Department of Primary Industries
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Macadamia grower's guide 2022

NUTRITION AND SOIL HEALTH – PART 1: THE FOUNDATIONS

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Disclaimers

Image acknowledgements

Large cover photo: an ideal macadamia orchard with grassed waterways and inter-row ground cover.

Smaller photos left to right: an active root zone of a healthy macadamia tree; composting the root zone creates a highly productive system; compost ready for spreading.

Unless otherwise stated, the images in this guide have been sourced from the NSW Department of Primary Industries.

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Macadamia grower's guide 2022

Nutrition and soil health – Part 1: the foundations

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About this guide

The '*Macadamia grower's guide project*' (2022–24) provides up-to-date resources that describe best management practices for macadamia growers. The online resources allow for timely updates incorporating new research findings and evolving macadamia management practices.

'*Nutrition and soil health*' is the first module developed in the project. There is a tremendous amount of information in this topic area, which is why there are 2 parts: '*Part 1: the foundations*' and '*Part 2: the next level*'.

This part, '*the foundations*', offers a framework for building and sustaining productive capacity that is beneficial in every macadamia orchard. The next level is a more detailed reference that supports managing specific nutrition and soil health issues, once these have been identified and quantified through monitoring soils and trees. '*The next level*' includes information on managing nutrition where it is easy to go wrong if the situation in the orchard is unclear.

This first module of the grower's guide uses the familiar print and online file formats. A developing web-based interface will support future modules.

NSW DPI maintains current information for macadamia growers. More up-to-date information may be available.

Contents

Foundations for nutrition and soil health

The nutrition and soil health foundations for macadamias prepare orchards for high productivity by:

- supporting soil and tree health
- ensuring inputs contribute to orchard productivity
- minimising excess fertiliser use
- reducing nutrient losses to the environment.

This foundation approach to nutrition and soil health (Figure 1) uses monitoring of soil and trees to inform decisions on:

- correcting pH
- building up organic matter
- implementing effective drainage
- replacing nutrients and correcting imbalances.

Working on these key action areas improves many issues that limit long-term productivity and prepares the orchard for targeted actions to lift yields further.

Detailed nutrition and soil health management can be complex and involve increased risks. Many growers work with advisors to collect and interpret information and decide what to do year to year.

The '*Macadamia grower's guide: nutrition and soil health – Part 2: the next level*' has more detail on specific soil and nutrition issues.

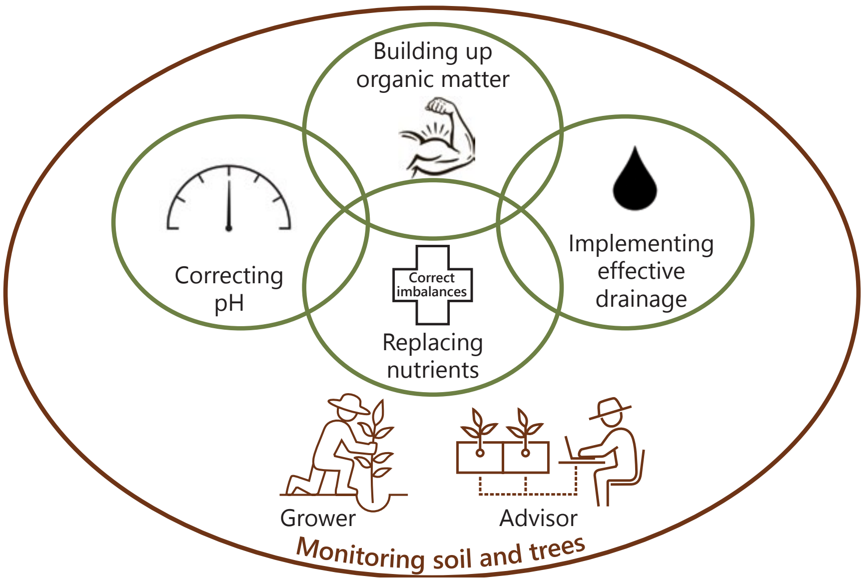


Figure 1. Monitoring soil and trees will guide the key activities of the foundations approach to soil health and nutrition.

Nutrition and soil health management are complex and depend on soil characteristics. The information in '*Nutrition and soil health – Part 1: the foundations*' introduces key principles for nutrition and soil health. We encourage growers to seek independent advice to enhance nutrition and soil health decisions.

The tree's relationship with the soil

Macadamia trees need nutrients to grow and produce nuts. Trees mostly take up nutrients from the soil through their feeder roots (Figure 2). These are the fine roots growing in the active root zone, which extends from the trunk to just outside the drip line of the canopy and down to a depth of approximately 400 mm in healthy soils.

Structural roots mainly provide physical support, anchoring the tree and extending deeper into the soil profile. Structural roots also assist in taking up water from deeper in the soil profile, especially as the upper sections dry out.

Conditions that favour feeder roots also favour nutrient uptake. Feeder roots are active when the soil has enough moisture. As plants take up nutrients that are dissolved in water, it is critical to have good moisture levels in the soil.

The active root zone decreases when the soil is bare, eroded or compacted (Figure 3). Without enough feeder roots, trees will struggle to take up water and nutrients to be productive. Ensuring soils support feeder root growth is critical for successful production.

Figure 2. The active root zone is where feeder roots are present.

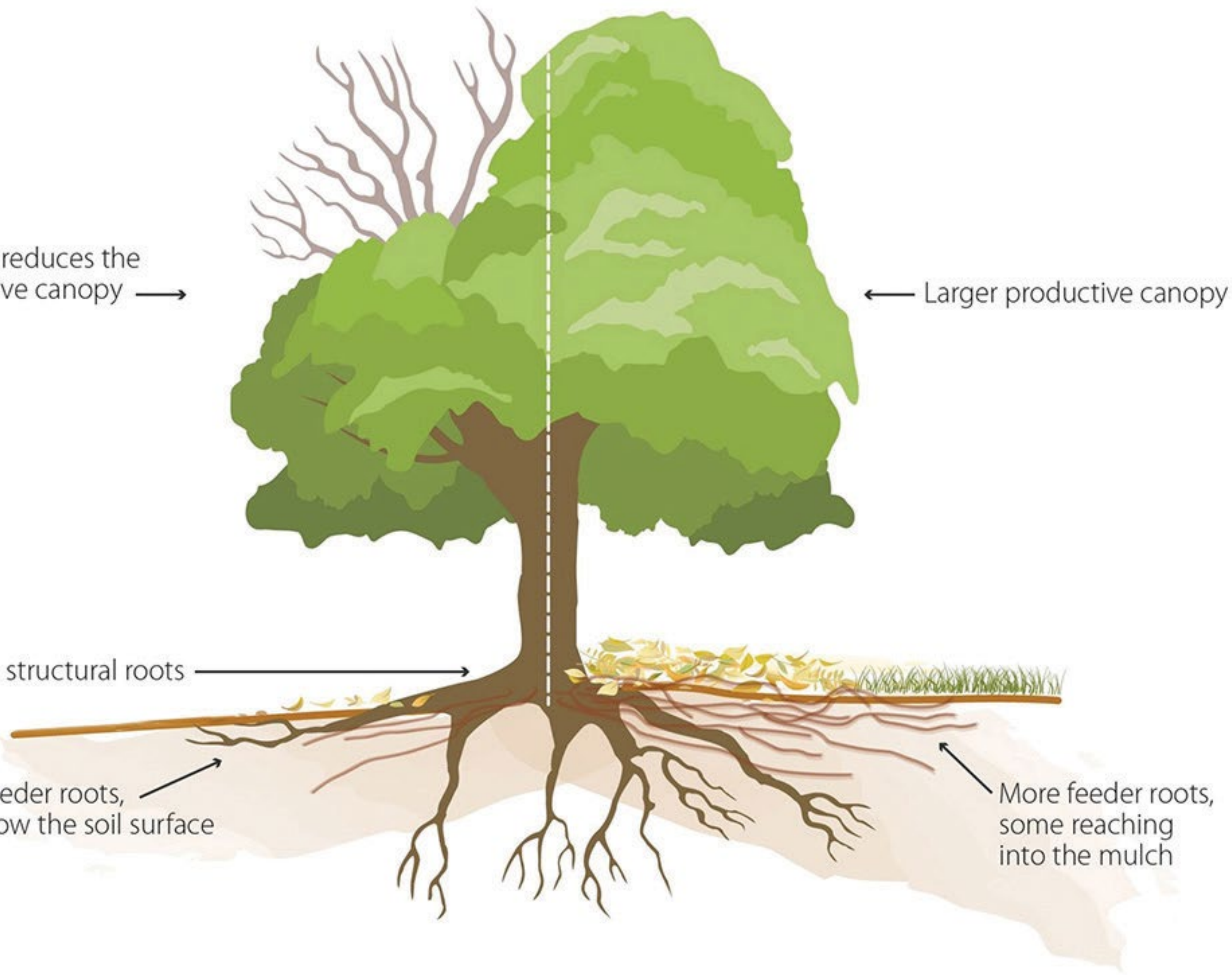


Figure 3. The tree's productive canopy and yield potential are related to the size of the active root zone and feeder root activity.

Orchards and soils that support feeder roots have:

- **ground cover** (Figure 4) to provide a sheltered soil environment
- **organic matter** inputs (Figure 5) applied under the tree (Figure 6) to improve water holding capacity and feed microbes that cycle nutrients into available forms
- **optimised pH** (Figure 7) to keep nutrients available to the trees
- **uncompacted soil** structure that exchanges moisture and air through interconnected pore spaces.

These attributes must be present to obtain the full value of fertiliser applications.

Figure 4. Grassed waterways and inter-row ground cover help improve soil conditions and prevent erosion.

Figure 5. Organic matter such as compost helps create good conditions for feeder roots.

Figure 6. Adding organic matter such as compost to the soil surface protects feeder roots and gives them more space to grow.

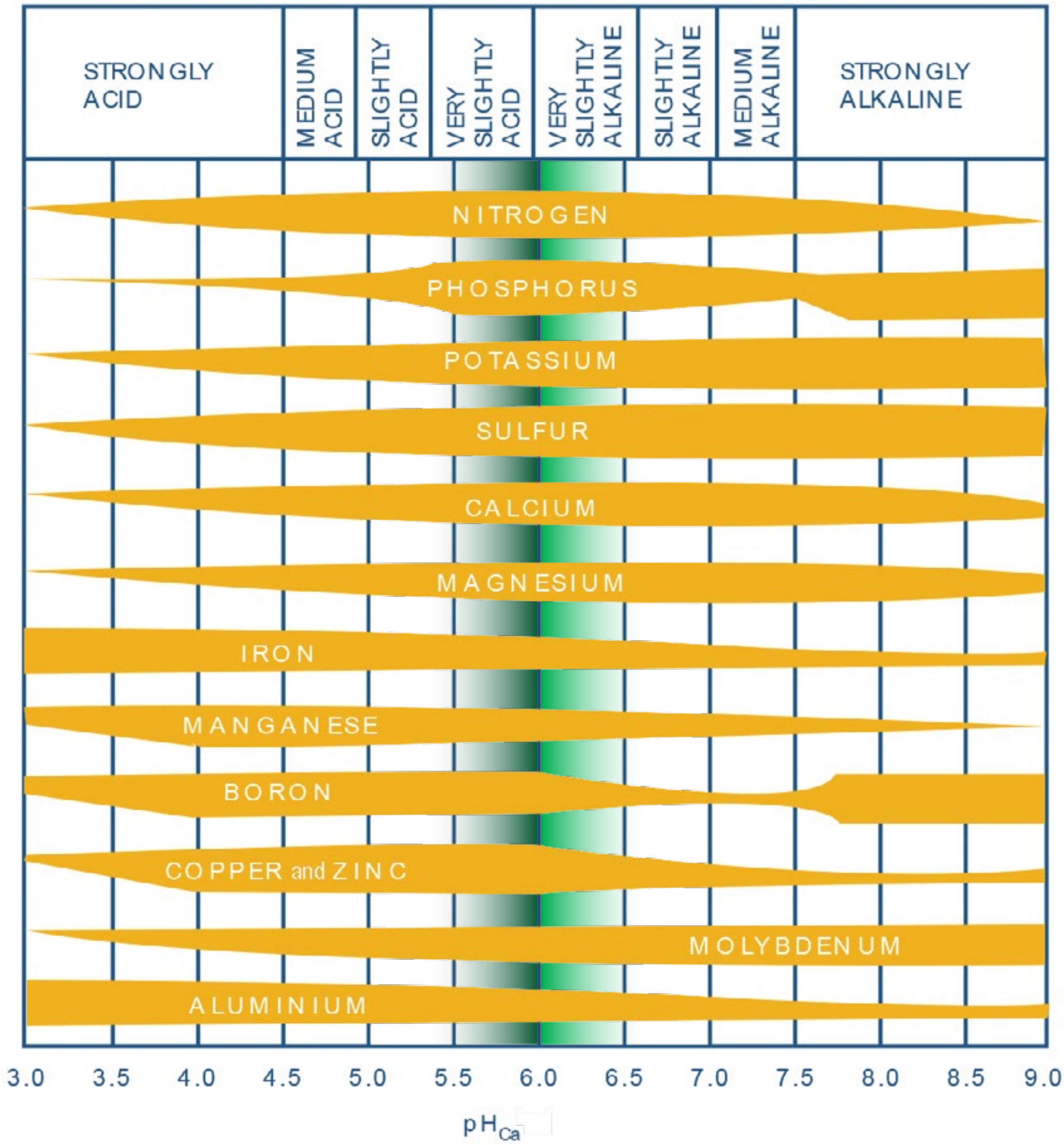
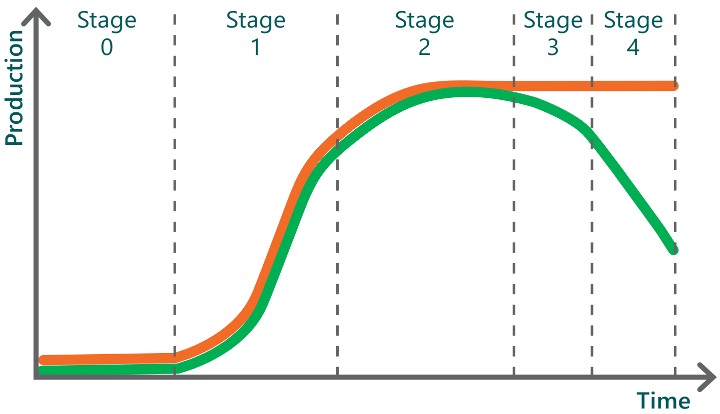


Figure 7. The availability of specific nutrients in soils changes with the pH. The thicker the yellow band, the more soluble the element is at that level of soil acidity or alkalinity. The target pH range for acidic soils is 5.5–6.0 pH_{Ca} (shaded in darker green) and for alkaline soils is 6.0–6.5 pH_{Ca} (in paler green). Source: adapted from Blake (2000).

Key activities to maintain soils

The '*Integrated orchard management guide*' (2016) describes how macadamia orchards progress through developmental stages. The goal of productive orchard management is to reach, stay in, or recover to integrated orchard management (IOM) stage 2 – peak production (Figure 8). Building and maintaining productive soils is vital for high nut yields and resilience to drought or soil-borne disease pressures.



The 5 stages observed by the AMS 2014 study tour group across Australian macadamia growing regions were:

Stage 0 – Preplant

Stage 1 – Early production

Stage 2 – Peak production

Stage 3 – Declining production

Stage 4 – Poor performance

Figure 8. The phases through which macadamia orchards can progress. The brown line represents the ideal performance of a macadamia orchard, plateauing at IOM stage 2. The green line represents declining production in the orchard with ongoing problems with the canopy, orchard floor and drainage systems.

Correcting soil pH

Moving soil pH into the target range, and keeping it there, is crucial for:

- preventing and correcting many nutrient deficiencies and toxicities
- optimising nutrient availability to plants
- supporting tree root development and soil life
- the ongoing development of beneficial soil structure.

Monitoring soil pH is essential because it changes even when yields are high and trees are healthy. By the time plants show symptoms or yield loss, soil pH has likely been moving for a long time and it will be harder to change.

Soil pH is usually measured using water (pH_w) or calcium chloride (pH_{Ca}). Use pH_{Ca} to make decisions about pH correction. Relying on pH_w creates more potential for error and can over or under-report the size of the correction required (Figure 9). Seasonal variability can also influence pH_w results by up to 0.6 units.

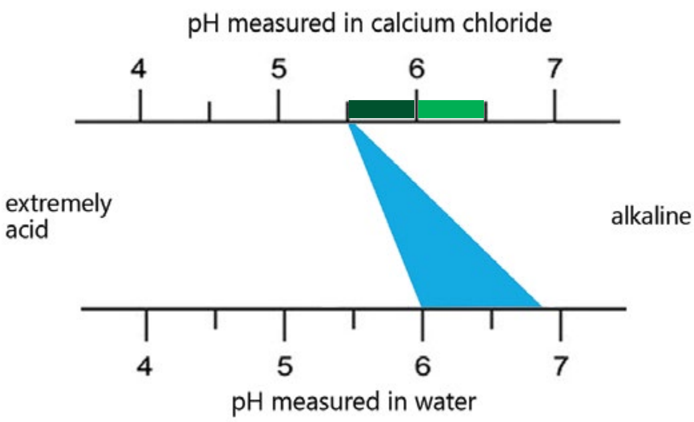


Figure 9. pH measured in water can be 0.5 to 1.3 pH units higher than when measured in calcium chloride (pH_{Ca}). The preferred range for acidic soils is 5.5–6.0 pH_{Ca} (shaded in darker green) and 6.0–6.5 pH_{Ca} for alkaline soils (in paler green). Source: adapted from Anon (2020).

The soil pH target for macadamia is 6.0 pH_{Ca}. Aim to bring soil pH to within 0.5 pH units of the target. The target ranges for macadamias are:

- 5.5–6.0 pH_{Ca} in naturally acidic soils
- 6.0–6.5 pH_{Ca} in naturally alkaline soils.

Start correcting pH before it moves out of the target range. It is easier and cheaper to achieve small corrections than large ones because the amount of material needed to create pH change increases by a factor of 10 for every pH unit.

Most soils used for macadamia production in Australia are naturally slightly acidic. Many agricultural practices, such as harvesting and applying some nitrogen (N) fertilisers, make soils more acidic (lower the soil pH). Correct soil acidity by applying liming materials, which react with and neutralise the acid.

In naturally acidic soils, select fertilisers to minimise effects on pH. If using acidifying fertilisers, apply sufficient additional lime to compensate for the acidity created (Table 1).

Table 1. Fertiliser forms and the amount of lime required to offset acidification.

Nitrogen source	Amount of lime (kg) required to offset each kilogram of fertiliser used
Potassium nitrate (13% N) Calcium nitrate (15.5% N) Composted poultry manure (3% N)	0
Urea (46% N) Ammonium nitrate (34% N)	2: 1kg 1kg
Diammonium phosphate (DAP) (18% N)	3.5: 1kg 1kg 1kg 1k
Sulfate of ammonia (21% N) Mono-ammonium phosphate (MAP; 11.3% N)	5.5: 1kg 1kg 1kg 1kg 1kg 1k

Source: adapted from Lines-Kelly (1992).

CEC, nutrients and pH

All soils have a cation exchange capacity (CEC), which is a measure of the soil's ability to hold positively charged ions. High CEC is good because the CEC stores plant available nutrients and buffers pH. CEC is mostly associated with clay minerals and organic matter.

Soil acidity is caused by a build-up of hydrogen cations. The early stages of acidification do not show up as pH change because hydrogen cations attach to CEC sites. This is how the CEC buffers pH.

Nutrient supply from the CEC declines as hydrogen cations occupy sites that could be holding useful nutrients. Nutrient supply is the more important and valuable long-term function of the CEC. Liming neutralises hydrogen cations, freeing up spaces in the CEC for nutrients.

Many high-producing orchards on naturally acidic soils apply low rates of liming materials (Figure 10) annually to offset acidification processes. Liming at higher rates can create nutrient imbalances and has a more significant effect on cash flow. Lime moves slowly through the soil profile. Liming each year or two has the extra advantage of helping create a steadier delivery of lime through the soil profile. Similarly, when acidifying materials are needed, applying smaller amounts in increments can be better than big doses.

Figure 10. Regularly applying small amounts of lime can offset acidifying processes. Photo: Anne Stead.

What if I have been told I need to apply a lot of lime?
Build up to the total over time and keep monitoring pH. The '*Macadamia grower's guide: nutrition and soil health – Part 2: the next level*' has information on safe incremental liming rates.

Some soils are naturally alkaline. High soil pH is corrected by applying acidifying materials such as ammonia fertilisers or elemental sulfur. These react within the soil to create acid, which reacts with and neutralises the alkalinity. Careful applications can create a small build-up of acidity to reduce the pH into the desirable range. Discuss the proposed method with an experienced soil consultant first, because localised acidity can occur, affecting plant growth.

Building up organic matter

Adequate organic matter levels are critical for sustained production. Organic matter is food for soil life and a source of plant nutrients. These nutrients become available as the organic matter is decomposed by microorganisms. As this breakdown occurs slowly, organic matter provides a slow-release form of nutrients.

Building up soil organic matter adds resources to the orchard's biological system. Orchards with low organic matter are more vulnerable to setbacks and declining yields from drought, disease (e.g. phytophthora) and other stresses.

Orchards gain organic matter in 3 main ways:

1. **applied as organic inputs** such as composts, manures or mulches sourced from offsite
2. **released into the soil by living plants** as root exudates; plants release sugars into the soil to feed microorganisms that boost nutrient availability in their root zones
3. **cycled biomass** within the orchard through pruning, chipping and mowing, as well as the turnover of root material in the soil.

Rundown orchards are most in need of high volumes of organic matter inputs from offsite. As fertility and biomass cycling increase, the orchard might need fewer organic matter inputs purchased from offsite.

Adding organic matter to the soil surface protects feeder roots and gives them more space to grow. Over time, organic matter inputs:

- **enhance rainfall infiltration**
- **increase water holding capacity** as each 1% rise of soil organic matter can supply around 100,000 L of extra plant-available water per hectare
- **build up the soil's CEC**, potentially increasing nutrient availability and buffering rapid pH changes
- **reduce toxicities** by taking up excess nutrients and other toxins (e.g. aluminium and pesticide residues)
- **create stable soil aggregates** that improve soil structure and reduce erosion.

Implementing effective drainage

Poor drainage causes both soil erosion and waterlogged soils, limiting orchard productivity.

Soil erosion results in a loss of resources from the orchard. Topsoil (0–100 mm) is the most valuable soil. It forms very slowly and is the first to be lost with erosion. Orchards can also lose fertiliser, mulches and harvestable nuts due to soil erosion. It is impossible to build up orchard resources and soil health with active soil erosion.

Signs of active soil erosion include:

- exposed roots (Figure 11)
- scoured channels
- dead tops
- nuts in drains (Figure 12)
- muddy run-off during rain.

Figure 11. Exposed roots are a sign of active soil erosion caused by water flow channelling down the tree row.

Figure 12. Nuts in drains and muddy run-off water are signs of active soil erosion.

It is impossible to build up orchard resources and soil health with active soil erosion.

Soil erosion is controlled by:

- effective, well-designed drainage systems that safely convey water through the orchard
- ground cover from living plants and mulches that meet slope-specific management guidelines.

Poorly drained soils impair root growth and tree performance. Roots need access to air to gain oxygen and remove carbon dioxide. Waterlogged soils, or soils with impaired sub-surface drainage, cannot supply enough air to roots.

Signs of poorly drained soils are:

- water sitting on the surface for long periods after rain or irrigation
- unpleasant odours from anaerobic bacteria
- stunted growth and lower yields compared to similar age and variety trees.

Refer to the '*Macadamia integrated orchard management drainage*' (2022) for more information on managing soil erosion and poorly drained soils in macadamias.

Monitoring soil and trees

Monitoring means collecting the same information multiple times, preferably over several years, with the trends forming the basis for making management decisions. A one-off soil test is often not a solid basis for making decisions.

Monitoring soil and plant tissues provides information about:

- whether the trees are getting enough nutrients
- any constraints or blockages that are restricting nutrient uptake
- the nutrient reserves in the orchard
- where to strategically build up the fertility and resilience of the orchard.

Strategic decision-making depends on understanding the current situation and possible future scenarios. Awareness of what is changing, both positively and negatively, helps evaluate current management practices. Regularly gathering information from the orchard will support sound decisions to improve the orchard.

Use the results from soil and plant tissue samples, along with the general recommendations for fertilisers for young and bearing trees, to inform specific decisions.

Soil health monitoring

The soil health framework focuses on soil functions that support trees by equally considering the chemical, biological and physical aspects of soil. Soil health monitoring reveals limitations that affect water and nutrient supply to the trees. These limitations need to be corrected for trees to make the best use of nutrient inputs.

The '*Macadamia soil health card*' is a tool developed by Australian macadamia growers. The card lists 10 tests involving observations and simple equipment. Annual monitoring gives insight into how soil health changes and supports early detection of developing soil problems.

Many growers work with consultants when collecting and interpreting information from soil and leaf analyses.

Soil tests

Soil analysis reveals nutrient deficiencies, sufficiencies and toxicities at the time of testing and the soil's nutrient reserves (present but currently unavailable). Usual soil analyses measure pH, nutrients (available and total), cation exchange capacity and organic matter levels. Soil analyses provide more accurate information on trends when the samples are collected from the same locations (Figure 13), at the same time of year, and are processed by the same laboratory.

Leaf tissue tests

Leaf tissue analysis provides information about the nutrient status within a tree. Leaf tissue results complement soil testing, help distinguish between nutrient uptake problems and deficiencies in the soil, and diagnose toxicities.

Replacing nutrients

General nutrition for young orchards

General fertiliser recommendations assume that any issues identified in pre-plant soil investigations have already been corrected. Soil improvements before tree planting will be included in '*Macadamia grower's guide: new orchards*'.

If fertiliser was applied at planting, do not apply more for the first few months after planting. Wait until the trees push a new leaf flush and the new growth has darkened towards mature leaf colour before applying nutrients. Newly planted trees have a small root system and low nutrient requirements. Apply small amounts of nutrients often during the growing season (from spring to autumn). Never apply large single doses of nutrients as this could reduce tree vigour and, in severe cases, kill the tree.

Apply granular or compound fertilisers every couple of months. The macronutrients nitrogen (N), phosphorus (P) and potassium (K) are the most important to apply. Although growing trees take up much larger amounts of macronutrients than micronutrients, including modest rates of micronutrients in the fertiliser mix can be beneficial. The young tree's micronutrient supply will mostly come from soil reserves or the pre-planting soil preparation, but small regular inputs can support future soil supply. Many growers apply pelleted poultry manure, blood and bone or similar organic fertilisers in addition to inorganic fertilisers.

Apply approximately 50 g of a mixed fertiliser with an N:P:K ratio of 15:4:11 (plus micronutrients) per application per tree during the first 2 years and about 70 g per application per tree during years 3 and 4. Compound fertilisers can be more effective than blends at applying uniform nutrient levels to each tree. Keep the fertiliser at least 100 mm from the trunk to limit damage to the bark and vascular tissues.

Hand spreading fertiliser is a good opportunity to assess tree health.

If irrigation is available, some nutrients can be applied via fertigation, usually monthly or more frequently if the CEC is low. Information on fertigation will be in the '*Macadamia grower's guide: irrigation*'.

Figure 13. The yellow mark on the tree trunk indicates this is a ‘sentinel’ tree, which is the focus of monitoring year-to-year. Regular soil testing from the same locations helps keep track of changes.

General nutrition for bearing orchards

Nutrition becomes more complex once trees produce nuts because harvesting removes nutrients. A nutrient balance 'game plan' for building soil fertility matches fertiliser rates to the nutrients that go out with every tonne of nut-in-shell (NIS) harvested from the orchard. Other inputs and losses in the nutrient balance include biomass changes, organic matter inputs and losses to the environment (Figure 14).

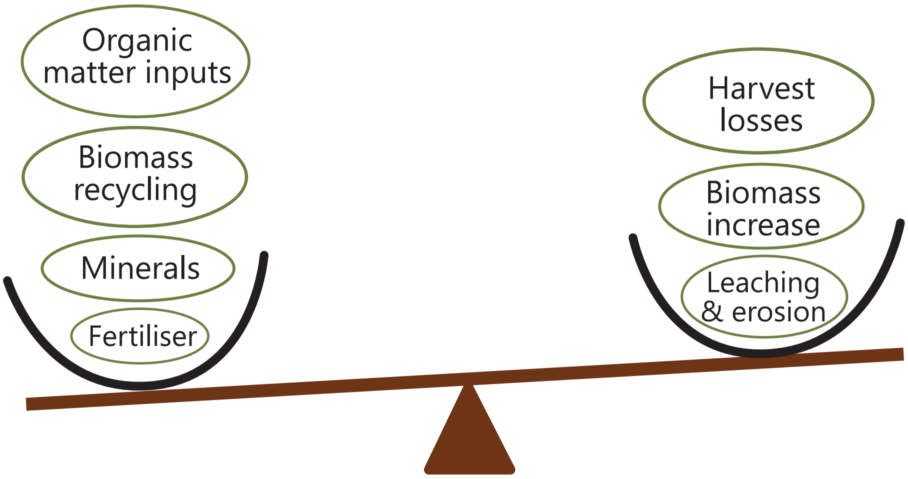


Figure 14. The nutrient balance of the orchard moves in response to the accumulated inputs and losses.

The orchard biomass is a sink of nutrients. Continuing tree growth draws on and immobilises soil nutrients. Active pruning to control tree size and recycling nutrients is an often forgotten but important part of managing the nutrient balance.

Sometimes extra nutrients are added to accommodate desirable tree growth and modest nutrient losses (such as leaching, erosion and soil fixation). A crop replacement approach will not meet demands when IOM red flags (e.g. exposed roots, tree height greater than row width and poor drainage) are present.

The rates in Table 2 and Table 3 are revised from the '*Growing guide: macadamia grower's guide*' (2004), based on more recent research (conducted in 2021 and 2022 as part of the NSW DPI Clean Coastal Catchments research project, and funded by the NSW Government's Marine Estate Management Strategy) that measured the nutrient contents of kernel, shell and husk separately and are appropriate in most situations for mature trees. The crop replacement figures can seem low, and some growers might be inclined to apply more nutrients. While this might help sustain yields, it results in nutrient losses and adverse environmental effects.

If dehusking occurs in-field or the husk is returned to the field, use Table 2. If dehusking occurs in a processing facility on or off the farm and is not returned to the field, use Table 3.

Table 2. General recommendations for nutrient replacement rates **where the husk is left in the orchard**.

	Nitrogen	Phosphorus	Potassium	Sulfur	Calcium	Magnesium	Boron	Copper	Zinc
	Kilograms per tonne (NIS @ 10% moisture content)						Grams per tonne (NIS @ 10% moisture content)		
1 t/ha actual*	7.3	0.6	1.6	0.7	0.4	0.5	5.7	6.7	7.3
1 t/ha adjusted**	9.5	0.6	1.9	0.7	0.4	0.6	5.7	6.7	7.3
2 t/ha adjusted	19.0	1.2	3.8	1.4	0.9	1.3	11.4	13.3	14.6
4 t/ha adjusted	38.0	2.4	7.7	2.9	1.8	2.6	22.9	26.6	29.1
6 t/ha adjusted	57.0	3.6	11.5	4.3	2.7	3.9	34.3	40.0	43.7

Table 3. General recommendations for nutrient replacement rates **where the husk is removed from the orchard**.

	Nitrogen	Phosphorus	Potassium	Sulfur	Calcium	Magnesium	Boron	Copper	Zinc
	Kilograms per tonne (NIS @ 10% moisture content)						Grams per tonne (NIS @ 10% moisture content)		
1 t/ha actual*	11.1	1.2	8.6	1.4	0.7	0.8	11.0	9.3	10.4
1 t/ha adjusted**	14.4	1.2	10.3	1.4	0.8	1.0	11.0	9.3	10.4
2 t/ha adjusted	28.8	2.4	20.6	2.7	1.5	2.0	22.1	18.6	20.7
4 t/ha adjusted	57.7	4.7	41.2	5.5	3.0	4.0	44.1	37.2	41.5
6 t/ha adjusted	86.5	7.1	61.8	8.2	4.6	6.0	66.2	55.7	62.2

*The average nutrient replacement requirements of 8 macadamia varieties. Research conducted in 2021 and 2022 as part of the NSW DPI Clean Coastal Catchments research project, and funded by the NSW Government's Marine Estate Management Strategy.

**The adjusted values add to the actual removal rates for nutrients vulnerable to leaching, boosting nitrogen by 30%, potassium by 20%, calcium by 10% and magnesium by 25%.

Nutrients can be either banded or broadcast. The critical requirement is to apply nutrients where the feeder roots are actively growing. Broadcast fertiliser to support trees and ground cover. Band fertiliser to prioritise trees. Organic matter is usually banded along tree rows because it is both a nutrient source and a soil amendment that improves conditions for feeder roots.

Alternatively, apply nutrients via fertigation through the irrigation system (further information on this will be in the '*Macadamia grower's guide: irrigation*').

Moving beyond general nutrition recommendations

Specific nutrient programs for macadamia orchards or blocks are based on information from monitoring soils and trees. They have short- and long-term strategies to improve tree performance.

The purpose of developing a specific nutrient program is to:

- meet peak demand for specific nutrients
- accommodate cultivar differences
- respond to changing conditions
- improve fertiliser efficiency
- correct or prevent nutrient imbalance
- support an increase in biomass
- improve environmental performance
- achieve a better economic return on investment.

Want to know more about moving beyond the general recommendations? The Macadamia grower's guide: nutrition and soil health – Part 2: the next level offers information on many of the issues.

In all agricultural industries, specific nutrient programs work towards implementing the 4R framework: right source, right rate, right place and the right time (Roberts 2007; Figure 15).

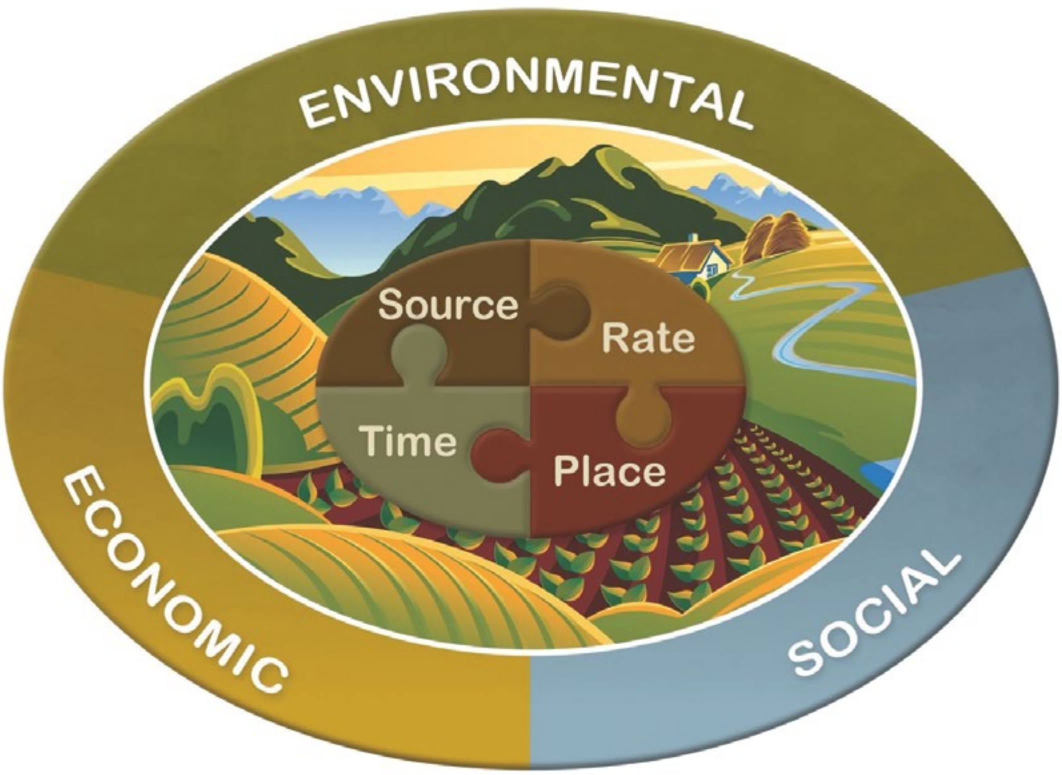


Figure 15. The 4Rs stand for right source, right rate, right place and the right time (Roberts 2007). These principles guide management practices to help keep nutrients on the farm. Implementing the 4Rs helps to align the economic, environmental and social components of nutrient management.

Ultimately, a specific nutrient program defines:

- **what to apply** – what product or products are the best source of the required nutrients that fit with other goals of soil management and budget
- **how much to apply** – the rate per hectare to supply the right amount of the required nutrients
- **where to apply** – to the inter-row, tree row, foliage or a combination of these
- **when to apply** – the time/s best matching crop stage, seasonal conditions, other orchard operations and under what circumstances to delay applications.

Nutrition and soil health management are complex and depend on soil characteristics. The information in Nutrition and soil health – Part 1: the foundations introduces key principles for nutrition and soil health. We encourage growers to seek independent advice to enhance nutrition and soil health decisions.

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NSW Department of Primary Industries
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NSW GOVERNMENT

Macadamia grower's guide: nutrition and soil health – the foundations

Monitoring soil and trees

Controlling pH

Building organic matter

Implementing effective drainage

Replacing nutrients

Hort Innovation
Strategic levy investment

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