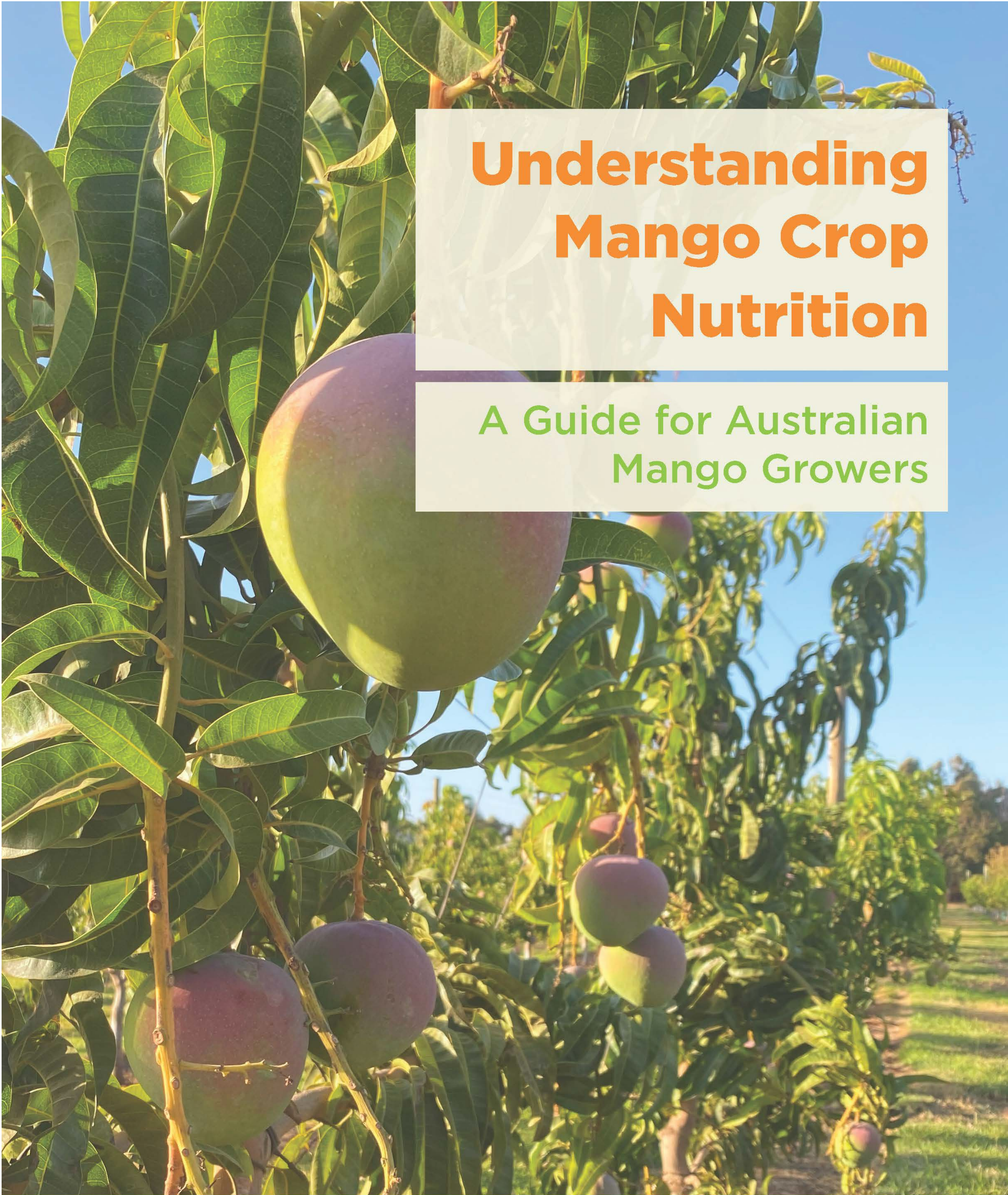

# Understanding Mango Crop Nutrition

## A Guide for Australian Mango Growers

A BEST PRACTICE RESOURCE

Hort Innovation · Australian Mangoes · Queensland Government · Northern Territory Government · Department of Primary Industries and Regional Development, Government of Western Australia · NT Farmers · CQUniversity Australia

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# Part 1: General Mango Nutrition

## Introduction

Having the right fertiliser program is critical for efficient tree growth, fruit yield and quality. It is important you get both the quantity and timing right.

The objective of your fertiliser program is to maintain the soil with adequate nutrition to supply the needs of the trees as they grow throughout the season. To do this effectively requires an understanding of your orchard's soil characteristics and the nutrient requirements for each growth stage of the orchard throughout the year.

## Soil Impacts on Crop Nutrition

### Soil type

The soil type varies considerably from orchard to orchard and within the same orchard. To best understand fertiliser requirements of your orchard it is important to conduct soil surveys to determine soil type. Soil types generally fall into one of the four following categories:

- Loam
- Sand
- Loamy sand
- Clay

Loams are characterised by having higher clay and silt content, while sands have a low proportion of these fine particles. Differences in soil type influences its ability to 'hold' nutrients in the soil profile.

Soils with a high proportion of fine, colloidal particles (e.g. loam) attract and hold nutrient elements better than coarser textured soils (e.g. sand). This is related to the soil chemistry and its physical characteristics. Water from rain or irrigation usually enters and quickly percolates through sand leaching nutrient elements, which are not strongly held by chemical bonds to the sand particles, to a depth where the mango roots cannot access them. Leaching also occurs in loamy soils but is less of a problem.

It is therefore necessary to modify fertiliser practices depending on the soil type involved. To maintain a reasonably constant availability of nutrients, loams generally require less frequent application of larger amounts of fertiliser. In contrast for sands, a strategy of applying small amounts (sand particles only hold small amounts of nutrient) at frequent intervals (to continually replace what is taken up or leached) may be more appropriate. Where soil type varies across a single property, different fertiliser strategies will be needed for each type. For all soil types, avoid applying fertilisers during the peak period of the wet season as extended periods of heavy rain following the application of fertiliser will result in significant losses.

## Soil tests

Fertiliser application rates should be guided by accurate and up-to-date soil tests (and ideally leaf tests), with testing recommended at least annually. The ideal time for soil testing is after harvest, as the nutrients removed by harvested fruit need to be replenished to support the next crop. Engage a knowledgeable local agronomist to conduct the tests and develop a nutrition plan tailored to your orchard's specific needs. In many growing regions, post-harvest coincides with the wet season, so it's essential to carefully manage fertiliser applications to minimise nutrient loss due to potential heavy rainfall and leaching.

## Soil acidity – pH

Soil pH should be about 6.5, within an acceptable range of 5.5 – 7.0. In some production regions of Australia, soil pH tends to be lower than 5.5 resulting in reduced availability of some soil nutrients including nitrogen, calcium and boron. In such situations the soil has become more acidic; a problem that can be corrected by adding lime or dolomite fertilisers. Soil pH can be increased by 0.11 units via the addition of 240kg lime/hectare or 400kg dolomite/hectare. When establishing an orchard, large amounts of lime may be required to correct low pH. To raise pH from 5.0 to 6.5 would require application of 3.6 t/ha of lime to the soil.

Lime should not be applied at the same time as nitrogen fertiliser because the high pH may cause loss of the nitrogen through volatilisation. Allow two weeks between the application of lime and nitrogen fertilisers. Lime and dolomite contain high levels of calcium and are often applied annually to raise pH and soil calcium levels. Dolomite contains magnesium and its use should be avoided if extra magnesium is not required.

Some soils have high limestone content associated with pH in the range of 7-8.  High soil pH reduces the availability of zinc and iron making foliar applications of these elements more important. Soil pH levels can be reduced by applying the sulphate form of fertilisers. Alkalising products such as lime and dolomite should not be used on these soil types.

## Healthy Root Systems

The mango root system is a combination of fine (5mm diameter or less), highly-branched surface roots and large (>5mm diameter), occasionally-branched lateral and tap roots. The fine, surface roots play an important role in nutrient and water uptake while the larger roots, which can grow many metres deep, mainly anchor the tree in the soil and take up water. In general, surface roots are most relevant when developing fertiliser strategies. Beneficial soil microorganisms, such as mycorrhizal fungi, may also play a role in nutrient availability. These micro-organisms are likely to be present in greatest numbers near the soil surface.

The fine surface roots usually grow within the top 30cm of the soil profile and, within that zone, most roots occur within the top 10cm. Nutrient uptake requires live, healthy roots to transport the nutrients from the soil environment through the root surface into the tree. A good supply of water, to ensure the nutrients are in solution, is important to enable effective uptake of nutrients by the trees. Moist soil also encourages proliferation and branching of fine roots and further improves the capacity of the tree to intercept and take up nutrients from the soil.

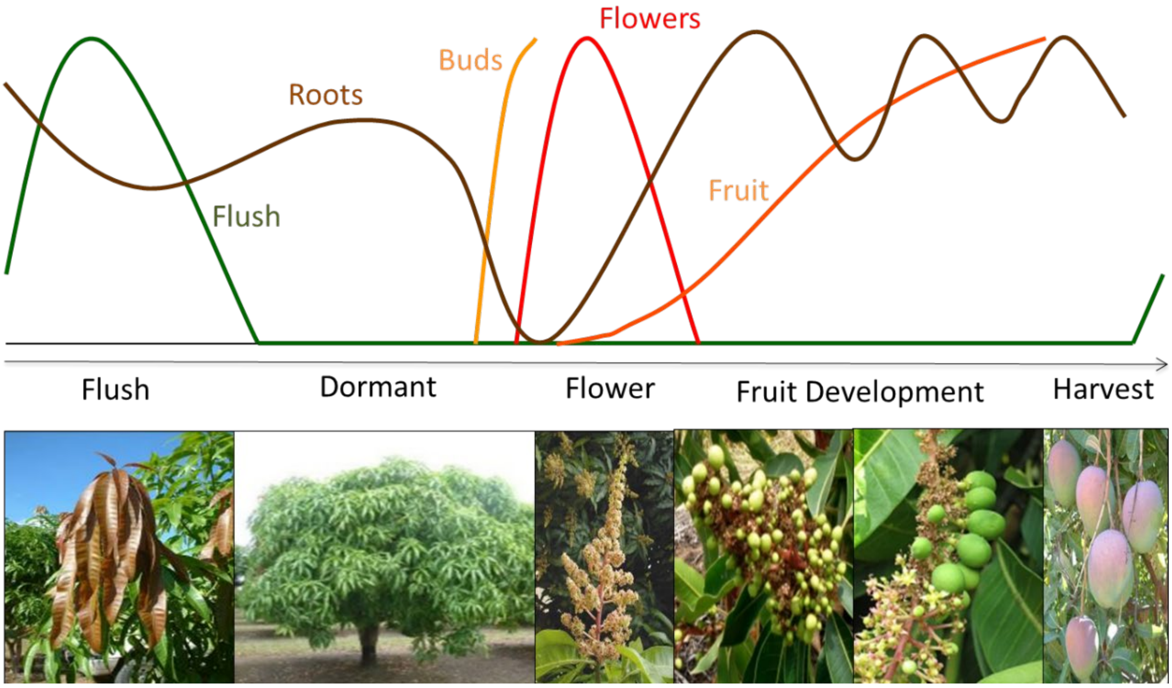
It is important to recognise that root growth is not random. As a rule of thumb, fine roots associated with nutrient uptake will proliferate in the regions of soil providing the most favourable environment for root growth. Soft, well-fertilised and moist soils, particularly those with high organic matter levels and a surface mulch layer, will have more fine roots than hard, dry soils that are not fertilised and exposed to high temperatures and drying. Hence, it is best to apply fertilisers to the area of soil that is wet following irrigation. Similarly, it is of limited value to apply fertilisers directly to dry soils, unless rainfall or irrigation is imminent. If the soil is dry the roots will not be active, the fertilisers will not be in solution and uptake by the tree is likely to be very low.

Fine, surface roots grow in bursts of activity or ‘flushes’ comparable to the shoot flushes that produce new leaves. Fertiliser applications should therefore be timed to coincide with periods of active root growth where possible (refer to root flushing below).

## Tree Growth Cycles

Mango trees experience a series of growth events known as phenological stages (Figure 1). These are influenced by variety, environment and management—this in turn impacts productivity. Each different growth phase has specific nutritional needs, so it is important to match fertiliser application to these demands.

***Figure 1. Tree growth cycles for a mango tree***




The sequence of canopy growth stages (from harvest) are:

1. **Shoot vegetative flushing** influences all subsequent plant growth phases by providing the photosynthetic capacity to support flower, fruit, root and shoot growth. The main period of shoot flushing in Australia's tropics, occurs after harvest in Spring/Summer, coinciding with the warmest and wettest periods of the year. Often two or three flushes may occur during this period. Secondary shoot flushes can also occur during dormancy or late flowering. However, these are generally undesirable as they can redirect plant resources away from fruit set and development, and potentially reduce that season's fruit yield and quality.
2. **Shoot dormancy** generally in late summer/autumn in tropical Australia. Dormancy is usually induced by lowering temperatures and reduced soil moisture levels. This dormant period is important for fruit production as it allows the new leaves to mature and harden and the tree to accumulate sufficient carbohydrate reserves for flowering.

3. **Flowering** occurs when the mature shoot terminals are triggered by plant responses to seasonal and climatic factors (particularly lower temperatures) to initiate a flower flush rather than a vegetative flush. The emergence of full or partial vegetative flushes at this time can be due to climatic effects (e.g. warm winters) and/or in response to excessive nutrients or moisture in the late dormancy period.

4. **Fruit development** is a very important period to have the nutrient balance right in the mango tree. The developing fruit have a particularly high demand for calcium, boron and potassium. Excessive and unwanted vegetative flush during this period can also redirect these elements to the flush instead of into the fruit. This can lead to numerous fruit quality disorders, increased fruit drop and reduced fruit size.

**Root flushing** in mangoes is not well understood but seems to be most common when the other phenological cycles are less active - towards the end of the main shoot flushing, during canopy dormancy and at intervals during fruit development and maturity. Root flushing is rarely observed during flowering. Events including cincturing, severe canopy pruning, soil waterlogging and cold weather can interfere with root development.

**Harvested fruit** removes nutrients from the orchard. A crop yielding 10 tonnes per hectare will deplete approximately 8.5 kg of nitrogen, 12.9 kg of potassium, 11.5 kg of calcium, and 2.0 kg of boron. This nutrient loss must be accounted for when developing the nutrition program for the following season. Shortly after harvest, trees will initiate a vigorous vegetative shoot flush, marking the restart of the annual growth cycle.

# Part 2: Key Nutrients

There are at least 14 elements or nutrients required for plant growth, however the four key nutrients for mango production are **nitrogen (N)**, **potassium (K)**, **calcium (Ca)** and **boron (B)**. Understanding the interactions of these four nutrients is critical to good productivity and fruit quality in mangoes.

## Nitrogen (N)

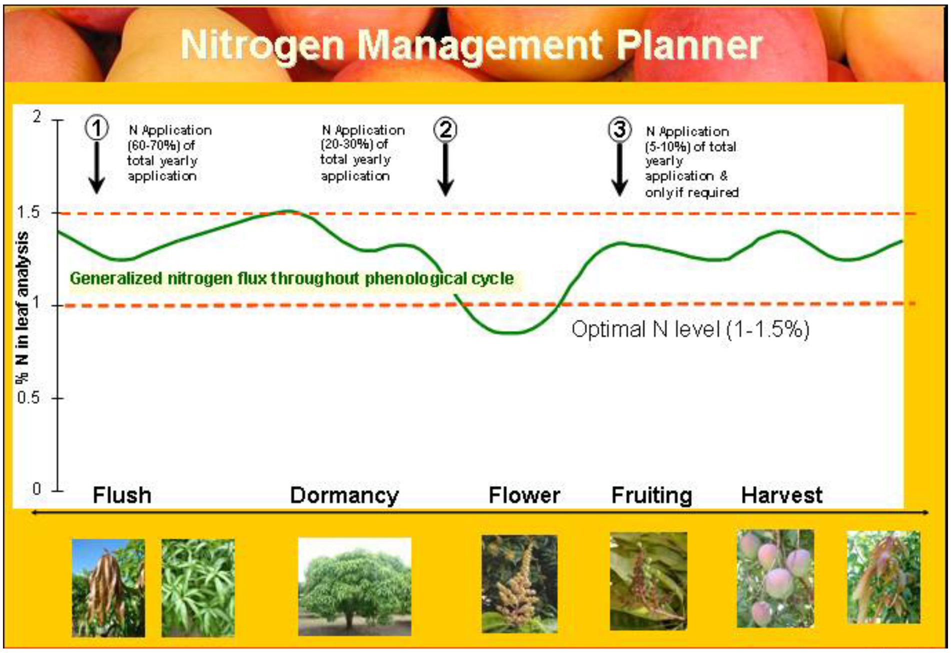
Nitrogen is the driver in plant processes. It is:

- essential for manufacture of chlorophyll, which in turn produces the sugars required for tree growth and development
- the most important element for growth, yield, and fruit quality

N is readily translocated in the tree; evident when flush 'yellows off' as it pushes out flower panicles. The use, timing and application rates for N vary widely across industry. Monitoring plant N levels (particularly after harvest) is very important to maintain optimum plant growth and productivity.

Applying well-timed, optimum quantities of N can increase tree vigour, stimulate flowering (in conjunction with potassium) and improve fruit set, retention, yield, size and brix or fruit sweetness (Figure 2).

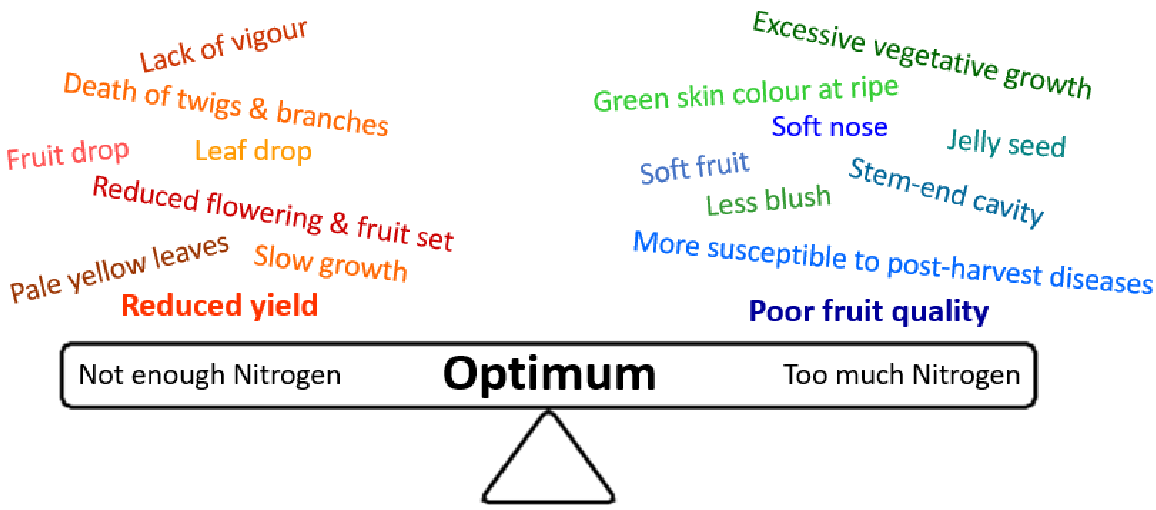
***Figure 2. Nitrogen Management Planner***



However, poorly timed or excessive amounts of N can significantly reduce mango productivity by promoting excessive or unwanted vegetative flush after dormancy, instead of flowers. Excessive flush during fruit development can also decrease fruit quality as calcium is directed to the leaves instead of fruit, causing less blush, soft fruit, fruit not colouring when ripe and increased post-harvest diseases and disorders.

This careful nitrogen balancing act is called 'The Nitrogen Conundrum'. The figure below shows the interaction of positive and negative effects of N in mangoes (Figure 3).

***Figure 3. The Nitrogen Conundrum***




**Excessive or poorly timed nitrogen (N)** application can negatively impact mango quality by promoting excessive or unwanted vegetative flush, which can divert calcium (Ca) away from the fruit and lead to issues such as:

- Reduced blush
- Soft fruit
- Fruit failing to colour properly when ripe
- Increased susceptibility to post-harvest diseases and disorders
- Lower fruit yields

Trees that appear 'too green' are often attributed to excessive nitrogen application, but other nutrients such as manganese (Mn), magnesium (Mg), and zinc (Zn), as well as the use of Paclobutrazol, can also contribute to this condition. Leaf tests, rather than soil tests, are the most reliable way to assess a tree's nitrogen status.

**Symptoms of nitrogen deficiency** include low-vigour trees with pale yellow foliage, often resulting in poor fruit retention. Nitrogen is mobile within the plant, meaning older leaves turn yellow first as nitrogen is redirected to younger leaves, which remain green. A nitrogen deficiency can also impair the uptake of other nutrients.

Insufficient nitrogen reduces photosynthesis and leaf growth, leading to problems such as:

- Lack of tree vigour
- Slow growth
- Twig and branch dieback
- Reduced flowering and fruit set
- Leaf drop
- Fruit drop
- Lower fruit yield

Experience and research have shown various mango cultivars have different requirements for nitrogen. Suggested leaf nitrogen levels for each of the commonly grown mango cultivars in Australia are shown in Table 1 below:

***Table 1. Optimum leaf nitrogen levels for the different mango cultivars.***

| Cultivar | Optimum leaf nitrogen level (%) |
|---|---|
| Asian cultivars | 1.2 – 1.4% |
| Calypso | 1.0 – 1.5% |
| Honey Gold | 1.3 – 1.4% |
| Keitt | 1.0 – 1.2% |
| Kensington Pride | 1.1 – 1.3% |
| R2E2 | 1.3 – 1.4% |

A good way to calculate nitrogen application rate is by the amount required per $m^2$ of canopy, that is, the area shaded by the tree. Based on research conducted on Honey Gold between 2007 and 2010, rule of thumb application rates for N are shown in Table 2 below:

***Table 2. Rule of thumb application amount of N per $m^2$ of canopy, based on measured leaf levels.***

| Leaf nitrogen (%) | Applied nitrogen per $m^2$ of canopy |
|---|---|
| <1.0% | 8g |
| 1 - 1.2% | 4g |
| 1.3 - 1.5% | None required |
| >1.5% | Levels too high |

## Calcium (Ca)

Calcium is the building block of plant cells, where it has three main roles. Calcium:

- Strengthens cell walls
- Is essential in all new growing points of mangoes including roots and root hairs, leaves, flowers and pollen tubes
- Keeps the cell walls elastic allowing cells to expand as they grow.

Calcium is needed in large amounts and most Calcium is taken up from the soil by new roots. Calcium, unlike nitrogen, does not move within the plant and remains in older tissues, making regular and efficient uptake crucial, especially during key growth periods. Uptake is passive and requires moist soil, with elements like potassium (K), magnesium (Mg), and sodium (Na) competing for absorption through the roots. The efficiency of calcium uptake is heavily influenced by particle size; smaller particles allow for faster absorption. For example, super fine gypsum and liquid products like Gyp-Flo, which contain smaller calcium particles, can enhance uptake compared to coarser materials. It is critical for calcium to be readily available during the first six to ten weeks of fruit development, when it is drawn into the fruit via water loss through stomates – the pores in the leave and fruit skin. This early calcium uptake is essential for fruit firmness, internal quality, and for maximising shelf life. Deficiencies are typically not visible on the tree but manifest in the fruit, leading to internal issues such as soft nose and jelly seed (shown in image 1 below).

***Image 1. Soft nose (left) and jelly seed (right). These disorders are linked to calcium deficiency in the fruit.***

- The form of calcium to apply depends on soil pH. For acidic soils (pH < 6.5), use lime or dolomite. If the pH is in the acceptable range (ideally 6.5 or between 5.5 and 7.5), use gypsum.
- Adequate moisture is required for calcium uptake. To minimise leaching, apply calcium towards the end of the wet season or just before/along with irrigation.

- Where practical, time calcium applications to coincide with root flushes (see mango phenology figure below).
- Fine-mesh liquid or powder forms of calcium are absorbed more quickly than coarser forms (listed below figure), so apply these during flowering and early fruit development.
- Foliar calcium products are increasingly popular, but they should only be applied during flowering or early fruit development when plant tissue uptake is most effective.

The following is a list of coarser calcium sources that are generally used when a slower, longer-term release of calcium is acceptable or when soil pH adjustments are needed:

1. **Agricultural Lime (Calcium Carbonate)** – Commonly used to raise soil pH, agricultural lime typically comes in larger, coarser particles compared to fine gypsum or liquid products. It breaks down more slowly and can take time to fully integrate into the soil.

2. **Gypsum (Standard Grade)** – While super fine gypsum offers faster calcium release, standard-grade gypsum contains coarser particles, which release calcium more slowly and may take longer to improve soil structure and nutrient availability.

3. **Dolomite (Calcium Magnesium Carbonate)** – Dolomite contains both calcium and magnesium, and is coarser than fine calcium products. It is often used to address magnesium deficiencies as well as calcium, but it dissolves more slowly due to its larger particle size.

## Boron (B)

Boron plays several roles in plant nutrition:

- Necessary for new cell growth where it affects the movement of plant hormones and sugars
- Essential for fruit set as it helps with pollen viability and pollen tube growth
- A key component of cell walls and helps Calcium move to the cell walls

Boron is highly soluble and is very easily leached from soils. Boron is similar to calcium as it is not translocated within the plant. Small amounts are required during all growth phases, but the majority is required during pollination and early fruit development. As it is only needed in small quantities, it is easy to go from deficiency to toxicity.

Symptoms of boron deficiency include 'shot hole'—small holes in the leaf or lopsided growth of leaves (see Image 2) and flower panicles bent at a right angle. R2E2 is particularly susceptible to low boron levels and lumpy/bumpy fruit is often associated with boron deficiency.

Toxicity symptoms of boron are a wavy burn pattern along the leaf margins of older leaves, starting at the leaf tip or a dark brown to black discolouration between the leaf veins.

***Image 2. Shot holes, indicated by the yellow arrows, are a key indicator of boron deficiency.***

Boron is needed each time there is a new growth event.

- Apply small amounts frequently, particularly on lighter soil types to avoid losses from leaching.
- Foliar applications can only be absorbed by soft tissue, i.e. new flush or flower panicles.
- Using a small amount of nitrogen will help with absorption or uptake.
- Applications at flowering will help pollination as boron helps in the development of pollen tubes.

**It is important to adhere to the recommended rate. Boron can be toxic to mangoes at high levels and care should be taken when applying this fertiliser.**

## Potassium (K)

In mango trees, potassium:

- Is required for cell division and expansion during all growth phases, but particularly fruit development
- Controls plant water uptake, and therefore the uptake of other nutrients, by regulating the opening and closing of the stomates
- Helps move sugars around the plant.

Key benefits of potassium on mangoes are increased fruit size and better flavour, skin and flesh colour. Potassium is very mobile in both the soil and plant. It competes with calcium, sodium (Na), and magnesium (Mg) for uptake, so ensure excessive amounts of potassium are not applied early in fruit development to outcompete the uptake of calcium.

Symptoms of potassium deficiency include general yellowing of leaf margins which can progress to a marginal leaf burn starting at the tip.

Potassium is required during cell division so apply it post-harvest, during flowering and especially fruit filling.

- It is easily leached so apply small amounts often, particularly in lighter soil types.
- Apply >60% of the required amount during the fruit filling period.
- Adjust the amount with your crop load, so apply more with a heavier crop.

Good results have been achieved when K fertiliser is split into small applications at several (up to five) two to three weekly intervals during fruit development compared to a single, large application early in this period. This can be most efficiently achieved via fertigation or using foliar canopy sprays.

# Part 3: Designing Your Fertiliser Program

A successful fertiliser program requires applying the **right nutrient** at the **right rate** at the **right time**, and in the **right place**.


Several key factors must be considered when developing a fertiliser plan:

- **Leaf and Soil Testing**
  Base applications on regular leaf and soil tests to ensure nutrients match the trees' needs.
- **Harvest Impact**
  Account for nutrients removed during the last harvest to guide replacements.
- **Nutrient Losses**
  Account for nutrient losses from:
  - **Leaching**: Nutrients washed below root zones.
  - **Fixation**: Nutrients binding to soil particles.
  - **Volatilisation**: Nutrients lost as gases (particularly nitrogen).
- **Growth Stage Requirements**
  Nutrient demand varies by growth phase (e.g., flowering, fruit set, vegetative growth). Tailor applications to meet these needs.
- **Orchard Zones**
  Identify areas with distinct soil types, topography, drainage patterns or tree health variations that may have different nutritional needs.

Understanding these factors will help you design a program that supports optimal tree health and productivity.

## Nutrient needs and losses

Table 3 (below) shows the amounts of the four key nutrients removed per ten tons of fruit/hectare, along with potential losses due to soil fixation, leaching, and volatilisation. Understanding the nutrient removal per tonne of fruit can help guide fertiliser application rates, particularly when adjusting for 'on' and 'off' production years. Higher nutrient application rates typically result in greater losses. This highlights the importance of regular soil and leaf testing to accurately assess nutrient availability and tailor fertiliser programs accordingly.

***Table 3. Key nutrient removal by 10 tonnes of fruit, fertiliser efficiency after leaching, fixation, and volatilisation, and replacement fertiliser equivalents.***

| Nutrient | Amount removed (kg) | Fertiliser efficiency | Fertiliser equivalent |
|---|---|---|---|
| N | 8.5 | 40% | 21.3 kg N |
| K | 12.9 | 60% | 21.5 kg K |
| Ca | 11.5 | 80% | 14.4 kg Ca |
| B | 2.0 | 40% | 5 kg B |

## The importance of regular soil and leaf testing

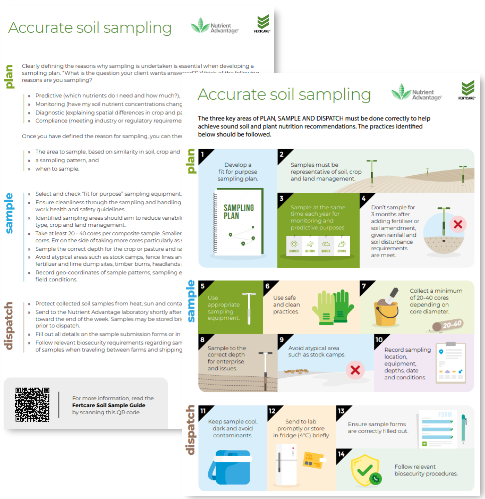
Regular soil and leaf tests, along with guidance from your local agronomist or crop consultant, are essential when interpreting test results and developing an effective fertiliser program. These practices play a critical role in maintaining tree health and optimising fruit production.

- **Combined Sampling**: Taking soil and leaf samples simultaneously allows for a more comprehensive understanding of your orchard's nutritional status.
- **Holistic Approach**: Use analysis results alongside key information about the orchard block (e.g. soil type, rootstock, variety), its history (e.g. yields, irregular bearing, fruit quality), and current conditions (e.g. tree health, leaching rain, drought, irrigation water quality, fruit load, tree size, recent canopy management) to tailor fertiliser programs to your specific needs.
- **Data-Driven Fertiliser Programmes**: A fertiliser program informed by test results and timed properly will help achieve high yields of robust, quality fruit while preventing unnecessary costs, environmental harm, and nutritional imbalances caused by over-fertilisation.
- **Flexibility**: Be ready to adjust fertiliser applications throughout the year based on changes in orchard conditions.
- **Accredited Testing**: Leaf and soil analysis kits, including sampling instructions, are usually available from your local fertiliser supplier or directly from the laboratory. Ensure you only use laboratories accredited by the Australasian Soil and Plant Analysis Council (ASPAC) or the National Association of Testing Authorities (NATA).

## Soil sampling

To optimise nutrition planning for mangoes, it is recommended to take soil samples right after harvest time.

- Allow enough time after fertiliser applications for them to be incorporated into the soil by rain or irrigation before sampling.
- Follow a zigzag path or grid pattern across the block to ensure a representative sample is collected. Choose sampling sites from trees that are typical of the block, and collect 15 to 30 soil cores. The number of cores should be sufficient to represent the entire block.
- If different sections of the block have distinct management histories or soil types, they should be sampled and analysed separately.
- Avoid sampling from the outermost rows or from under trees at the ends of rows. Record or mark your sampling locations for future reference.
- Take two samples per tree (one from each side), from a depth of 0-15 cm, collected from inside the drip line. Use a stainless steel or plastic sampling tool that is free of contaminants.
- Place the soil cores into a clean plastic bucket and mix them thoroughly.
- Take a subsample in the amount requested by the laboratory for testing.
- Send the sample(s) to an ASPAC or NATA accredited laboratory for analysis.
- Unlike leaf tissue tests, which have standardised extraction methods across laboratories, soil nutrient extraction techniques can vary. It is important to compare your results against the optimum ranges provided by the laboratory that conducted the analysis.




To view the Accurate soil sampling infographic scan the QR code or click here.


To view *A guide for 'fit for purpose' soil sampling*, scan the QR code or click here.

## Leaf sampling

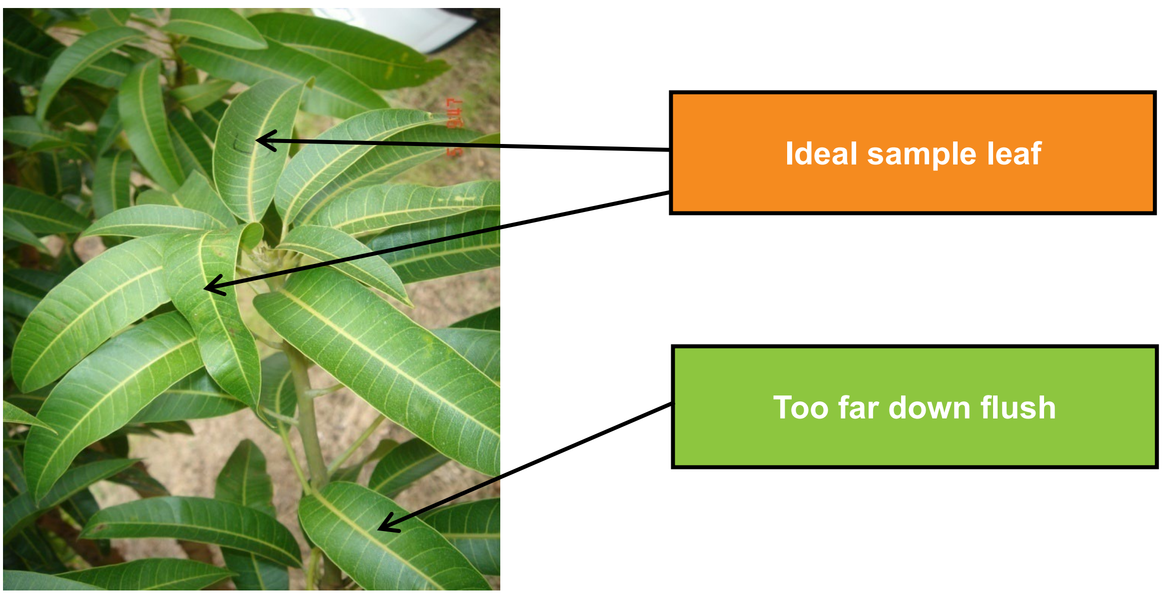
To optimise nutrition planning for mangoes, it is recommended to take leaf samples twice per year—once after harvest and again at pre-flowering.

- Leaf analysis results, combined with tree condition and yield data, provide a valuable way to assess how well you've managed canopy health and productivity over the previous 12 months, allowing for necessary adjustments in the following year.
- The goal is to sample leaves from the same shoots that will bear the next crop. These are the leaves that will be closest to the flowering and early fruit development stages.
- Collect a sample of 40 leaves from across the block. You can either take one leaf per tree from 40 representative trees or two leaves per tree from 20 trees. Follow a zigzag or grid pattern across the block to ensure the sample is representative. Avoid sampling from outer rows or trees at the ends of rows.
- Only collect mature leaves (typically the 3rd or 4th leaf from the growing tip) and ensure you have included leaves from all sides of the tree. Ideal sample leaves are shown in Image 3.
- The sample should not include leaves from more than one variety, from trees of different ages, different soil types, or blocks managed under different practices.
- Mark the sampled trees for future comparisons.
- Send the sample(s) for analysis to an ASPAC or NATA accredited laboratory.


The following information is from Fertcare® Plant sampling for agriculture - A guide. To view the guide, scan the QR code or click here.

- **Handling Samples**: Samples must reach the laboratory in a good, clean condition and should be collected into a clean paper bag. The sample needs to be cooled immediately and chilled to less than 5°C in a refrigerator or cold room as soon as possible (DO NOT freeze the plant material)
- **Washing Samples**: In some cases, it is necessary to wash samples. This is particularly important where iron levels are of concern and the samples are dusty, or for copper, zinc and manganese, where the plants have recently been sprayed with fungicides. Rinse samples in deionised or distilled water to remove dust. Where there is likely contamination by crop sprays, wash samples in water containing a non-ionic wetting agent e.g. Teepol solution, Alconox Detergent, Agral 600, BS1000, (do not use phosphate-based detergent) and then rinse three times in deionised water. Dry the leaves with paper towels and place them in the paper bag provided.
- **Drying Samples**: Samples can be dried in the paper bag at temperatures between 40°C and 80°C. In hot summer conditions, the sample can be dried on the car dashboard (if dust contamination is likely, seal the bag by folding the end). Alternatively place samples in a thermal oven (set to lowest possible setting). If using a microwave oven, set at low power for 1 - 2 minutes. Ensure samples don't burn or discolour.

***Image 3. Ideal sample leaves for leaf nutrition tests.***



## Using soil and leaf test results to determine fertiliser requirements

The guide below (Table 4) shows optimum soil test results for most important soil nutrients. These suggested levels are expressed in mg/kg dry soil, which is equivalent to ppm (parts per million). Optimum leaf nutrient levels are presented below in Table 5.

***Table 4. Optimum soil nutrient levels for the key nutrients.***

| Element | Optimum range | Comments - seek independent advice to tailor nutrition requirements to suit your orchard |
|---|---|---|
| Nitrogen – N | **No clear guidelines** | There are many forms of nitrogen in soil and a measure at any one time may not accurately reflect the amount of available N for the tree. Leaf tests are the preferred method for informing N nutrition. |
| Phosphorus – P | **70 mg/kg** | Once achieved the level should be quite stable. |
| Potassium – K | **100-150 mg/kg** | The K level can fluctuate as a result of uptake by trees and leaching. Pay particular attention to K fertiliser during the period of fruit development. If flowering is particularly intense then adding extra K could be warranted. |
| Calcium – Ca | **≥1,000 mg/kg** | There is some evidence that levels as high as 2,000 mg/kg or more can be beneficial. The advantages of maintaining soil Calcium at levels above 1,000 mg/kg remain to be proven. |
| Magnesium – Mg | **90-120 mg/kg** | For maintenance of healthy plant growth. At higher levels it is associated with green skin colour and poor blush of the fruit at maturity. Also, an imbalance in the Ca:Mg ratio can interfere with Calcium uptake. Aim to keep the Ca:Mg ratio about 8:1. If irrigation water is drawn from a dolomitic soil, Mg levels may be high, particularly during the irrigation season. In this situation, very high levels of Calcium may be required to maintain the Ca:Mg ratio around 8:1. |
| Sulphur – S | **12-20 mg/kg** | S will be applied as part of other fertilisers that contain sulphates and will generally not need special application. |
| Boron – B | **1-2 mg/kg** | Based on data from the most common method of analysis. |
| Copper – Cu | **2 mg/kg** | Copper sprays are often applied as part of a fungicide program that provides adequate Cu for the trees. In such situations the copper reading may be much higher than 2 mg/kg but is not likely to be a concern. |
| Manganese – Mn | **≥4 mg/kg** | Rates as high as 50 mg/kg will do no harm. |

| | | |
|---|---|---|
| Iron – Fe | **≥5 mg/kg** | Rates as high as 60 mg/kg or more will do no harm. Lateritic soil can have high Fe levels. |
| Molybdenum – Mo | | This is not usually part of a soil analysis. It is **minute amounts** commonly included in trace element pre-mixes. If not, then a foliar spray of sodium molybdate at 0.5-1.0 g/L once or twice per year will be sufficient. |
| Zinc – Zn | **2-5 mg/kg** | |

Table 5 shows the desired leaf nutrient ranges and categorises nutrients into three groups:

- **Macronutrients**: Required in large quantities.
- **Micronutrients**: Needed in smaller amounts, also known as trace nutrients.
- **Sodium**: A non-essential nutrient which needs to be monitored, as high levels can cause leaf burn, wilting, reduced productivity, and lower fruit yield.

***Table 5. Desired leaf nutrient ranges.*** Key nutrients are highlighted in green.

| Category | Nutrient | Units | Desired range |
|---|---|---|---|
| Macronutrient | Calcium | % Ca | 2.0 – 3.5 |
| | Magnesium | % Mg | 0.15 – 0.4 |
| | Nitrogen | % N | 1.0 – 1.5 |
| | Phosphorus | % P | 0.08 – 0.18 |
| | Potassium | % K | 0.7 – 1.2 |
| | Sulphur | % S | 0.1 – 0.2 |
| Micronutrient | Boron | ppm B | 50 – 70 |
| | Chloride | % Cl | <0.25 |
| | Copper | ppm Cu | 10 – 20 |
| | Iron | ppm Fe | 30 – 120 |
| | Manganese | ppm Mn | 60 – 500 |
| | Zinc | ppm Zn | 20 – 100 |
| | Molybdenum | ppm Mo | 0.05 – 1.0 |
| Non-essential | Sodium | % Na | <0.20 |

Use high quality fertilisers, which have detailed analyses of their content to ensure that accurate amounts of nutrient are applied. Whilst nutrient deficiencies are more common, sometimes nutrient levels can be too high. This may result from a recent application of a fungicide spray containing, for example, copper or manganese.

RIGHT TIME

## Aligning fertiliser timing with tree phenology

Mango trees require a steady supply of nutrients throughout the year, although demand decreases during dormancy. Once optimal soil nutrient levels are achieved, the recommended approach in orchard management is to apply small amounts of easily leached nutrients, such as nitrogen, potassium, and boron, at frequent intervals.

Nitrogen management is particularly important. The largest portion of nitrogen should be applied immediately after harvest to support post-harvest recovery and subsequent vegetative growth. During key stages—such as flower bud emergence, flowering, fruit set, and fruit growth—large doses of nitrogen should be avoided, as excessive nitrogen at these times can encourage vegetative growth at the expense of fruit retention. Maintaining adequate nitrogen levels throughout these stages is crucial, but without over-application. High nitrogen levels can also reduce calcium content in the fruit, compromising quality and accelerating deterioration.

Boron is essential year-round, particularly during flowering, pollination, fruit set, and fruit growth. Other nutrients, especially nitrogen and calcium, are generally applied after post-harvest hedging or pruning and during the flushing period to support the rapid vegetative growth that follows.

### Fertiliser intervals for mango orchards

Selecting the most suitable fertiliser application intervals depends on factors such as soil texture and other local conditions:

- **Soil Texture**: Light, sandy soils have low cation exchange capacity (CEC), meaning they hold fewer nutrients in the root zone. In these soils, frequent light applications are necessary to maintain nutrient supply. Heavier clay soils, which have a higher CEC, can retain more nutrients, allowing for longer intervals between applications. Increasing the organic matter content can improve the nutrient and water retention capacity of all soil types.
- **Nutrient Type**: Easily leached nutrients like nitrogen, potassium, and boron should be applied regularly. In sandy soils, this may be weekly, whereas in clay soils, it could be every two to three months. Other nutrients can be applied based on leaf or soil analysis results indicating low availability.
- **Expected Rainfall**: In high-rainfall areas, frequent, lighter applications help minimise nutrient loss through leaching.
- **Fertigation vs. Solid Fertiliser Application**: Fertigation allows for more frequent applications. However, it is important to monitor soil pH in the wetted area under the sprinklers, as it may become more acidic over time and require correction.
- **Fertiliser Solubility**: Soluble fertilisers like urea, potassium sulphate, and boron should be applied at shorter intervals, while less soluble fertilisers such as lime can be applied less frequently.

**Management Preferences**: Your fertilisation schedule can also be adjusted based on personal management practices and preferences.

Careful planning based on these factors will help maintain optimal nutrient levels for mango tree health and productivity.

A nutrition planner, which outlines the recommended percentages of the four key nutrients, is shown in Figure 4 (below). The actual amounts to be applied should be determined based on leaf and soil analyses, or in consultation with your nutrition advisor. The percentages indicated in the planner correspond approximately to the stages in the growth cycle when it is recommended to apply those nutrients. As mentioned above, smaller and more frequent nutrient applications are advised within these application windows.

***Figure 4. A nutrition planner for Nitrogen, Calcium, Boron and Potassium application for mangoes.***

| | Flush | Dormancy | Flowering | Fruit Development | Harvest |
|---|---|---|---|---|---|
| Nitrogen | 60-70% | | 20-30% | 5-10% (if needed) | |
| Calcium | 50% | | 20% | 30% | |
| Boron | 20% | 20% | 40% | 20% | |
| Potassium | 20% | | 20% | 60% | |

RIGHT PLACE

## Targeted fertiliser application techniques

For optimal mango tree nutrition, fertilisers should generally be applied directly to the soil. Exceptions include foliar sprays for boron and the use of potassium nitrate, which is applied to induce flowering.

### Application under and near the canopy

In general, fertiliser should be distributed evenly across the area beneath the tree canopy, extending out to approximately one metre beyond the drip line. This approach is beneficial for several reasons:

- Most feeder roots are primarily located in this zone, particularly within the area that is watered by irrigation emitters.
- Encouraging feeder roots to extend beyond the drip line allows for a greater volume of soil to be utilised for nutrients and moisture absorption.

In mature mango trees, roots may reach into the middle of the inter-row, provided that the soil is not severely compacted. However, it is recommended to configure the fertiliser spreader to ensure that the majority of the fertiliser is applied under the tree canopy.

### Whole area broadcasting

For products like lime, dolomite, or sulphur that are intended to modify soil pH, it is generally recommended to apply these across the entire orchard floor, regardless of tree size. An exception would be when attempting to adjust the pH specifically within the wetted zone under sprinklers, such as when using micro-fine lime.

### Banding application

For nutrients like phosphorus and zinc, which may become immobilised in certain soil types, banding is advisable. Soil types that commonly fix phosphorus include krasnozems, red earths, podzols, and Karri loams, while soils with high clay content are known to retain zinc. By applying the fertiliser in a narrow band, a greater proportion of the nutrients remains available for plant uptake. Banding can be done in two primary ways:

- Hand-spreading the fertiliser in a 30 cm band around the dripline of each tree.
- Mechanically applying it in straight 30 cm bands parallel to the tree rows along both sides of the drip line, either manually or using a boom spray.

### Boom spraying to the ground

This technique is often employed for applying trace elements, such as boron, in low quantities when fertigation is not feasible. Due to the small granule size and low application rates, broadcasting is impractical; however, it can also be used for banding.

Typically, a weedicide boom or a similar apparatus is used to spray the fertiliser under the canopy or along the drip line from a tank containing dissolved nutrients. The correct dosage is determined by considering the concentration of fertiliser in the tank, the nozzle delivery rate, and the speed of the tractor.

### Fertigation (fertilisers through irrigation)

If you utilise fertigation to deliver most of your fertiliser, your irrigation system should be designed to:

- Ensure that the majority of the under-tree area is adequately watered.
- Provide uniform distribution across the orchard, ensuring that each tree receives an equal dosage.
- Select sprinklers that offer an even distribution pattern.

A fertigation system with a very limited wetted area, such as one using a single drip line with few emitters, is generally unsuitable as it restricts effective nutrient distribution and uptake.

When the irrigation system effectively covers a large proportion of the under-tree area and ensures uniform water distribution across the wetted area and the orchard block, fertigation becomes a highly efficient method for applying fertilisers. It reduces labour costs, enhances nutrient uptake efficiency, and allows for more frequent and convenient fertiliser applications. With effective fertigation practices, the annual rates of nitrogen and potassium can typically be reduced by around 25%.

Fertilisers should be dissolved in water within a drum or tank and then injected into the irrigation system. The preferred equipment includes a venturi injection pump or a pressure differential system. It is crucial that the fertilisers used are highly soluble to prevent damage to pumps and blockages in pipes. Additionally, mixtures of fertiliser must be compatible to avoid precipitate formation that could clog sprinklers or harm root systems. Key requirements include effective filtration and a uniform irrigation system that delivers consistent water amounts to all trees in the orchard.

When designing a fertigation system, it is essential to focus on the area of ground that is wetted by the irrigation system. If this area is relatively small (20% or less of the orchard floor), fertiliser application could become too concentrated, potentially harming root health, especially for nutrients that can be toxic, like boron. Conversely, if the wetted area is excessively large (80% or more of the orchard floor), much of the fertiliser may be inaccessible to the roots, particularly in younger trees. Some irrigation systems are designed to allow adjustments to wet a larger area as the trees mature.

A list of suitable straight fertilisers for use in fertigation is provided below (Table 6). Not all fertilisers are compatible; it is advisable to consult suppliers for guidance on compatibility. Additionally, many fertiliser companies offer proprietary blends of nutrients specifically designed for fertigation use.

***Table 6. Soluble fertilisers suitable for fertigation.***

| Fertiliser | Main nutrients applied |
|---|---|
| Urea | Nitrogen |
| Calcium nitrate | Nitrogen, calcium |
| Potassium nitrate | Nitrogen, potassium |
| Potassium sulphate ('K spray') | Potassium |
| MAP (technical grade) | Nitrogen, phosphorus |
| Magnesium sulphate (Epsom salts) | Magnesium |
| Solubor | Boron |
| Boric acid | Boron |
| Zinc sulphate heptahydrate | Zinc |
| Iron sulphate | Iron |
| Iron chelate | Iron |
| Manganese sulphate | Manganese |
| Copper sulphate heptahydrate | Copper |

## Pre-fertigation preparation

Before initiating a fertigation programme, it is crucial to conduct a comprehensive analysis of your irrigation water. Ensure that tests include not only pH and salinity but also iron, boron, hardness, and bicarbonate levels. It is advisable to seek expert guidance for the design and operation of your fertigation system.

One potential challenge associated with fertigation is the significant drop in pH within the wetted area compared to the non-wetted zone due to the acidifying effects of the fertilisers. Regular monitoring of soil pH is essential for both the wetted and non-wetted areas, as most fertilisers tend to acidify the soil. Soil samples should be collected from the surface layer (0 to 15 cm) as well as from deeper soil (up to 30 cm). To maintain soil pH within the desired range, applications of micro-fine lime can be made through the fertigation system as a suspension, provided there is adequate agitation.

### Foliar application

Foliar nutrient sprays are typically not recommended for mango trees for the following reasons:

- The waxy surface of the leaves hinders substantial nutrient uptake.
- Any nutrients that are absorbed tend to have limited distribution to other parts of the tree where they are required.

It is important to note that leaf tissue tests conducted after foliar applications may yield unreliable results due to residues remaining on the leaf surface and within the waxy cuticle, which do not accurately reflect the nutrient levels within the leaf cells.

The exceptions to this are the application of a boron foliar spray or potassium nitrate to induce flowering.

# Conclusion

In conclusion, successful mango nutrition management begins with understanding the unique characteristics of your soil, monitoring its pH, and supporting healthy root systems. By aligning nutrient applications with the tree's growth cycles and focusing on key nutrients like nitrogen, calcium, boron, and potassium, growers can meet the specific demands of their orchards. Regular soil and leaf testing provide essential data to tailor nutrition plans, ensuring optimal tree health and productivity. A strategic, data-driven approach is key to achieving sustainable and high-quality mango yields.

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***MG17000* (2018-2022)**

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***MG10013* (2011-2014) and MG06007 (2008-2011)**

The projects 'MG06007 Delivering Mango Technology" and 'MG10013 Delivering Information and Technology to the Australian Mango Industry' (2008-2014) were pivotal in identifying and assembling the latest mango nutrition information and practices into a series of grower information resources. This information was presented to growers in each of the major mango growing regions of Australia through a series of conference and workshop presentations titled; 'Food for Fruit – Nutrition management in mangoes'. These projects were funded by Horticulture Australia Limited, mango grower levies and partners including QDAF, NTDPI, Tropical Horticulture Consulting, NT Farmers, AMIA and Pinata.

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