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Macadamia grower's guide 2024

BEARING TREES

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Macadamia grower's guide: bearing trees

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About this guide

Managing bearing trees aims to maintain high yields for many years. This bearing trees module supports decisions about managing orchards planted 4 or more years ago and corresponds with stage 2 in the macadamia integrated orchard management (IOM) framework. *Bearing trees* (IOM stage 2) follows on from *Young trees* (IOM stage 1).

NSW DPIRD maintains up-to-date resources for macadamia growers on the Nuts webpage (https://www.dpi.nsw.gov.au/agriculture/horticulture/nuts).

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

- The *Macadamia grower's guide: new orchards* is about site selection, orchard design and planting.
- The *Macadamia grower's guide: young trees* describes the management of young trees, including pruning.
- The *Macadamia grower's guide: bearing trees* focuses on keeping bearing trees in peak production.
- The *Macadamia grower's guide: nutrition and soil health the foundations* and *the next level* cover soil, nutrient additions and managing the orchard floor to support productive orchards.
- The *Macadamia grower's guide: cultivars* describes the macadamia cultivars available for planting and their use in Australian growing regions.
- The *Macadamia integrated orchard management guides* bring together the management of the canopy, orchard floor, and drainage to promote and sustain high productivity.
- The Macadamia plant protection guide provides regular updates on managing pests and diseases.

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Contents

Overview

Bearing trees in integrated orchard management

Bearing tree management starts once the trees are producing commercial harvests and are approaching optimal production. Growers can sustain high-producing mature orchards by:

- pruning to maintain optimal canopy dimensions, light conditions and promoting bearing (fruiting) wood throughout the canopy
- protecting trees from stress that reduces yields and quality
- promoting favourable soil conditions for healthy root systems.

Since 2016, the Australian macadamia industry has used the integrated orchard management (IOM) framework to manage orchards. The IOM framework (Figure 1) describes the optimal stages of development (brown line) and potential decline (green line) of macadamia orchards. Bearing trees are in peak production in IOM stage 2 and might become less productive in IOM stages 3 and 4.

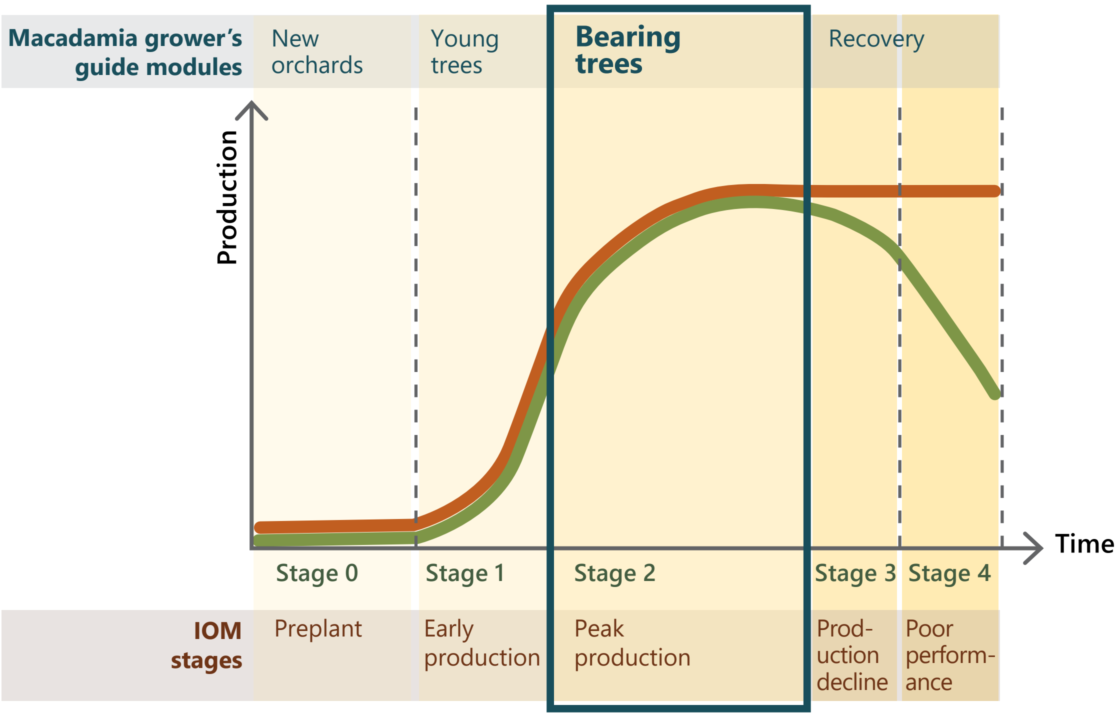

Figure 1. Bearing trees are in integrated orchard management (IOM) stage 2.

At the start of IOM stage 2:

- trees are producing commercially harvestable yields (worth picking up)
- tree canopies join within the row and light conditions are optimal for productivity
- stable orchard floors can easily meet the guidelines for slope-specific ground cover.

The orchard system is performing close to design specifications. The priority is sustaining a highly productive canopy with a stable orchard floor and soil conditions that support the trees. The best outcome is to keep the orchard in IOM stage 2 for as long as possible.

Successful IOM stage 2 orchards have:

- healthy trees and high yields
- pruning practices that maintain a productive canopy with optimal dimensions for the orchard design
- stable *foundations* of nutrition and soil health where:
  - soil pH is in the target range ($5.5–6.5_{Ca}$)
  - there is an active program to maintain or build up organic matter
  - the drainage system minimises soil erosion and poorly drained areas
  - results from monitoring soil and trees are used to help inform how the soil is managed alongside the general nutrition recommendations for bearing trees.
- *Next level* soil management that customises support for trees where needed
- where used, irrigation patterns (e.g. when to water and how much to apply) reduce competition between fruiting and leafy growth.

The signs that an orchard could soon deteriorate into IOM stage 3, before yield decline, include:

- canopy dimensions are larger than is optimal for the orchard design, with trees getting taller and branches reaching further across the inter-rows (Figure 2)
- the light environment is changing and:
  - most nuts are developing in the top third of the canopy
  - there are few leaves or fine branches in the lower canopy
  - living ground cover is disappearing.

The *Macadamia integrated orchard management practice guide 2016* lists other red flags, which are visual signs of orchard decline.

Figure 2. Trees with larger than ideal canopy dimensions are taller than the row width, and branches reach into the inter-row.

Growth in bearing trees

Macadamia trees have a cyclic growth pattern that responds to environmental cues such as rainfall and temperature. The general pattern is earlier and accelerated in the tropical north and later and elongated in more temperate southern areas. Some orchard practices give the best results when undertaken at specific growth stages (Figure 3). For example, hedging is better if delayed until at least 10 weeks after peak flowering to avoid a new flush that is triggered by the hedging from competing with nut set.

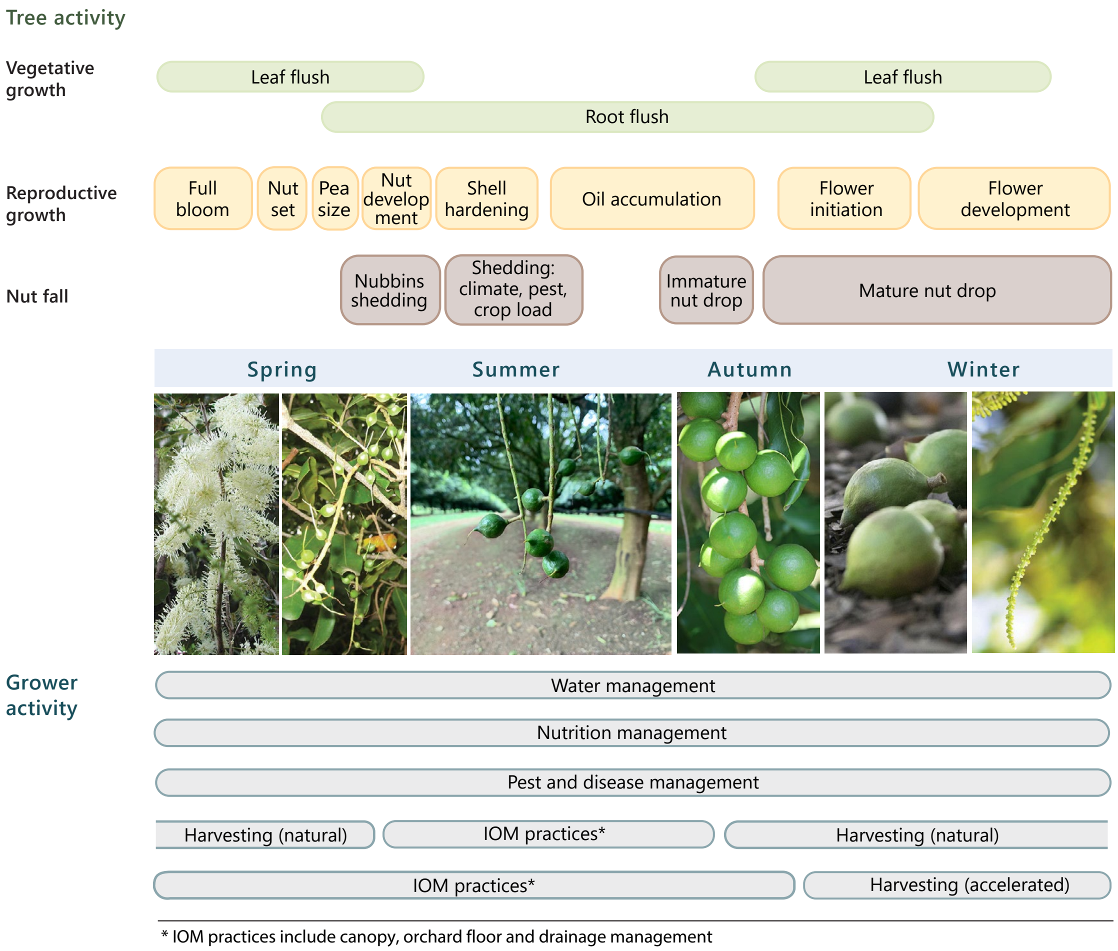

Figure 3. Orchard practices for all stages of growth throughout the year.

Macadamia produces new shoots and leaves in vegetative flushes. The new growth is light green and gradually 'hardens off' to the dark green of typical macadamia leaves (Figure 4). The leaves grow in groups (whorls) of 3 or 4 from a single point (node) on the shoot. Three buds develop at the base (axil) of each leaf (Figure 5). Multiple new shoots or flower racemes can emerge at each leaf whorl.

When unmanaged, the close buds can produce dense growth that shades the inner canopy and creates an undesirably complex branch architecture. Appropriate pruning reduces these problems.

Macadamia trees produce an abundance of flowers. Shedding or crop load adjustment occurs in 3 stages:

1. Fall of unfertilised flowers (typically, less than 5% of flowers set nuts).
2. Rapid fall of small immature nuts between 3 and 8 weeks after nut set (when the nut is about the size of a pea).
3. Fall of larger immature nuts from 10 weeks after nut set. High temperatures, moisture stress, pest damage (e.g. macadamia seed weevil), diseases (e.g. husk spot) and competition for resources from new shoots exacerbate nut drop at this stage.

Inside the nut, there are 2 ovules or immature seeds. Usually, only one develops to produce a kernel as a typical, round macadamia nut. It takes 5–6 months for macadamia to go from flowering to mature nuts on trees.

Figure 4. Buds at the base of a leaf.

Figure 5. Light green leaves are new flush, and the dark green leaves are mature flush.

Energy and yield

Growth and production in macadamia trees depend on their interception of radiant energy from the sun. Leaves convert solar energy into carbohydrates that fuel growth and reproduction. Having more leaves exposed to direct sunlight gives more productivity. Leaves provide energy that can be used immediately or stored. Orchards with trees that have leaves facing light-filled inter-rows have more photosynthetic capacity than those with sunlight only reaching the top of the canopy.

Macadamia leaves that are heavily shaded do not photosynthesise at the same level as leaves in full sun. When shade-adapted leaves are exposed to full sun, they are unable to increase their level of photosynthesis to the same rate as leaves that have always been exposed to full sunlight. This makes pruning to ensure adequate sunlight is distributed through a macadamia canopy critical for long-term productivity. As trees grow, the challenge is maintaining the canopy so the inter-row sides receive full sunlight for efficient productivity (Figure 6).

Figure 6. Sunlight to the sides as well as the top optimises the energy for the tree.

Carbohydrates not used for maintenance, growth or reproduction accumulate in the tree as energy reserves. This is measured as total non-structural carbohydrates (TNSC). Trees tend to accumulate TNSC in autumn and winter and might deplete those stores during nut development in spring (Figure 7), especially if the production of new carbohydrates through photosynthesis is low. A tree without adequate carbohydrates available has less capacity to develop nuts. Beyond yields, TNSC supports tree survival through severe stress, such as drought.

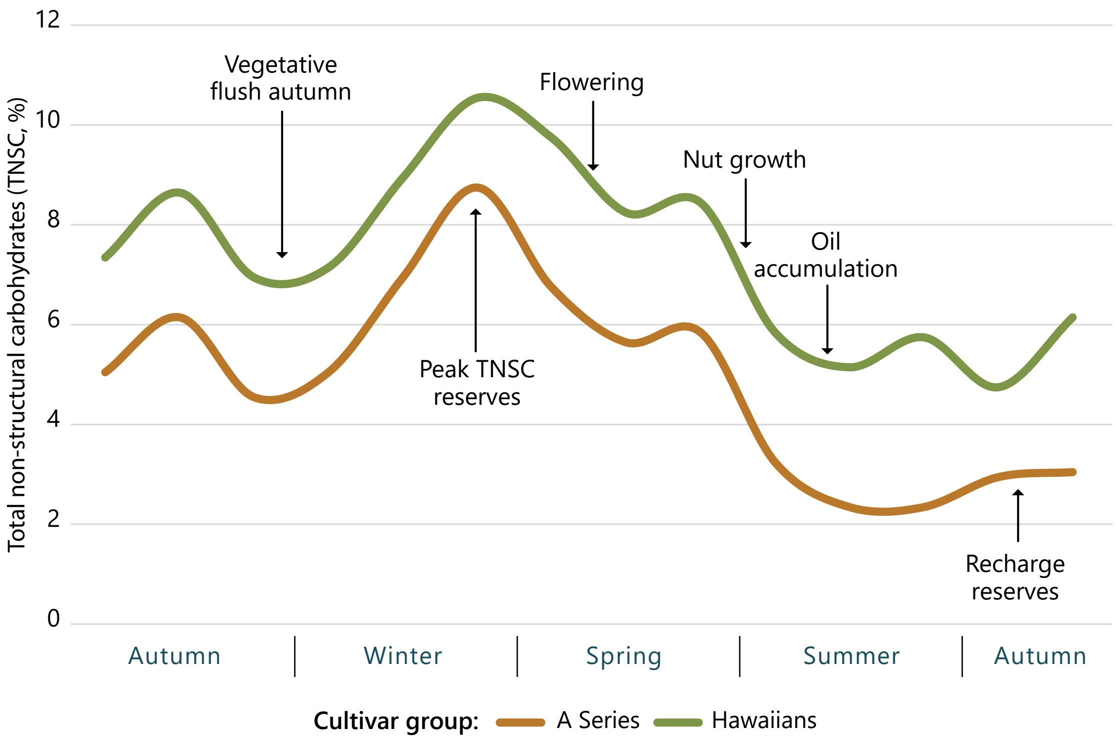

Figure 7. The tree's accumulated energy reserves are measured as total non-structural carbohydrates (TNSC).

Potential yield is the yield possible in the absence of other limiting factors such as pest damage or moisture stress. Potential yield depends on the tree's stored energy level and the more immediate energy from current photosynthesis in leaves near the developing nuts. The TNSC support flower production, pollination and nut retention.

Some of the shedding (premature nut drop) is the tree's way of reducing its nut load when it has insufficient energy to support all the set nuts or any competing new flush. Growers can minimise shedding by providing good growing conditions to support overall health and allow the tree to photosynthesise optimally, e.g. access to sunlight, increasing soil organic matter, ensuring all roots are fully covered, providing good drainage and enough nutrition to optimise potential yield.

Individual macadamia leaves can live for many years but are most productive soon after they reach full size and harden. The tree needs to replenish the supply of young leaves to remain healthy, vigorous and productive.

Flushing/vegetative growth

The timing of flushing is influenced most by temperature and soil moisture (rainfall or irrigation). Flushing appears to be inhibited by low temperatures in winter and high temperatures in summer (Figure 8).

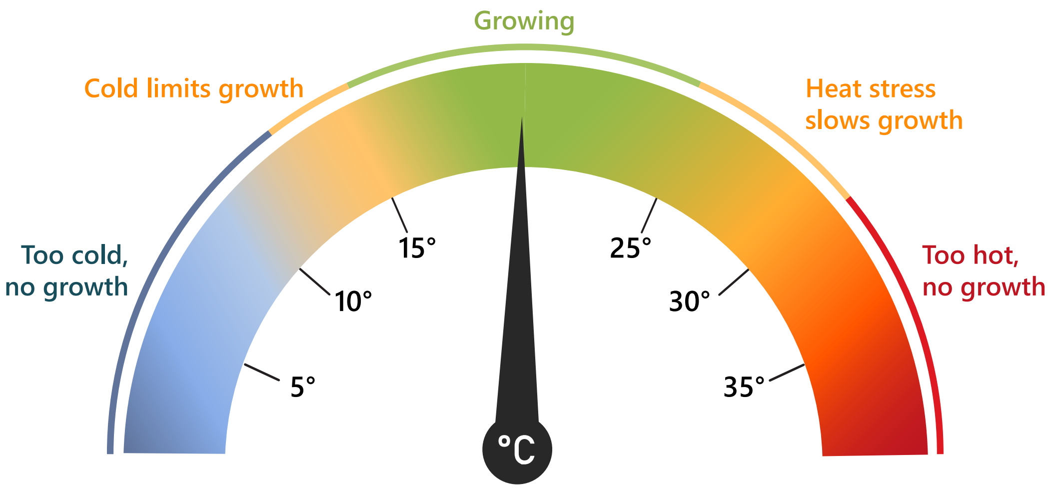

Figure 8. How temperature affects growth rates in macadamia. Source: Trochoulias and Lahav (1983).

A peak flush in late summer/early autumn is associated with high yields in the following year. Water management can manipulate the timing of flushing. Mild water stress suppresses flushing. Supplying adequate water after mild water stress can initiate a new flush. Growers can try to reduce the risk of new flush competing with nut set and nut development by allowing mild water stress during flowering. To avoid production loses, moisture stress must not be significant.

Typically, a flush of root growth follows on from a leaf flush. Root tips produce growth regulators, which help maintain the balance between shoot and root growth. As a dense mat of surface feeder roots is desirable for healthy trees, the root flush is as important as the leaf flush, even though it is less visible.

Growers can support healthy roots by implementing optimal soil conditions. Refer to the *Macadamia grower's guide: nutrition and soil health: the foundations* and *the next level*.

Flowering

Flower buds initiate in autumn and develop into racemes in late winter and/or early spring. The exact timing of flowering depends on cultivar, location and climatic conditions. Some cultivars, such as A4, A16 and 741, have a short flowering period, while others, such as 246 and 842, have a prolonged one. Flowering is earlier in north Queensland (Qld) and later in northern New South Wales (NSW). For further information on flowering times, refer to the *Macadamia grower's guide: cultivars*.

Nut development

Industry recognises nut set at a stage called 'match head'. This description refers to the developing fruit being similar in size to a match head (Figure 9). Nuts slowly expand until reaching maximum fresh weight at about 18 weeks after nut set (Figure 10). At this point, the shell has fully formed and hardened, and the kernel is in the oil accumulation phase. This phase takes a lot of energy, and the stored carbohydrates are an important energy source if conditions do not support continuous high rates of photosynthesis (Figure 7).

Kernels are usually mature 21 weeks after nut set in southeast Qld and 24 weeks after nut set in northern NSW. Maturity is hastened in warm climates and delayed in more temperate climates. The kernel is mature when it has more than 72% oil content.

Figure 9. 'Match head' size nut, early in nut development.

Figure 10. Nuts are full size and at the start of oil accumulation phase.

The start and end of nut drop timing varies between cultivars, with the earliest starting in mid-February, while most start in late March. Some cultivars do not drop their nuts until late in the season, even when they have matured much earlier. These cultivars have a greater risk of pest build-up and disease carryover. Extended harvest delays the start and shortens the window for other orchard practices, such as pruning, enhancing soil health and repairing drainage networks. Using hormonal sprays (such as ethephon) and tree shakers might assist with completing harvest earlier than the natural nut drop pattern. Completing harvest earlier allows more time for the photosynthesising leaves to replenish the stored energy reserves (TNSC) that were depleted through nut development.

The dosage and timing of hormonal sprays are critical in achieving a beneficial result without over-stressing the tree. The dosages vary for specific cultivars and growers are advised to obtain information on the rate and timing for their situation.

Observe the following precautions for hormone treatments:

- Do not apply to weak or stressed plants.
- Do not apply if it might rain within 8 hours of application.
- Do not apply if mean day/night temperatures might fall below 18 °C.
- Do not mix with alkaline water (pH >7).

Pruning

To successfully prune bearing trees:

- **Plan to prune** each tree, in some form, at least every 3 years.
- **Perform pruning in blocks** rather than single trees or rows to prevent the surrounding trees from shading the pruned tree and forcing the pruned tree to grow upwards.
- **Prioritise controlling canopy dimensions** and **managing light infiltration into the canopy**.

There will be less light, ground cover, and more bare branches low in the tree long before you notice a decline in yield.

Cutting too much material can reduce productivity because the tree will respond by putting resources into regrowth instead of producing nuts. Aim to remove no more than 20% of the leafy canopy in a pruning session. Cutting too little material might mean the season's pruning activity will not enhance light infiltration or reduce canopy, as it will all grow back within a year.

The *Macadamia integrated orchard management guide 2016* details the broad options for canopy management practices and where these fit into the IOM stages. Table 1 lists the practices suitable for bearing trees (in IOM stage 2). Select practices according to the improvements you want to see in the canopy.

Cut to direct future growth

Cut placement directs future growth. There are 2 main types of cuts: limb removal and limb rejuvenation. Limb removal cuts away an entire limb or shoot, **directing growth to other limbs**. Cutting part of a limb or shoot is called limb rejuvenation because this **directs growth to lower buds** on that limb (Figure 11). Excavators with a 'cut and grab' attachment (Figure 12) are becoming more common for pruning operations previously performed with pole saws.

Figure 11. Limb removal cuts away entire shoots (left), while rejuvenation (right) cuts part of the limb or branch.

Table 1. Integrated orchard management (IOM) canopy management practices for bearing trees (IOM stage 2).

Practice	Description	Improves					
		Light to canopy interior	Alley width	Tree height	Fruiting wood: Cultivars with a bearing wood age of 2 years.	Fruiting wood: Cultivars with a bearing wood age of 3–4 years.	Access
Limb removal	Removing whole limbs to encourage growth in other limbs.	yes	no	yes	yes	yes	no
Limb rejuvenation	Cutting back parts of limbs to encourage growth from the remaining sections.	yes	no	yes	yes	yes	no
Light hedging	Tipping up to 600 mm off the sides of tree canopies, usually with machinery.	no	yes	no	yes	no	yes
Hedging and limb removal	Limb removal one year, followed by light hedging the next.	yes	yes	yes	yes	yes	yes
Hedging and limb rejuvenation	Cutting back dominant limbs followed by heavy hedging.	yes	yes	yes	no	yes	yes
Manual skirting	Removing low branches, usually with a chainsaw.	no	no	no	no	no	yes
Mechanical skirting	Removing low branches with mechanical hedger.	no	no	no	no	no	yes

Figure 12. An excavator with a cut-and-grab attachment for pruning.

Limb removal

The limb or shoot is cut off at the collar of the branch (Figure 11). Limb removal cuts are sometimes called thinning. These cuts do not (usually) stimulate new growth near the cut.

Use limb removal to:

- increase the light within the canopy
- remove competing or conflicting limbs
- remove limbs with narrow branching angles (which are likely to break later, Figure 13)
- control a section of the tree where regrowth is undesirable (e.g. skirting low branches).

Limb removal does not increase local shoot growth as much as limb rejuvenation. Instead, the development of other limbs is encouraged. Sometimes, removing lower limbs allows other limbs to 'relax' into the newly available space. 'Rogue' limbs pushing into neighbouring trees are good candidates for limb removal (Figure 14).

Figure 13. Allowing a limb with a narrow branch angle to grow has created a problem where the weak junction has cracked. The limb will potentially split in high wind.

Figure 14. 'Rogue' limbs pushing into the canopies of neighbouring trees are best removed.

Limb rejuvenation

Limb rejuvenation is removing part of a shoot or limb (Figure 15) while leaving a portion of the limb for regrowth (Figure 16) and is sometimes called heading. Growth increases on the limb from the buds below the cut.

Limb rejuvenation cuts:

- shorten and strengthen branches
- induce further branching from buds directly below the cut
- direct growth into branches favourable to the desired tree shape
- reduce competition to a central leader, or create a new leader
- stage development of new fruiting wood
- maintain tree height:row width ratio at <1:1
- can stimulate regrowth in a canopy that has become dark and unproductive at the centre of the tree.

The amount and length of new growth are affected by the severity of the cut, wood age, growth stage, and orientation.

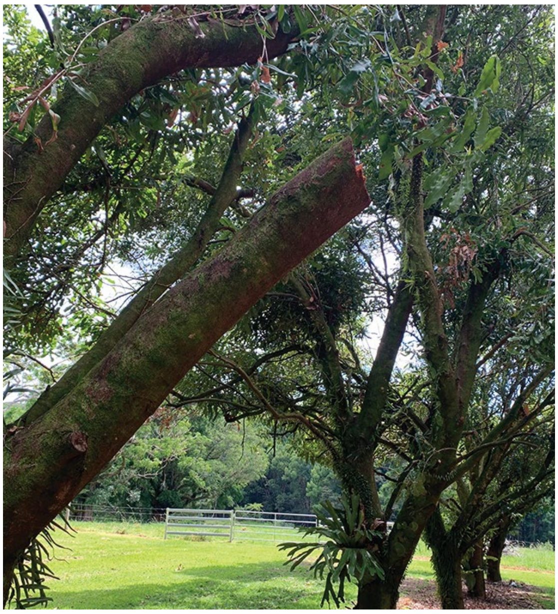

Figure 15. A limb rejuvenation cut to gradually reduce tree height and improve light conditions.

Figure 16. An example of limb rejuvenation cut after 1 year in a mature tree with strong regrowth.

Severity of the cut

The severity of the cut describes how much of the shoot the cut removes.

A more severe cut (Figure 17) will have:

- longer recovery
- more regrowth.

While a less severe cut will have:

- quicker recovery
- less regrowth.

The strongest regrowth usually occurs when a cut removes between half and three-quarters of the branch, retaining some well-developed buds. More severe cuts that remove more than three-quarters of the branch lead to slower regrowth. Less severe cuts that remove less than half of the branch stimulate many buds, with the response at each bud less vigorous.

Figure 17. A more severe cut removes most of a branch.

Keep in mind where you want the new fruiting wood in the canopy, as there needs to be regrowth to provide the fruiting wood sites. Often this means a cut needs to be made 1 m below where you would like to see new fruiting sites (Figure 18).

Wood age

The most stimulation occurs with cuts to 1-year-old wood. Usually, vigorous shoots develop from the 3–4 buds immediately below the cut. The growth response might be less vigorous after cuts into older wood. In bearing trees, guiding the new growth for future productivity is most important.

Figure 18. In this extreme case of orchard recovery, trees were brought back down to 4 m to grow a 6–8 m tall tree.

Growth stage

In macadamia, the growth stage can be limb-specific and not uniform throughout the tree. Pruning after a flush has started stimulates regrowth quickly. Pruning during semi-dormancy might produce little or no immediate new shoots but might create more growth overall because the post-pruning regrowth occurs throughout the next flush.

Shoot orientation

Orientation is the angle from the horizontal of the limb. Limb rejuvenation cuts are more useful on flatter-angled shoots. Upright limbs are best left uncut or removed because limb rejuvenation cuts tend to produce vigorous regrowth at very narrow angles. This growth can create undesirable shade in the canopy and have low fruiting potential.

Some new shoots that develop below a previous cut might be water shoots growing at narrow or near vertical angles and crowded together. Remove these undesirable shoots with limb removal cuts (Figure 19).

Figure 19. Remove undesirable new shoots (water shoots) if they develop after limb removal cuts.

Remove weak trees

An important way to increase the average performance of orchard trees is to remove and replace weak trees or blocks. These never achieve the desirable production, or might be a block that is on a particularly steep slope, or a block in an area that does not have adequate soil. Weak blocks often cost more than the value of the crop they produce. These blocks bring the farm's average productivity down and are best removed so that more energy can be spent on developing sound blocks to be even better.

Protecting trees

Wind

Wind damage in bearing trees appears as broken branches after gusty wind (Figure 20 and Figure 21). Strategic pruning to reduce the risk of wind damage encourages steady production and minimises the damage from strong wind. Prune to remove the branches most likely to snap. The vulnerable branches grow at tight, vertical angles (Figure 13) or are large, isolated from the main canopy and move excessively in the wind.

Trees with canopies linked in the row support each other, creating a strong, hedge-like structure. Substantial changes, such as removing every second tree, can leave the remaining trees isolated and more susceptible to wind damage. Support robust recovery by also pruning the remaining trees to remove newly vulnerable branches.

Figure 20. Storm damage to a branch with a narrow crotch angle.

Figure 21. Vulnerable exposed limbs at the tops of trees knocked over by strong wind.

Pests

The NSW DPIRD *Macadamia plant protection guide* explains the range of pests that can affect macadamia and the treatments available for growers. While managing young trees, many growers monitor pests and diseases themselves.

Once trees become productive, the variety and complexity of potential pests and diseases multiplies. Most growers with bearing trees employ a pest consultant. Benchmarking in 2023 recorded the average costs for a pest scout at around $105/ha, which is around 1% of the cost of production.

Some benefits of employing a pest consultant include:

- timely treatment recommendations
- an understanding of the area around your farm and the potential of pest incursions through an area-wide management (AWM) approach
- follow-up monitoring of treatment efficacy
- saves time and money on unnecessary treatments
- considers other farm features that might be helpful for management, i.e. beneficial pest populations and pest-harbouring trees within the orchard
- identifies hotspots so treatments can be focused on these areas.

Monitoring

Pest scouts monitor the orchard for seasonal pests. A good pest/integrated pest and disease management (IPDM) consultant will have comprehensive knowledge of crop phenology, pest and beneficial identification, pest life cycles and habits, sampling methods and economic threshold levels for each pest.

Some pests cause damage at specific stages of development e.g. lace bug at flowering, while others can cause damage at any stage e.g. fruit spotting bug. Other pests will attack more mature nuts e.g. macadamia nut borer, cockatoos, and rats. The frequency of visits by the pest scout will vary. The monitoring effort could be more intense (e.g. fortnightly) from August to March and less intense (e.g. monthly) for the remainder of the year.

Pest and disease scouting involves gaining a representative sample of the block. Pest scouts might monitor by following a V or W pattern, modified according to the block size and expected number of trees to visit. Variations in cultivar, tree age, phenological stage, aspect, and neighbouring vegetation are all considered. Pest scouts will check for pests according to crop stage and life cycle. Once hotspots (where pests first appear or have more intense activity) emerge, they will survey these areas first and continue monitoring the remainder of the block. Usually, a scouting record sheet is completed for each block to gain similar information that documents change over time (Table 2). In some cases, a whole farm might be a single block, but for assessment accuracy, a 'block' should be no more than 5,000 trees. A block sample size will generally consist of a minimum of 300 nuts.

There are also drop sheet tests where a chemical spray is applied to drop the whole insect population from the tree. It is impractical to get a representative sample of a block through drop sheeting, as you would need to drop sheet about 1.5% of the trees for an accurate assessment to make a treatment recommendation. Strategic drop sheeting can detail the pest and beneficial population at that time and the broader dynamics of incidental populations.

A threshold is the level of pest or its eggs observed that triggers a decision to act. A threshold combines the level of damage tolerable (to the grower) and the pest numbers or number of eggs identified across the block. Pest consultants should discuss the threshold limit based on the amount of damage you will accept.

The acceptable limits for crop damage affect the threshold to determine when to apply pest control options. Other considerations for treatment recommendations will be:

- the beneficials present
- environmental factors such as average temperatures that promote or delay pest development and rainfall.

Table 2. An example integrated pest and disease management (IPDM) monitoring record sheet.

Tree	Pest or disease							Beneficials			
	FSB*	MNB	MFC								
1											
2											
3											
4											
5											
6											
7											
8											
9											
10											
11											
12											
13											
14											
15											
16											
17											
18											
19											
20											
Total											
%											

* FSB = fruit spotting bug, MNB = macadamia nut borer, MFC = macadamia flower caterpillar.

The types of thresholds for each pest (Table 3) can differ and some pests have more than one treatment threshold. For example:

- Macadamia nut borer thresholds are based on the average number of pests trapped per week and then, later in the season, eggs per 100 nuts.
- The monolepta treatment threshold is triggered by the proportion of leaf damage within the orchard.
- Fruit spotting bug spray decisions are based on the percentage of infested nuts shed and then, as the retained nuts develop, when bug counts within nearby monitoring hedges show greater than 30% of stage 5 nymphs within the hedge.

When consultants recommend a treatment, a post-treatment inspection is required to verify its effectiveness. If a pest population is building but not yet at a threshold level, the pest scout might return quickly to monitor the population changes. Communicating with your pest consultant regularly during the crucial crop development phases can also help ensure a successful crop, as you might observe things in the orchard between visits that assist your consultant, and they can give you advance notice of actions they might recommend.

Table 3. An example of pre-defined thresholds that trigger a treatment action.

Pest	Treatment threshold/s	
Fruit/banana spotting bug	4% damaged nuts (during nut-shedding)	>30% stage 5 nymphs within a trap hedge (post-shedding onwards)
Green vegetable bug	4% damaged nuts (during nut-shedding)	Adult bugs observed post-shedding
Leptocoris	4% damaged nuts (during nut-shedding)	Large numbers on alternate host plants, e.g. golden rain tree, post-shedding
Macadamia flower caterpillar	40% of green flowers with eggs	NA
Macadamia nut borer	1 live egg/100 nuts (during nut-shedding)	3 live eggs/100 nuts (post-shedding)
Macadamia seed weevil	1 egg lay	Lay mark on nut >8 mm diameter

Spray treatments: contractor or own sprayer?

Will you employ a contract sprayer or purchase and use your own equipment? There is no set figure on how large an orchard must be to justify purchasing and operating equipment. There are strengths and weaknesses of using a contractor vs owning and operating your own equipment. A significant difference is the ability to control the timing of treatments when you have your own equipment. Using contractors allows improved return on capital. Determining the right balance for your orchard will be the key to determining which path you take.

Refer to the *Macadamia plant protection guide* for information on pest treatments (https://www.dpi.nsw.gov.au/agriculture/horticulture/nuts/growing-guides/macadamia-protection-guide).

Diseases

Phytophthora

Once present in the orchard, phytophthora disease (caused by *Phytophthora cinnamomi*) is difficult to eradicate. Phytophthora disease is less likely when adequate soil preparation occurs before planting and management supports healthy soil. Later, good soil management to alleviate compacted and wet soil can greatly reduce the damage from phytophthora disease.

Phytophthora disease can appear as yellow leaves, ooze sap exuding from the trunk (Figure 22) and trunk canker. No single practice can control the disease. Phytophthora management is holistic and relies on:

- careful site selection for new orchards (refer to *Macadamia grower's guide: new orchards*)
- a strategic plan for good soil and tree health management (refer to *Macadamia grower's guide: soil health and nutrition foundations*)
- continued monitoring (refer to *Macadamia plant protection guide*)
- ensuring nursery plants are free from disease before delivery (refer to *Macadamia grower's guide: new orchards*)
- ensuring that the new plants have a well-developed root system (refer to *Macadamia grower's guide: new orchards*)
- strategic fungicide application to severely affected trees (refer to *Macadamia plant protection guide*).

Figure 22. Ooze sap exuding from the trunk is a symptom of phytophthora disease.

Botryosphaeria canker

Not often seen in young trees, this disease will find its way through low sap flow and injury to young plants. It is most likely where physical damage, such as from hail stones, has created an entry point for the disease. Avoid training young trees when wet, cool weather is persistent. The disease is also often associated with poor root development, so ensure the soil is healthy, well drained and within the correct pH range (5.5–6.5_{Ca}). Refer to *Macadamia grower's guide: nutrition and soil health – the next level* for more information on protecting trees from disease.

Botryosphaeria will often appear as a single branch dying back. Cut that branch back to below the dead area. If you see wedging, it is most likely to be Botryosphaeria. Keep cutting back the branch until there is no wedging (Figure 23). Destroy material that has wedging. New growth should extend from the clean-cut areas. Ensure that soil health has been enhanced to support this new growth.

Figure 23. A discoloured cross-section typical of branch dieback.

Phytophthora works from the ground up.
Botryosphaeria works from the top down.
Both are influenced strongly by soil health and tree health.

Integrated pest and disease management scorecard

The macadamia integrated pest and disease management (IPDM) scorecard (Table 4) helps growers manage and monitor pest and disease levels in their orchards. The scorecard is a tool that provides a systematic way of assessing the toxicity of pest and disease management practices on beneficial organisms. Growers can aim to keep their overall IPDM score as low as possible while maintaining adequate productivity as a high proportion of saleable kernel.

The IPDM scoring system assigns each chemical applied a score based on its effect on pests, diseases, and the environment. These values are in the *Macadamia plant protection guide* on the pages for the target pest.

- Score 1: when used with care, the chemical will have little effect on beneficials.
- Score 5: use this chemical with caution, and assess the chemical's effect on beneficials present before application.
- Score 10: this chemical is likely to have substantial, negative, off-target effects, including on beneficial arthropods.

The goal is to achieve the lowest possible score, in combination with high sound kernel production, which indicates effective and sustainable pest and disease management. Scores ≤50 with sound kernel >1 t/ha are considered good practice and achievable in a 'normal' season. Low scores are often associated with:

- sound IOM
- a strong foundational approach to nutrition and soil health
- pest, disease and beneficial monitoring and record-keeping
- goal setting, such as reducing the use of certain chemicals or improving the balance of beneficial insects in the orchard.

High scores with low sound kernel production might be related to canopy management issues, poor spray coverage, poor application timing and IOM red flags.

Macadamia growers can use the IPDM scorecard to check their performance and demonstrate changes in their management practices towards healthier orchards and better yields. For further information on the macadamia IPDM scorecard, refer to the *Macadamia plant protection guide.*

Table 4. An example integrated pest and disease management (IPDM) scorecard.

Instructions:

- record the pest or disease, chemical and IPDM score in the table
- at the end of the season, tally up the IPDM score
- insert production in tonnes of saleable kernel (t/ha) in the bottom corner
- scan the document and email it to jeremy.bright@dpi.nsw.gov.au

Pest	Product and active ingredient	IPDM score
E.g. macadamia lace bug	Transform® Isoclast®, sulfoxaflor	5
Total		

Saleable kernel (t/ha) __________

Nutrition and soil health – the foundations

Applying nutrients

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 removed 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 environmental losses (Figure 24).

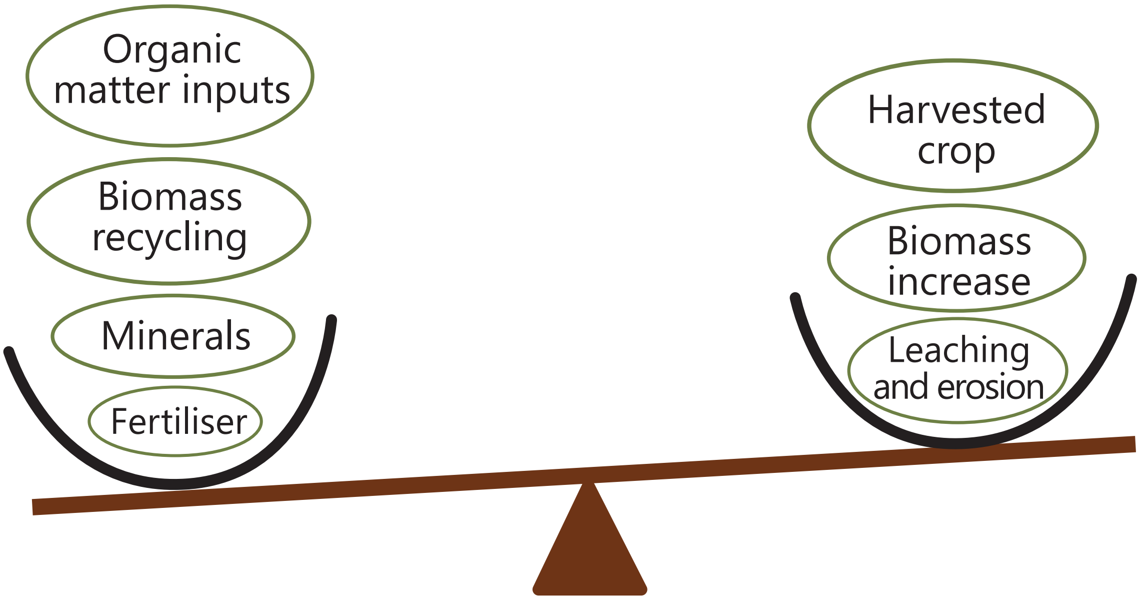

Figure 24. The nutrient balance of the orchard moves in response to the accumulated inputs and losses.

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

Sometimes, extra nutrients are added to accommodate desirable tree growth and replace 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 and poor drainage) are present.

The rates in Table 5 and Table 6 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 DPIRD Clean Coastal Catchments research project, 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. Higher nutrient applications are probably necessary to sustain yields until the nutrient losses from 'red flag' issues are resolved. However, nutrient losses to the environment are likely, as are adverse environmental effects.

Consider the quality of the products you use for adding nutrients, their placement, and the time before they become available from the soil for uptake alongside the actual root mass, or lack of, to take up the nutrients. Also, be aware that the soil's cation exchange capacity (CEC) reflects the plant-available storage capacity for many nutrients. We recommend you comprehensively implement the foundations before developing a more sophisticated nutrition program.

Table 5. 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 6. 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 was conducted in 2021 and 2022 as part of the NSW DPIRD Clean Coastal Catchments research project, 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%.

Building organic matter

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, where plants release sugars into the soil to feed microorganisms that boost nutrient availability in their root zones
3. cycling biomass within the orchard through pruning, chipping and mowing, and the turnover of root material in the soil.

Some techniques to build organic matter include:

- applying compost or mulch to the tree rows
- growing healthy plants, including cover crops, in the tree and inter-rows, and letting this grow to >300 mm before mowing
- throwing mown material from the inter-rows to the tree rows.

Ground cover

Aim for living ground cover to dominate the inter-rows to protect the soil, maintain the profiles of drainage features and provide mulch for the tree rows. Mulch suppresses weeds, reduces soil moisture loss, maintains a more even soil temperature and improves soil structure. Grow mulch material in the inter-row area to throw into the tree row. Top up mulch with other organic materials such as coarse straw, sugar cane mulch, composted nut husk, woodchip, and chicken or cow manure applied to the tree rows (Figure 25).

Figure 25. Aim for a combination of living ground cover to dominate the inter-rows and mulch under the tree line.

Bare soil is undesirable in an orchard; having mulch and ground cover will enhance soil health.

Nutrition and soil health – the next level

Nutrition and soil health part 2: the next level is a detailed resource for growers who have established foundational practices and have monitoring information on their soil and tree conditions (Figure 26).

- The focus on maintaining topsoil pH in the target range continues, and subsoil pH is slowly corrected.
- Biomass and nutrients cycle within the orchard through strategic pruning and inter-row crops.
- Use soil and leaf tissue tests to manage nutrient availability and uptake by optimising the form, rate, timing and technique of nutrient applications.
- Consider site-specific soil issues related to soil physics, texture, and structure.
- Manage orchard operations to reduce soil disturbance and compaction to minimise harmful effects on soil conditions.
- Deficiencies and toxicities have been corrected.

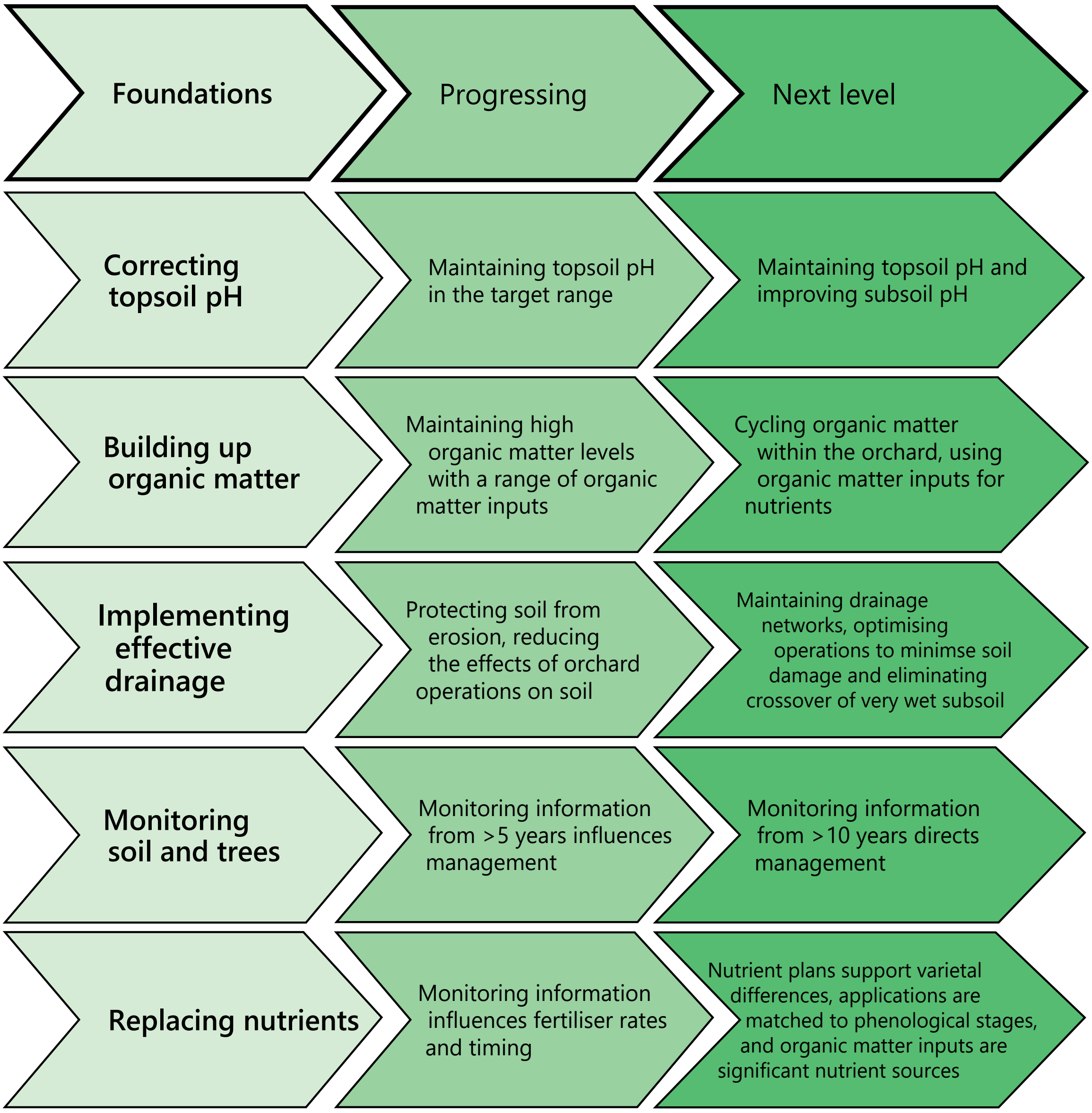

Figure 26. The foundations are the start of good practice in managing nutrition and soil health in macadamia. Growers with high-performing orchards implement key activities towards *the next level*.

Watering

Bearing trees need adequate soil moisture to produce good yields. In some regions, rainfall meets the plant's water needs, while in others, it will not. In some regions, good orchard floor management can build sufficient soil organic matter to allow enough soil moisture to support trees through drier periods. In other areas, supplementary irrigation remains essential (Table 7). The need for irrigation varies with annual rainfall and its distribution throughout the year, such as a pronounced wet or dry season, which creates the need for irrigation even with high annual rainfall. Supplementary irrigation can be helpful in regions where irrigation is not essential, but a cost-benefit analysis should be considered before investing in a system.

Table 7. Typical regional irrigation requirements for bearing trees.

Region	Annual rainfall (mm)	Irrigation used
NSW mid-north coast	1,486	No
NSW northern rivers – coastal floodplain	1,469	No
NSW northern rivers – plateau	1,825	No
Southeast QLD – Glasshouse Mountains and Peachester	1,414	Maybe
Southeast QLD – Gympie and Kin Kin	1,105	Yes
Central QLD – Bundaberg, Maryborough, Childers and Gin Gin	998	Yes
North QLD – Mackay, Rockhampton	1,526	Yes
North QLD – Emerald	560	Yes
Far north QLD – Mareeba and Burdekin	836	Yes
South WA	726	Yes

Only a small proportion of the tree's water use goes into growing stems, leaves, roots and nuts. Most water moves through the tree and transpires (evaporates through the tiny pores or stomata on the leaf surface) into the air. The water moving through the tree carries nutrients from the roots and cools sunlit leaves that would otherwise get sunburnt.

Water use depends on tree demand and the ability of the soil to supply sufficient water to the roots. The tree responds to scarce water by closing leaf pores (stomata), reducing water use and growth. Too much water also causes stress by limiting the oxygen supply to roots. The roots cannot do their usual metabolic tasks without oxygen and will die back, making minimising poorly drained soil a critical task (refer to *Macadamia integrated orchard management drainage 2022*).

The level of moisture stress and its effect on macadamia will be determined by the timing of the phenological stage and its duration.

- **At the start of flowering**, trees are not producing new leafy shoots, so mild moisture stress typically has little or no effect on yield or quality.
- **During flowering**, nut set and early nut development, significant moisture stress can reduce yields. This period often has high temperatures, low humidity and low rainfall, which might lead to significant moisture stress. Trees under extreme moisture stress might shed nuts until mid-way through nut maturation.
- **As nuts develop**, quality becomes increasingly sensitive, and severe moisture stress can lead to small kernels, immaturity, and low oil content.

An irrigation program aims to supply the trees' immediate needs and maintain soil moisture above a desirable minimum without overwatering. The critical decisions are how much and how often to irrigate. Moisture stress, from both too little and too much water, slows the tree's development. Factors such as tree age, cultivar, soil type, and weather conditions (e.g. recent rainfall, temperature, and humidity) affect watering regimes.

The water demand is higher when:

- there is full sunlight
- humidity is low
- temperature is high
- wind speed is high
- trees carry more leaves exposed to sunlight.

Trees under some water stress during the day will often recover at night.

After rain or irrigation, excess water seeps down through the soil, allowing air to enter the large pores between soil particles. At this point, the soil is at **field capacity**, where much of the water is held loosely in soil pores and around soil particles, and it is relatively easy for trees to take up moisture. Soil holds moisture more tightly as it dries, and trees work harder to create the suction needed to extract the water.

The suction required to remove water from the soil (the soil water tension) is measured in kilopascals (kPa). Field capacity is generally about -8 kPa to -10 kPa. Water that can be easily extracted from the soil by the plant is called **readily available water** (RAW). The RAW zone ranges from field capacity to the **refill point**, about -20 to -60 kPa. The desirable time to water is when soil moisture is at or just above the refill point.

Water is present only in smaller pores as the soil dries past the refill point. Trees must exert a tension greater than -60 kPa to extract this water. The extra effort might stress trees. Eventually, the soil can dry to a point where the tree can no longer extract any water. This is the **permanent wilting point**, where the tree will wilt and die from lack of water. Conventionally, this is defined as having a soil water tension of -1,500 kPa.

Soil water tension increases at different rates, depending on the soil type and the range of soil pore sizes. For example, sandy soil with few small pores will move more quickly from the refill point to the permanent wilting point than loam or clay-textured soil.

Irrigation success means keeping the soil in the RAW zone (between field capacity and refill point; Figure 27) as much as possible. More information on RAW is in NSW DPIRD Primefact 1362, *Determining readily available water to assist with irrigation management*.

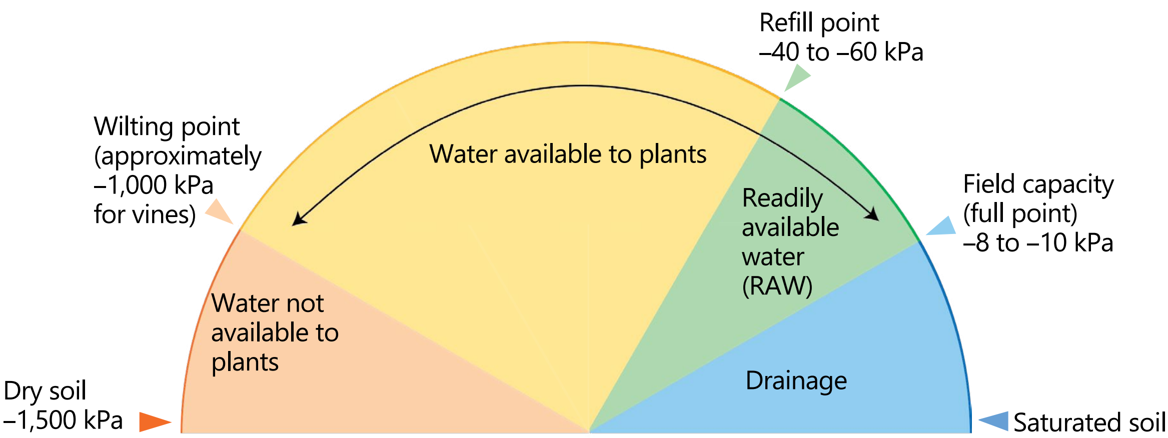

Figure 27. Soil water status.

Irrigation systems

An irrigation system should be capable of delivering the required amounts of water to each tree when needed, without waste. Ask a qualified irrigation expert to prepare an irrigation design and plan.

Sprinklers suit many soil types, including those with low infiltration rates and water-holding capacity. The 2 preferred irrigation systems in macadamia are under-tree sprinklers (micro-jets or mini-sprinklers; Figure 28) and drip (trickle tape; Figure 29).

- Micro-jets have no moving parts, provide less coverage than mini-sprinklers and operate at pressures between 50 and 150 kPa.
- Mini-sprinklers use fast spinning rotors to distribute the water, operate at higher pressures of 125–200 kPa and have a higher discharge rate than micro-jets.

Drip application applies water directly to the root zone, maintaining soil moisture by frequently irrigating a limited soil volume. It is the most efficient for water use but is less suitable for soil with low infiltration rates or water-holding capacity. Young trees often start with one drip line and a second line is added as the trees grow.

Each system has its advantages and disadvantages (Table 8). More detailed information is available from NSW DPIRD Primefact 1367, *Aspects to consider when choosing an irrigation system for horticulture*.

Figure 28. Mini-sprinklers are commonly used in macadamia. Photo: Chris Fuller, Nutworks.

Figure 29. Drip tape system in macadamia. Photo: Chris Fuller, Nutworks.

Water storage

Water for macadamia irrigation can come from irrigation scheme supply, farm dams and, in small quantities, pumped groundwater. A minimum reservoir of 0.5 ML/ha of orchard is needed to provide 1 month's storage for an irrigation program planning to deliver up to 5 ML/ha/year.

Table 8. Advantages and disadvantages of drip and sprinkler systems.

Irrigation system	Advantages	Disadvantages
Drip	• Easily automated. • Highly suitable for fertigation. • Even distribution across blocks. • Delivers precise water volumes. • Access to the orchard when irrigating. • Low pump costs. • Foliage remains dry. • Nuts at harvest are kept dry.	• Restricts root volume. • Does not assist in breaking down organic matter. • Does not assist in mobilising solid fertilisers applied to the soil surface. • High filtration costs. • Limited leaching ability. • Unable to irrigate inter-rows. • More easily blocked.
Micro-jets, sprinklers	• Easily automated. • Suits most soil types. • Well suited to fertigation. • Delivers precise water volumes. • Able to irrigate the inter-row. • Allows use of solid fertiliser. • Supports a larger root volume. • Supports soil biological processes and breakdown of organic materials.	• Need to prune more to keep the tree skirt up. • Waters more weeds. • Shadow effect on water distribution at the trunk. • Wind can affect uniformity. • More prone to damage from machinery and animals, e.g. ants can get in the sprinklers. • Expensive to maintain.

How much

There are many factors affecting the amount of water required when irrigating. Some key considerations are cultivar, tree age, climate, soil type and irrigation system used. In macadamia, this can vary from 35 L/day up to 110 L/day.

Irrigation tops up soil moisture by replacing a proportion of the water used by the tree through transpiration and the water lost from the soil surface through evaporation. The total water loss from the orchard is called evapotranspiration.

To compensate for inefficiencies in the irrigation system, apply more water than the minimum amount the tree should need. How much extra to apply is highly variable. Factors that can contribute to irrigation inefficiency include:

1. leaks
2. low or uneven water pressure
3. blocked emitters of sprinklers or drippers
4. evaporation
5. surface run-off
6. deep drainage to below the root zone.

In practice, this means adding a nominal percentage to the expected evapotranspiration in the irrigation plan, monitoring trees and soil for signs of under or overwatering and using that information to refine the irrigation plan. Rarely are irrigation systems perfect, and the performance of most irrigation systems declines over time. Attention to performance, through troubleshooting issues as they emerge, cleaning lines and timely renewal of components are ongoing tasks for the system's life. In areas where the need for irrigation is marginal, the time demands and maintenance costs might outweigh the benefits of having the system.

The amount of water that moves into the soil, as opposed to that which runs off over the soil surface, depends on the infiltration rate (the rate at which water soaks into an already moist soil). This rate differs for different soil types. Monitor the irrigation delivery for surface run-off that indicates when the application rate exceeds the infiltration rate. Where run-off occurs, reduce the water delivery rate or use multiple short irrigation cycles as needed to apply the total volume without causing run-off.

Surface run-off is an inefficient use of water that can cause soil erosion and nutrient losses in some areas and boggy areas elsewhere, where the risk of phytophthora disease increases. Deep drainage is inefficient for water use and removes nutrients from the root zone.

Monitoring soil moisture

Monitoring soil moisture tells us how much water the trees need and when, which can significantly improve irrigation efficiency. Monitoring before an irrigation cycle helps schedule the amount of water to apply and predict the timing of the next irrigation. It might be possible to reduce the planned watering without affecting yield or nut quality. Monitoring after irrigation can indicate how deeply the applied water reaches in the profile, which helps to refine the irrigation plan to apply sufficient water without overwatering.

Growers can monitor soil moisture status by measuring soil water tension or the volumetric water content. There are many options with varying levels of complexity and reliability. The goal is to have a system that informs how often to water (the frequency), how long to water for (the duration in minutes) and the amount to apply (the volume in L).

Most of the feeder roots of macadamia trees are in the top 400 mm of soil, so soil water monitoring devices used for irrigation scheduling need to concentrate on this part of the soil profile. It is also helpful to monitor soil moisture deeper than 400 mm as macadamia roots might extend to 1 m, depending on soil type, and the tree might have access to additional soil water at depth. The deep monitoring also informs us when excess water is applied, leading to deep drainage. As soil moisture monitoring can be complex, we recommend you seek expert advice, particularly when setting up the system.

Tensiometers

Tensiometers measure the suction required to draw water out of the soil. They generally operate within a range of 0 kPa to –80 kPa. The higher (more negative) the reading, the drier the soil. They are usually installed halfway between the tree trunk and the edge of the tree canopy in 'nests' of at least 2 tensiometers:

- at 300 mm deep to inform irrigation frequency
- at 600 or 900 mm deep to inform irrigation duration.

The ceramic tip at the base of the tensiometer requires good contact with the soil and is suited to sandy and clay loam soil types. The maintenance needs and frequency of manually reading tensiometers can be a drawback for this system. However, checking the tensiometers daily and ensuring they are correctly working gives the grower a good insight into the soil water dynamics.

GDot soil moisture sensor

Using a gypsum block sensor, the GDot measures the suction required to draw water from the soil. Its simplicity and lower price make it a good start-up choice for growers looking to monitor their soil moisture quickly and easily.

The GDot has 7 yellow 'flip dots' indicating the tension required for the tree roots to take up water. The flip dots indicate the soil is at field capacity; as they disappear, water uptake is becoming harder. A few flip dots left mean soil moisture is approaching the refill point and irrigation is required.

Fullstop™ wetting front detector

Initially designed by CSIRO to encourage farmers to monitor moisture levels, the Fullstop™ is a simple, easy-to-use system to monitor moisture as it moves down the soil profile. The detectors are plastic, have no electronics and do not require power. A funnel-shaped reservoir buried at a desired depth collects water as it moves through the soil profile. An indicator flag (fitted to an extension tube) is triggered when the reservoir is full. The Fullstop™ is often used as a quick visual aid to gauge when irrigation water has reached a specific level in the root zone. They can be installed in pairs to gauge if the irrigation cycle delivers too little or too much water.

Capacitance probes

Capacitance probes measure soil water as a percentage of the total soil volume. Recently, this system has become more affordable. PVC access tubes are installed at selected sites to represent the whole block. Multiple sensors can be located at various depths to cover the root zone. Each sensor emits a small electric field that extends beyond the access tube into the soil. Changes in soil moisture produce changes in the electric field, which software converts into soil moisture content.

There are portable and fixed capacitance probes. A popular portable capacitance probe is the Diviner®, while a popular fixed probe is Enviroscan®. Portable devices require the user to visit the site to get readings but allow monitoring of more sites, which can be beneficial if there are changes in soil type across the farm. Fixed probe sites can be connected to a transmitter, such as a weather station, and report in real time. The cost of each set of probes can limit how many to install. For more detailed information, refer to NSW DPIRD Primefact 1365, *Using capacitance probes for irrigation scheduling*.

Dendrometers (which measure changes in trunk diameter during the day) and **sap flow meters** (for estimating total plant water use) can provide further information about the amount and timing of tree water uptake. Usually, most water is taken up mid-morning, depending on several factors. This monitoring level is often used in horticultural research (Figure 30) and is not essential for managing farm irrigation.

Figure 30. A dendrometer measuring trunk diameter.

How often

Watering frequency depends on the water demand and the supply capability of the irrigation system. The water demand is affected by factors such as soil type, infiltration rate, temperature, evaporation, crop phenological phase and tree size. Drier weather conditions will influence the required watering frequency for bearing trees with large canopy and root volumes.

Aim to irrigate **before** the soil dries to the **refill point;** this is where the tree cannot easily extract water and growth is limited. For most tree crops, the refill point is between -40 and -60 kPa; however, drip irrigation often uses a refill point of -20 kPa because the actual watered area is smaller.

Maintaining the top 100 mm of soil in the upper part of the RAW zone (close to field capacity) seems advantageous, perhaps because nutrient uptake predominantly occurs in this zone. This approach requires shorter, more frequent irrigation cycles.

Active feeder roots in the top 100–150 mm of soil should have easy access to moisture to allow optimal photosynthesis in the leaves, creating the energy for higher productivity.

Very dry air conditions

Very dry air is a problem in some north Qld regions. It creates a stressful condition that causes macadamia trees to close their stomata (leaf pores). This restricts transpiration and growth, even if soil moisture is adequate.

Vapour pressure deficit (VPD) measures the drying pressure the air exerts on plants. It is the difference between the amount of moisture in the air and the amount of water it can hold at the same temperature. The favourable VPD range for macadamia is between 0.8 and 2.0 kPa (Figure 31). Above this, macadamia will react to protect themselves from excess drying.

Very dry air conditions reduce tree demand for water, and growers should modify their irrigation programs to reduce the risk of over-irrigating. Some growers apply water via elevated sprinklers to increase humidity and improve the growing conditions on hot, dry days.

°C	Relative Humidity, %RH													°F
	35%	40%	45%	50%	55%	60%	65%	70%	75%	80%	85%	90%	95%	100%	
15°	1.11	1.02	0.94	0.85	0.77	0.68	0.60	0.51	0.43	0.34	0.26	0.17	0.09	-	59.0°
16°	1.18	1.09	1.00	0.91	0.82	0.73	0.64	0.55	0.45	0.36	0.27	0.18	0.09	-	60.8°
17°	1.26	1.16	1.07	0.97	0.87	0.78	0.68	0.58	0.48	0.39	0.29	0.19	0.10	-	62.6°
18°	1.34	1.24	1.14	1.03	0.93	0.83	0.72	0.62	0.52	0.41	0.31	0.21	0.10	-	64.4°
19°	1.43	1.32	1.21	1.10	0.99	0.88	0.77	0.66	0.55	0.44	0.33	0.22	0.11	-	66.2°
20°	1.52	1.40	1.29	1.17	1.05	0.94	0.82	0.70	0.58	0.47	0.35	0.23	0.12	-	68.0°
21°	1.62	1.49	1.37	1.24	1.12	1.00	0.87	0.75	0.62	0.50	0.37	0.25	0.12	-	69.8°
22°	1.72	1.59	1.45	1.32	1.19	1.06	0.93	0.79	0.66	0.53	0.40	0.26	0.13	-	71.6°
23°	1.83	1.69	1.55	1.41	1.26	1.12	0.98	0.84	0.70	0.56	0.42	0.28	0.14	-	73.4°
24°	1.94	1.79	1.64	1.49	1.34	1.19	1.05	0.90	0.75	0.60	0.45	0.30	0.15	-	75.2°
25°	2.06	1.90	1.74	1.59	1.43	1.27	1.11	0.95	0.79	0.63	0.48	0.32	0.16	-	77.0°
26°	2.19	2.02	1.85	1.68	1.51	1.35	1.18	1.01	0.84	0.67	0.50	0.34	0.17	-	78.8°
27°	2.32	2.14	1.96	1.78	1.61	1.43	1.25	1.07	0.89	0.71	0.54	0.36	0.18	-	80.6°
28°	2.46	2.27	2.08	1.89	1.70	1.51	1.32	1.13	0.95	0.76	0.57	0.38	0.19	-	82.4°
29°	2.61	2.41	2.20	2.00	1.80	1.60	1.40	1.20	1.00	0.80	0.60	0.40	0.20	-	84.2°
30°	2.76	2.55	2.34	2.12	1.91	1.70	1.49	1.27	1.06	0.85	0.64	0.42	0.21	-	86.0°
31°	2.92	2.70	2.47	2.25	2.02	1.80	1.57	1.35	1.12	0.90	0.67	0.45	0.22	-	87.8°
32°	3.09	2.86	2.62	2.38	2.14	1.90	1.67	1.43	1.19	0.95	0.71	0.48	0.24	-	89.6°
33°	3.27	3.02	2.77	2.52	2.27	2.01	1.76	1.51	1.26	1.01	0.76	0.50	0.25	-	91.4°
34°	3.46	3.20	2.93	2.66	2.40	2.13	1.86	1.60	1.33	1.07	0.80	0.53	0.27	-	93.2°
35°	3.66	3.38	3.10	2.81	2.53	2.25	1.97	1.69	1.41	1.13	0.84	0.56	0.28	-	95°

COLOR LEGEND

DANGEROUS | HIGH STRESS | FLOWER | VEGETATIVE | NURSERY | FUNGAL PATHOGENS | DEW POINT

Figure 31. The favourable vapour pressure deficit (VPD) range for macadamia growth is between 0.8 and 2.0 kPa, highlighted by the black outline. Source: Integrated Bioengineering.

Troubleshooting irrigation

It is common for irrigation systems to be imperfect. No matter how much care and expense has gone into the design and installation of the system, expect problems to emerge. The main issues to look for and correct are underwatering (Table 9), overwatering (Table 10) and water quality (Table 11). Always check the quality of the water from its source. Water quality can change due to many factors, such as drought, rainfall, and turbidity.

Table 9. Why some trees are not getting enough water and what to do.

Check for	Strategy to resolve
Higher water demand from trees.	Review the irrigation plan monthly to adapt to changing climate and crop stage.
Blocked, non-operational or restricted emitters. Inspect emitters during irrigation and look for trees growing slower than their neighbours.	Clear, fix or replace emitters*. Flush the system (lines and filters) to reduce blockages (Figure 32).
Leaks: look for extra green areas of ground cover.	Find and fix leaks.
Water pressure problems: pressures that are too low can lead to the upper parts of the block receiving less than the planned water volume in the irrigation cycle, and pressures that are too high can burst or damage fittings, reducing the evenness of watering.	Investigate and resolve the cause. Schedule regular service and maintenance programs for the system.
Irrigation water drains through to below the root zone. Look for water coming through subsurface drains after irrigation cycles or monitor soil moisture at 1 m deep.	Use shorter duration, possibly less frequent, irrigation cycles.

* An emitter is where water emerges from the delivery system e.g. a dripper or sprinkler.

Table 10. Why do some trees get too much water and what to do.

Check for	Strategy to resolve
Reduced water demand from trees.	Review the irrigation plan at least monthly to adapt to changing climate and crop stage.
Missing or damaged emitters.	Fix or replace emitters.
Delivery rates exceed infiltration capacity, leading to surface run-off and water concentration in some areas.	Use shorter irrigation cycles or lower water delivery rates.
Soil that remains very wet long after the irrigation cycle finishes.	Investigate drainage issues, considering the position in the landscape, run-on, subsurface flows, and impaired drainage. Solutions might include watering less, changing the irrigation block layout and subsurface drainage.

Table 11. Water quality issues, what to look for and what to do.

Check for	Strategy to resolve
Leaf margins burnt or scalded ground cover plants near emitters.	Check water electrical conductivity (EC) and ensure it is below 1,000 micro-siemens.
Discoloured leaves.	Check the water pH and ensure it is between 5.5 and 6.5.

Figure 32. Flush the system (lines and filters) regularly to reduce blockages.

Fix weak links in orchard operations

Managers of bearing trees strive to maintain their orchards in the 'sweet spot' to prevent decline. Continuously reviewing and refining various aspects of the orchard system are crucial. As an evolving entity, the orchard requires ongoing improvement of practices, infrastructure, and tools.

Doing nothing is not an option.
Doing the same thing indefinitely will not work either.

Water supply

Review the irrigation system's performance:

- Are pumps and delivery lines supplying enough water to deliver the scheduled irrigation reliably? Does anything need upgrading?
- How much labour is going into running and maintaining the irrigation system? Is it excessive? How is staff time spread across tasks, and what can be streamlined?
- Is tree performance consistent, or are some areas doing better than others? Is this related to irrigation management, and if so, how can it be improved?

The performance of most irrigation systems degrades with age. This decline is slowed by adequate maintenance and relieved by appropriate upgrades to components. Both actions are most useful when informed by monitoring that identifies problem areas as they arise.

Flushing lines, mainly where there is potential for the build-up of calcium deposits, is essential to keep the system working as intended. Set up a regular program to check and clean filters to reduce the potential for foreign material to clog up lines and sprinklers. Regularly checking sprinkler output is also very important. Monitor water quality, including pH, which affects nutrient availability and the performance of some pest treatments.

Drainage

As trees grow, there will be more:

- shading of the orchard floor that reduces the vigour of living ground cover, especially in the tree rows
- branches creating the funnel effect that leads to more stem flow (concentrated water running down the trunks of trees)
- soil movement in heavy rain, with some areas filling with sediment while others, especially on steeper slopes, are losing topsoil.

Monitoring and maintaining drainage infrastructure and slope-specific ground cover levels are essential to protect the soil. Include maintaining light for living ground cover in your pruning objectives. Regular pruning ensures that pruning needs remain moderate, manageable, and beneficial for tree productivity. Waiting too long will mean more intense pruning and reduced short- to medium-term yields.

Equipment and buildings

Service equipment as required. Calibrate sprayers annually because poor spray coverage is costly in crop quality when unresolved, and it is one of the most straightforward issues to amend. If appropriate spray coverage is still difficult to achieve, look at the canopy structure before changing equipment. The canopy height or density might need to be reduced for more effective treatments. Review harvest, handling, on-farm storage capacity and marketing of the crop.

Access

Check for parts of roadways that are not enduring as well as they should. Prioritise resolving concentrated surface water flows on track surfaces and persistently wet areas. Minimise traffic on the orchard in wet weather, as driving on wet tracks is a leading cause of damage, compaction and soil structure decline. Committing to the annual maintenance of access roads helps spread the workload and ongoing costs.

Organise access for pollination services to spread bee hives around the orchard at 4–6 hives per hectare rather than in one accessible spot (Figure 33). Consider an access road around the orchard if it is not practical to take hives in.

Figure 33. Beehives are better distributed around the orchard than banked in one area. Consider access tracks for hive distribution.

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How to recognise the 'sweet spot' for sustained high production:

In the sweet spot:

- Canopy dimensions correct
- Light inside the canopy
- Nut production throughout the canopy
- Living ground cover present

Past the sweet spot:

- Canopy dimensions oversized
- Not enough light inside the canopy
- Nut production only in the upper canopy
- Living ground cover is declining