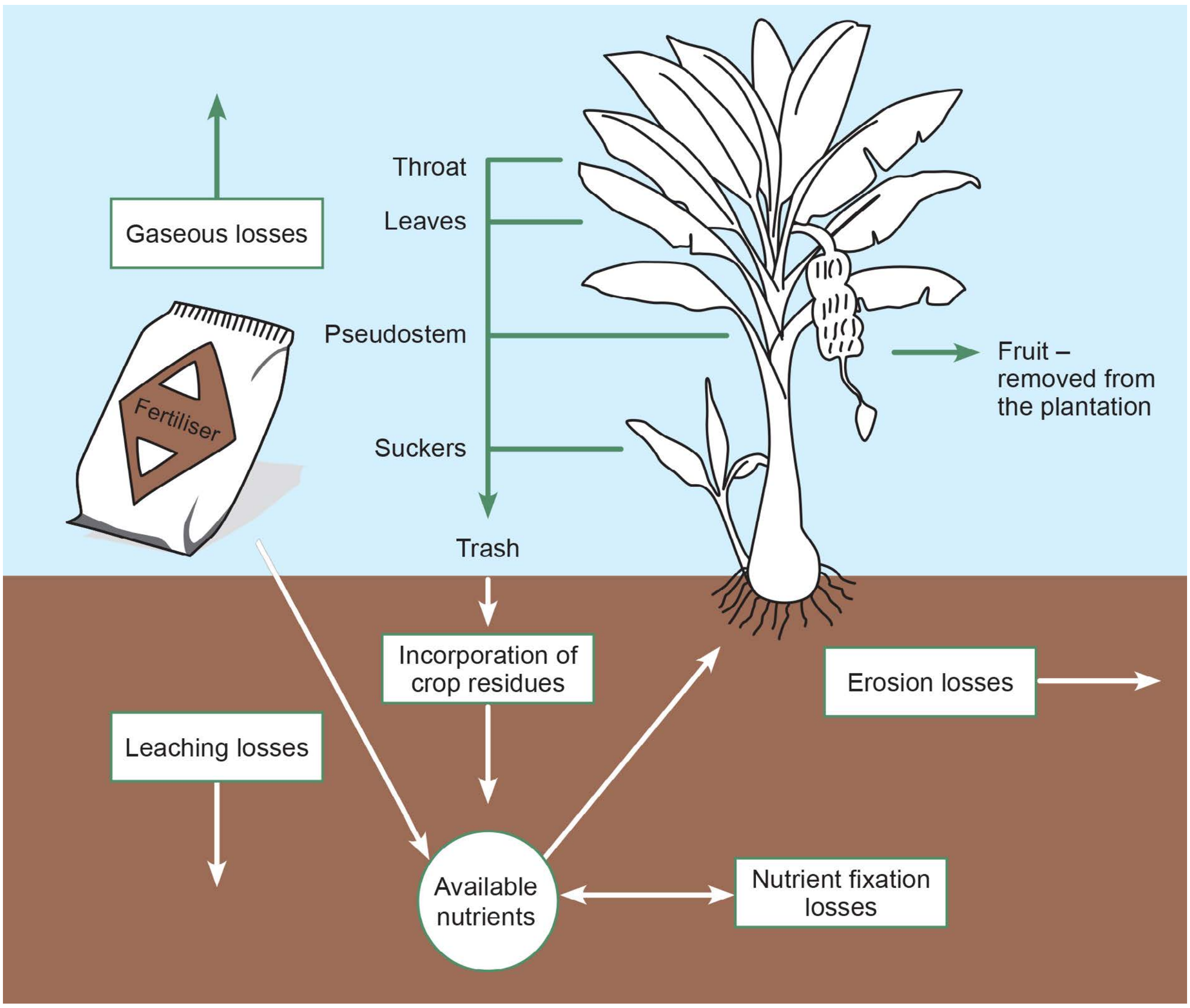

Figure 29. Nutrient recycling in bananas.

'The parent plant can supply up to 40% of total nutrients needed by the sucker in the first 10 weeks after harvest' (Robinson & Galán Saúco, 2010).

Table 3. Amount of nutrient recycling in banana plantations from mother plants to suckers per hectare based on a 50 t/ha yield (from Lahav & Turner, 1989).

Nutrient	Kg in mother plant	% Recycled
Nitrogen	199	51
Potassium	660	46
Calcium	126	55
Magnesium	76	61
Zinc	4.2	88

Matching application to demand – the 4Rs of plant nutrition

Fertilising to crop phenology promotes best management practice for nutrient application, maximises crop nutrient uptake and minimises nutrient loss. The 4Rs of plant nutrition or nutrient stewardship provide the principles of fertilising to phenological demand.

1. The right source – the fertiliser type the plant requires.
2. The right rate – how much the plant requires.
3. The right time – when the plant requires it.
4. The right place – where the plant requires it.

When determining the right nutrient and the rate at which you are going to apply it, it is important to consider the soil type your plants are growing in, the results of your soil and leaf tests, past records and also your yield, as this will tell you how much nutrition the crop removed.

Nutrient loss

Nutrients in banana plantations are distributed throughout the soil and the plant. Many of the nutrients are soluble and some is in the fruit, which is harvested and removed from the plantation. Microorganisms in the soil also convert nitrogen to gasses, making it more available to plants, but also more easily lost. Nutrients are lost through:

» fruit removal

» leaching

» volatilisation (gasses)

» fixation.

Heavy rain can leach nutrients, particularly potassium, from inside the banana leaf.

The Banana Best Management Practices (BMP) guidelines features comprehensive information about soil and nutrient management, and were developed by growers for growers.

The BMP helps growers:

» assess environmental performance using a self-assessment checklist

» implement practices to reduce soil and fertiliser loss.

To find out more about the BMP and to register go to bmp.abgc.org.au

Table 3 shows the amount of nutrient removed per tonne of fruit from a banana plantation and the equivalent amount of fertiliser it takes to replace this.

Table 4. Amount of nutrients removed per tonne of fruit.

Nutrient	Kg removed	Fertiliser equivalent (kg)
Potassium	15.6	36 kg of potassium sulphate
Phosphorus	0.6	11.4 kg single superphosphate
Nitrogen	3.8	8.25 kg of urea
Calcium	2	9 kg of gypsum
Magnesium	1	2 kg Granomag
Sulphur	0.44	106 g potassium sulphate
Zinc	0.01	3.5 g zinc sulphate
Boron	0.14	0.7 kg of Solubor

Table 4 shows the percentage of key nutrients lost through leaching, erosion and volatilisation. This varies considerably due to soil type, rainfall events, slope of the land and plantation floor management. Understanding and taking into account or reducing these losses is important when developing a good nutrition program.

Table 5. Amount and pathway of nutrient loss.

Nutrient lost	Amount and pathway of nutrient loss
Nitrogen	30 to 50+% through leaching and volatilisation
Potassium	20 to 30% through leaching
Calcium	5 to 20% through soil erosion or run off
Boron	Up to 60% through leaching

Leaf and soil sampling

Leaf and soil sampling allows growers to maintain fertiliser levels in both their soil and plant for optimal growth. Soils should be tested before undertaking new plantings to determine what nutrients are already in the soil and to incorporate the less soluble nutrients such as phosphorus and calcium. Conducting regular leaf and soil analysis at the same time once, or multiple times, each year allows growers to compare and fine-tune fertiliser applications to yield and seasonal variations. It also shows if the plant is taking up applied nutrients.

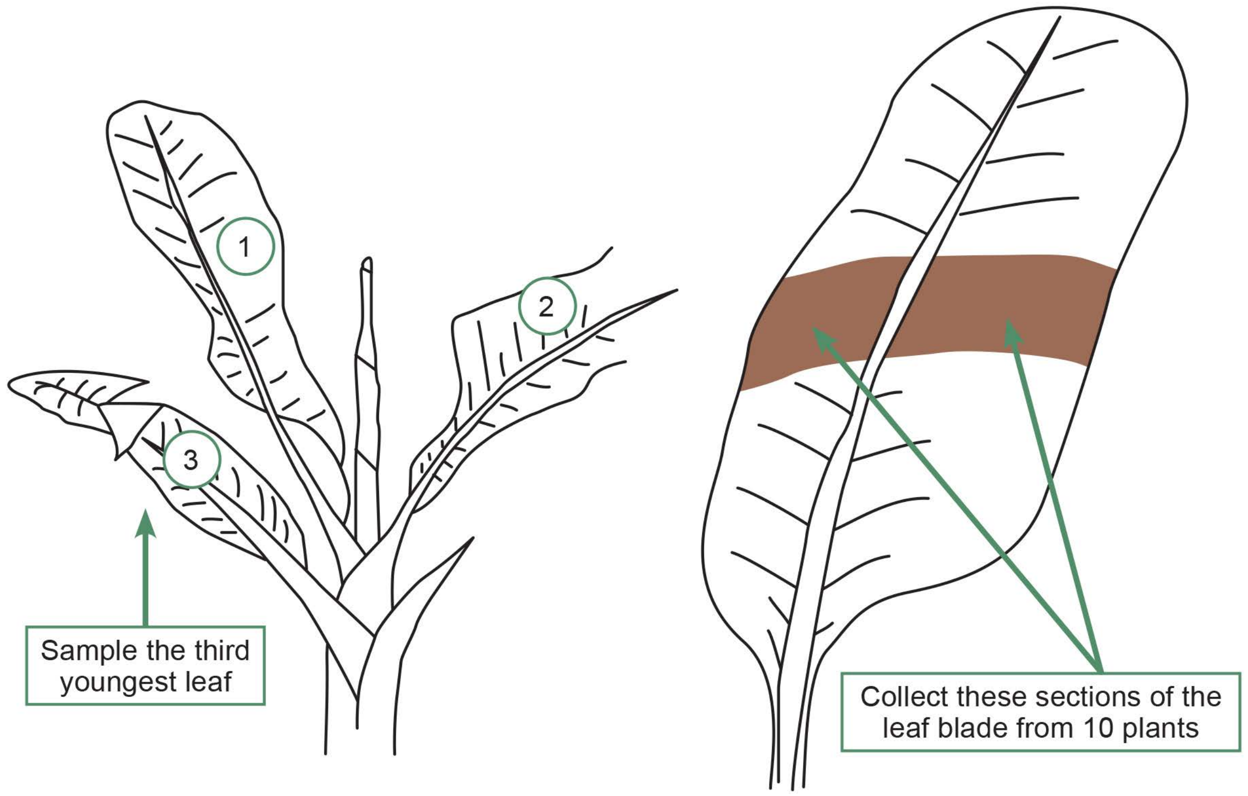

Figure 30. How to collect leaf samples for analysis.

Leaf and soil analysis kits are available from your local rural supplies store or the laboratory to which you intend to send your samples to for testing.

Leaf sampling should be undertaken before bunch emergence and from the same growth stage each time. From medium sized suckers, sample the third-last, fully-emerged leaf that can be easily reached from the ground. Half-way along this leaf take strips of leaf blade 20 cm wide from each side to the midrib (Figure 30). Take samples from a minimum of 10 plants per block; this should be approximately 100 g of leaf tissue. Samples should be taken from each block and variety separately and can be taken at any time of the year and sent to the laboratory as soon as possible.

Avoid sampling leaves if you have recently used foliar fertilisers, as the fertilisers on the leaf surface will affect the results. Similarly, manganese levels in leaf analyses should be ignored if mancozeb fungicides have been used.

Separate **soil samples** should be submitted from each soil type and from paddocks that have been managed differently, as these factors can affect fertiliser needs. Take samples at least six weeks after fertilising.

Collect a minimum of 20 soil cores at 0–15 cm depth from different locations of the site being tested and thoroughly mix in a bucket. Avoid collecting leaf or organic matter from the soil surface. Fill the container supplied in the kit with a subsample from the bucket to ensure the sample is representative of the block being tested. Banana roots are mainly in the top 40 cm of the soil and soil samples generally sample the 0–15 cm. Periodically sampling soil from 15–40 cm will allow soil conditions in the whole banana root zone, particularly pH, to be monitored.

A guide for soil sampling can be found at the NSW DPI website and is listed in the online resources section at the end of this book.

Nutrient standards

Leaf and soil nutrient standards (see tables 6 and 7) provide a guide for growers to monitor and optimise fertiliser application. Recording and maintaining records of leaf levels, crop yield and the types and amount of fertiliser you added over several years will tell you if the amounts of fertiliser you added are too little, enough or too much.

Two different species of bananas *Musa acuminata* (called A) and *M. balbisiana* (called B) have crossed in some banana cultivars. Unlike most species that have only two sets of chromosomes, some banana varieties have more than two sets. Most of the bananas grown in Australia have three sets of chromosomes.

Cavendish are designated AAA, Ladyfinger is AAB and Ducasse is ABB. Goldfinger has four sets of chromosomes and is designated AAAB. Banana varieties with a greater percentage of their genetic makeup from *M. balbisiana* have lower leaf level standards than those with a higher percentage of *M. acuminata* (Table 6).

Different selections of the same variety can have different leaf level standards. However, the different varieties, particularly those related to Ladyfinger and Ducasse have lower leaf nutrient standards than Cavendish (Table 6). All fertiliser applications should be based on leaf and soil tests used in conjunction with yield records.

All nutrients are important, however the essential nutrients for bananas are:

- Nitrogen
- Phosphorus
- Calcium
- Magnesium
- Sulphur
- Zinc
- Boron

Adjusting fertiliser rates: The recommended leaf nutrient standard for potassium in Cavendish bananas is 3–4%. If potassium levels from your Cavendish leaf samples are 2.4% and you've applied 200 kg/ha of potassium in the past year, your application rate is too low – approximately 20% less than the recommended level.

Add 20% more – 240 kg/ha – of potassium for the coming year.

Sampling the leaves at the same time again next year will tell you if you have applied enough potassium. If leaf levels are too low on the second sample, increase the potassium rate and if they are too high, you can drop the potassium rate for the coming year.

You can use this method to help optimise your fertiliser application rates for each element.

Table 6. Nutrient standards for leaf samples for Cavendish and Ladyfinger bananas. Taken from *Plant analysis and interpretation manual* 2nd ed., 1997 and the *Subtropical banana grower's handbook*, 2004

Nutrient	Unit	Optimum – Cavendish	Optimum – Ladyfinger
Nitrogen	%	2.8–4.0	2.4–3.2
Phosphorus	%	0.19–0.25	0.15–0.2
Potassium	%	3.0–4.0	2.4–3.2
Calcium	%	0.74–1.25	0.74–1.25
Magnesium	%	0.3–0.46	0.3–0.46
Boron	mg/kg or ppm	10–20	10–20
Zinc	mg/kg or ppm	20–35	20–35

Table 7. Table 6: Optimum standards for soil samples taken from the *Subtropical banana grower's handbook*, 2004.

Nutrient	Optimum
pH (1:5 water tested)	5.0–6.5
Potassium	0.4–0.5 cmol(+)/kg
Phosphorus (Colwell)	50–75 mg/kg, higher in soils with high phosphorus adsorption
Calcium	4.0–10.0 cmol(+)/kg
Magnesium	1.0–3.0 cmol(+)/kg
Conductivity	<0.15 dS/m

Bananas are a long-term crop and phosphorus demand is long, slow and low compared with annual crops. Tracking soil phosphorus levels over time through soil tests allows growers to determine if their application rate is correct. Soil tests showing an upward trend in phosphorus levels over time indicate that excess phosphorus is being applied and application rates can be reduced.

The balance of the cations (calcium, potassium and magnesium) in the soil is often used as an indicator of soil fertility. The ratio of calcium and magnesium in the soil, however, has not been found to influence plant growth except at extreme values, rarely encountered in banana growing soils. At these extreme values, an excess of one cation can cause a deficiency of another. Plant roots are able to selectively take up some nutrients from the soil as an adaptation to variations in the ratios of nutrients present.

To reduce losses and costs it is important that the amount of fertiliser to be applied is measured. The weight of a handful fertiliser was measured for six different people. For urea, the weight ranged from 11.3 g to 22.5 g – a 100% difference – with an average of 16.6 grams.

Use a container to measure the correct amount of fertiliser to apply, not your hand.

Fertiliser placement

The bananas' fine roots and root hairs take up nutrients. The majority of these roots are located in the top 40 cm of the soil profile. Banana root systems are very spreading however, the majority of roots are within 1–2 m of the corm. Roots are often concentrated where there is a large amount of trash. The majority of roots in double row planting are in between the rows. In single row plantings, it is best to spread the fertiliser over the plantation, concentrating on the uphill side of the follower.

For growers with access to irrigation, fertigation (using the irrigation system to deliver nutrients) is the most efficient way of fertilising bananas. It is less labour intensive and delivers the right amount of nutrient at the right time, together with the water needed to take the nutrient up. Fertigation follows the little and often approach, and because of this, losses through erosion, leaching and volatilisation are almost eliminated. Efficient fertigation can reduce annual rates of nitrogen and potassium by up to 25%.

Adjusting soil pH

Soils in most subtropical banana production areas are usually acid and might require lime applications to adjust the pH. Regular applications of nitrogen fertilisers, with the exception of nitrate fertilisers, usually reduce the pH.

Nitrate fertilisers, while expensive, can increase soil pH to a depth of at least 60 cm, while liming acts to reduce soil pH only in the top 20 cm of soil. Low pH soils can also cause calcium and magnesium deficiency and aluminium and manganese toxicity.

Different soils respond differently to lime and it is difficult to give an exact application rate for liming. Application rates of 250 kg/ha of lime and 400 kg/ha of dolomite on average, will increase the soil pH by approximately 0.1 units.

If you have acid soils, adding lime to the soil will make it less acid. There are several liming materials available and before you buy any liming products it is best to compare the products to determine which one will do the best job and give you value for money.

The neutralising value (NV) tells you the lime's capacity to neutralise soil acidity. Ideally your product should have an NV over 95. The NV should be listed on the lime bag or supplied by the seller.

The fineness of the lime tells you how quickly it will react. Finer limes react quicker and the seller has to specify percentages of different sized particles in the lime.

You can compare the value for money of different liming products by checking the NV and fineness against the spread cost.

The liming efficiency of the product can be calculated by (fineness × NV) ÷ 100 = efficiency.

The efficiency of different liming products can be compared using (spread cost × 100) ÷ efficiency = comparative cost.

Fertiliser timing

To reduce fertiliser losses it is best to apply smaller amounts of fertiliser more frequently. Based on phenological demand, Figure 31 gives an example of the percentage of the total annual amount of fertilisers applied throughout the year and the timing of these applications for growers who cannot fertigate. These recommendations increase the amount of fertiliser applied during periods of greatest growth and development – the warmer months – and reduce the amounts applied during cooler months when growth and development are less. This is fertilising to phenology.

Banana varieties with *Musa balbisiana* in their genome (see feature box top left page 25) have greater cold tolerance and grow year round, particularly through a warm winter. Growers can still fertilise these varieties, however, the growth rate does slow, so winter fertiliser applications can be reduced.

Good practice for fertilising bananas is to work to targets for the total amount of nitrogen, phosphorus and potassium applied to your plantation each year.

There is little yield response data or understanding of the loss pathways for fertilisers in New South Wales banana plantations, however, based on an average yield of 20 t/ha target applications for nitrogen should be 100 kg/ha/yr and potassium 220 kg/ha/yr.

Phosphorus applications should be guided by annual soil tests, as demand for phosphorus is low in bananas. However, an application rate of 20 kg/ha/yr is a starting point. A minimum soil level for phosphorus is 50 mg/kg (Colwell); continue montioring levels at 75 mg/kg and if soil levels rise above 100 mg/kg, phosphorus can be removed from your fertiliser program. If soil levels are rising year by year, application rates can be reduced.

Target total applications of 100 kg/ha/yr nitrogen, 220 kg/ha/yr potassium and 20 kg/ha/yr of phosphorus, split across several applications a year, for a 20 t/ha crop. Soil and leaf tests are critical to monitor this, especially for phosphorus.

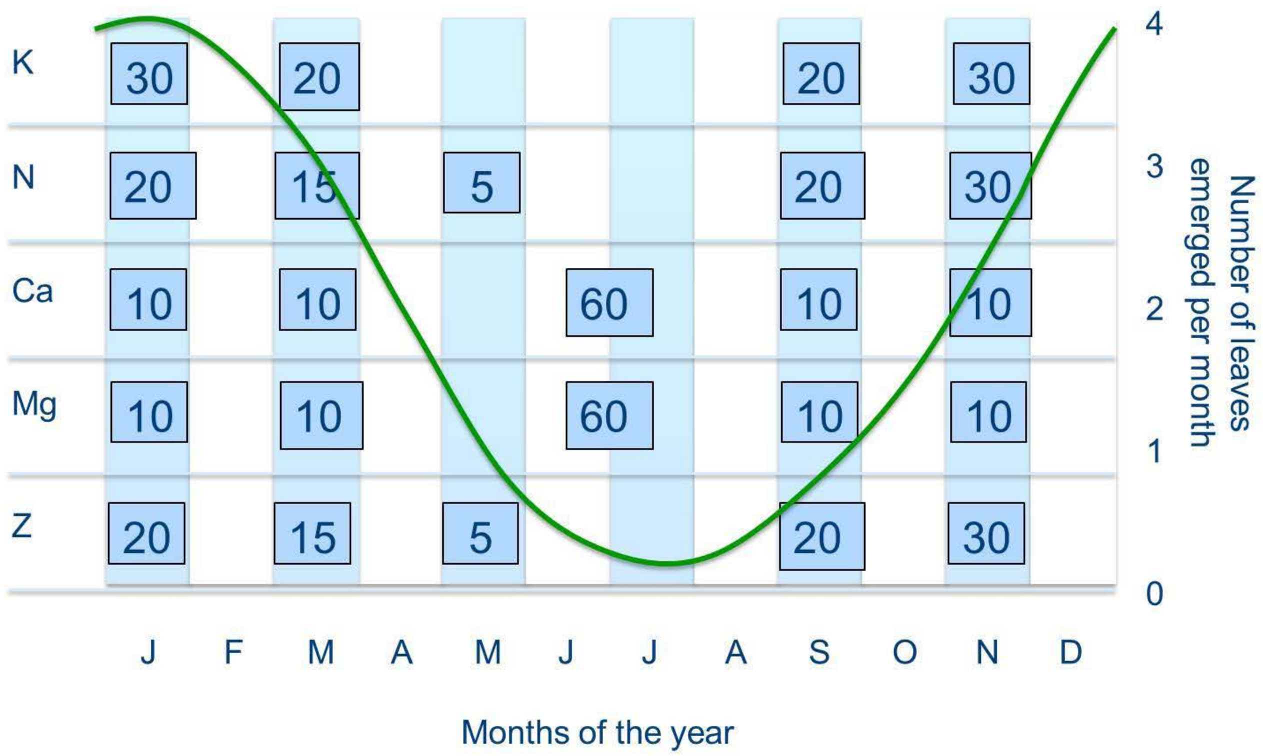

Figure 31. Monthly nutrition calendar showing suggested application rates as a percent of yearly total plotted against average monthly leaf emergence rates.

Designing a banana nutrition program

References and further reading

Akehurst A, Newley P & Hickey M. (2008). *Soil and water best management practices for NSW banana growers*. New South Wales Department of Primary Industries. (http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0007/242359/soil-and-water-best-management-practices-for-nsw-banana-growers.pdf)

Armour J, Berthelson S, Ruaysoongnern S, Moody P & Noble D, (2005). Remediation of soil acidification by form of nitrogen fertiliser on grass swards of Australia and Thailand. *Proceedings of the international symposium on management of tropical sandy soils*. Food and Agriculture Organization for the United Nations. Thailand.

Broadley R, Rigden P, Chay-Prove P & Daniells J. (2004). *Subtropical banana information kit*. Agrilink. Queensland Department of Primary Industries and Fisheries (http://era.daf.qld.gov.au/1966/)

Gowen S (Ed) (1995). *Bananas and plantains*. Chapman and Hall, London, U.K.

Lahav E & Turner DW (1989). *Fertilising for high yield banana* IPI – Bulletin 7. International Potash Institute, Berne, Switzerland (http://www.ipipotash.org/udocs/ipi_bulletin_7_fertilising_for_high_yield_banana.pdf)

Lopez A & Espinosa J (2000). *Manual on the nutrition and fertilization of banana*. International Plant Nutrition Institute, Georgia, U.S.A. (https://store.ipni.net/products/manual-on-the-nutrition-and-fertilization-of-banana)

Newley P, Akehurst, A & Campbell B (2008). *Banana growing guide – Cavendish bananas*. New South Wales Department of Primary Industries. (http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0007/251899/Banana-growing-guide-cavendish-bananas-1.pdf)

Newley P, Akehurst A, Trevorrow N & Campbell B (2008). *Banana growing basics for New South Wales*. New South Wales Department of Primary Industries. (http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0008/223010/Banana-growing-basics-for-NSW.pdf)

Pattison T & Lindsay S (2006). *Banana root and soil health user's manual*. Queensland Department of Primary Industries, Brisbane, Australia. (http://era.daf.qld.gov.au/3498/)

Reuter DJ & Robinson JB (1997). *Plant analysis an interpretation manual*. 2nd edition CSIRO Publishing, Collingwood, Australia.

Robinson JC, & Galán Saúco V. (2010). *Bananas and plantains*. 2nd edition. Crop production science in horticulture 19. CAB International, Wallingford, U.K.

Vimpany I, Johns G & Atkinson I (1991). *Fertilising bananas in New South Wales*. New South Wales Agriculture.

Online resources

General information on soil and fertiliser management

DPI soil management (http://www.dpi.nsw.gov.au/agriculture/resources/soils)

Collecting and submitting soil samples

DPI soil testing (http://www.dpi.nsw.gov.au/aboutus/services/das/soils#Preparing-and-submitting-samples)