

Macadamia grower's handbook

Reprint – information current in 2004



REPRINT INFORMATION – PLEASE READ!

For updated information please call 13 25 23 or visit the website www.deedi.qld.gov.au

This publication has been reprinted as a digital book without any changes to the content published in 2004. We advise readers to take particular note of the areas most likely to be out-of-date and so requiring further research:

- Chemical recommendations—check with an agronomist or Infopest www.infopest.qld.gov.au
- Financial information—costs and returns listed in this publication are out of date. Please contact an adviser or industry body to assist with identifying more current figures.
- Varieties—new varieties are likely to be available and some older varieties may no longer be recommended. Check with an agronomist, call the Business Information Centre on 13 25 23, visit our website www.deedi.qld.gov.au or contact the industry body.
- Contacts—many of the contact details may have changed and there could be several new contacts available. The industry organisation may be able to assist you to find the information or services you require.
- Organisation names—most government agencies referred to in this publication have had name changes. Contact the Business Information Centre on 13 25 23 or the industry organisation to find out the current name and contact details for these agencies.
- Additional information—many other sources of information are now available for each crop. Contact an agronomist, Business Information Centre on 13 25 23 or the industry organisation for other suggested reading.

Even with these limitations we believe this information kit provides important and valuable information for intending and existing growers.

This publication was last revised in 2004. The information is not current and the accuracy of the information cannot be guaranteed by the State of Queensland.

This information has been made available to assist users to identify issues involved in macadamia production. This information is not to be used or relied upon by users for any purpose which may expose the user or any other person to loss or damage. Users should conduct their own inquiries and rely on their own independent professional advice.

While every care has been taken in preparing this publication, the State of Queensland accepts no responsibility for decisions or actions taken as a result of any data, information, statement or advice, expressed or implied, contained in this publication.



Queensland Government

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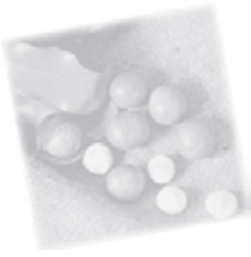


Chapter

Additional information
on some
KEY ISSUES

This chapter contains some additional useful information on some of the important decision making areas and information needs for macadamias. The information supplements the information in other chapters, particularly the Growing the crop chapter, and should be used in conjunction with it.

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Economics of macadamia growing

This section contains an economic analysis for a hypothetical orchard in southeast Queensland or northern New South Wales. The analysis provides the following details:

- Variable costs and gross margin analysis for a mature orchard.
- A gross margin sensitivity analysis for a range of yields and prices.
- Fixed costs.

Note that the information is intended to provide only an indication of potential costs and returns from the crop – it is not to be taken as confirmation of the profitability of macadamias at any particular site. It is recommended that individuals seek professional financial advice and develop a thorough business plan (including a full cash flow analysis) for their own specific circumstances.

Note also that the example shows only variable and fixed annual costs – it takes no account of the significant capital expenditure required to establish a macadamia enterprise.

Assumptions

Assumptions made in the analysis include:

- Macadamia is the only crop grown.
- The orchard is 20 hectares of trees planted at 8 m x 4 m or 312 trees per hectare.
- The orchard is not irrigated.
- The orchard is 15 years old and marketed yields are 3500 kg per hectare of nut-in-shell (NIS) at 10% moisture content.
- The price received is \$2.50 per kg of NIS.
- Labour is paid at a casual rate of \$20 per hour, which includes award wage, super, payroll tax, and workcover. The analysis costs all labour at this rate, whether it is owner-operated, an employed manager or casual labourers.
- Machinery costs include fuel and oil only; maintenance costs are listed as a fixed cost.
- Figures used in the analysis were current as of September 2004.
- Depreciation is not included.

i See *The capital you need* on page 5 for brief details on capital required.

Annual variable costs

Item	No./yr	Units/ha	Unit	\$/unit	\$/ha			Total \$/ha
					Labour	Machinery	Material	
Weed and erosion control								
Slashing – labour	6	1	hr	20.00	120			
Slashing – machinery	6	1	hr	15.00		90		
Weed spraying – labour	3	1	hr	20.00	60			
Weed spraying – machinery	3	1	hr	15.00		45		
Glyphosate	3	1	L	6.00			18	
TOTAL					180	135	18	333
Nutrition								
Leaf analysis	1	1/20 ha	test				10	
Soil analysis	1	1/20 ha	test				10	
Fertiliser spreading – labour	3	1	hr	20.00	60			
Fertiliser spreading – machinery	3	1	hr	15.00		45		
N:P:K fertiliser mix	3	312	kg	0.54			505	
TOTAL					60	45	525	630
Pest and disease control								
Spraying – labour	3	2.00	hr	20.00	120			
Spraying – machinery	3	2.00	hr	15.00		90		
Copper oxychloride for husk spot	1	4.00	kg	4.00			16	
Carbendazim for husk spot	2	1.25	L	29.50			74	
Beta-cyfluthrin for pests	2	1.00	L	33.50			67	
Endosulfan for pests	1	3.50	L	11.00			39	
Vermin control (labour)	1	2	hr	20	40			
Coumatetryl for rats	1	1	kg	21			21	
Pest scouting services (contract)					60			
TOTAL					220	90	217	527
Canopy management								
Tree care – labour	1	3	hr	20.00	60			
Mechanical pruning – contractor	1	1.25	hr	100.00		125		
Pruning disposal – labour	1	2	hr	20.00	40			
Pruning disposal – machinery	1	2	hr	15.00		30		
TOTAL					100	155		255
Harvesting and marketing								
Machine harvest – labour	5	6.0	hr	20.00	600			
Machine harvest – machinery	5	6.0	hr	25.00		750		
Hand harvest	5	1.0	hr	20.00	100			
Pre-harvest preparation (sweeping/mulch) – labour	1	6.0	hr	20.00	120			
Pre-harvest preparation (sweeping/mulch) – machinery	1	6.0	hr	15.00		90		
Dehusk, sort and handle	5	6.0	hr	20.00	600			
Freight	1	3500	per kg	0.05		175		
Levy	1	3500	per kg	0.08			280	
TOTAL					1420	1015	280	2715
TOTAL ANNUAL VARIABLE COSTS/HA					1980	1440	1040	4460
TOTAL ANNUAL VARIABLE COSTS/20 HA OF ORCHARD					39600	28800	20800	89200
TOTAL INCOME FROM NUT SALES/20 HA OF ORCHARD (3.5 T/HA @ \$2.50/KG)								175000
GROSS MARGIN/20 HA OF ORCHARD								85800

Gross margin sensitivity analysis

Gross margin* for 20 ha orchard for a range of yields and nut-in-shell (NIS) prices.

Yield (t/ha)	Average price/kg NIS (\$)				
	\$1.50	\$2.00	\$2.50	\$3.00	\$3.50
2.5	-11,600	13,400	38,400	63,400	88,400
3.0	2,100	32,100	62,100	92,100	122,100
3.5	15,800	50,800	85,800	120,800	155,800
4.0	29,500	69,500	109,500	149,500	189,500
4.5	43,200	88,200	133,200	178,200	223,200

* Gross margin is defined as income less variable costs (that is, it does not account for fixed or capital costs)

An indication of fixed costs for a 20 ha orchard is shown below. These need to be deducted from the gross margin figures to give a more accurate indication of profitability.

Fixed costs per year for 20 ha orchard (assumes macadamia is the only crop)

Item	Total \$
Repairs & maintenance – labour	4500
Repairs & maintenance – materials	6000
Repairs & maintenance – service costs	6000
Fuel & oil – non-specified	2000
Electricity and gas	2000
Accountants fees	2000
Telephone/fax/email	1000
Registrations	1300
Insurance	3000
Administration	2000
General transport	1600
TOTAL ANNUAL FIXED COSTS for the 20 ha orchard	31400

Taxation

This is an important issue for both new growers and those purchasing an established orchard. It is complex and specialised and professional advice from an experienced horticultural accountant is recommended.

The costs of establishing an orchard and its maintenance until a positive cash flow is achieved are substantial. Funding this appropriately is an essential requirement for successful macadamia farming. Many growers fund the orchard through other sources of income and the ability to deduct allowable expenditure is important.

Firstly you must be in the business of farming and have commenced the business. The size of an orchard and a sound business approach are some requirements for the Taxation Office to class you as a primary producer. As

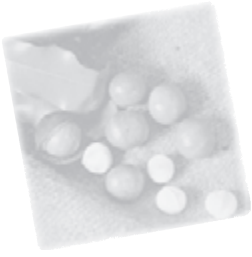
an indicator, an orchard of less than 1500 trees may be classed as a hobby farm. Determination of primary production status is by the viability of the farming, which is assessed on a property by property basis.

Macadamia farming is covered by Div. 10F of the Income Tax Assessment Act. In simple terms, this requires the costs of establishing the orchard to be recorded as capital (establishment) expenditure. This cost includes the grafted trees, preparation, planting, fertiliser, labour and other costs until the orchard is established. This total is written off over 'the effective life' of the trees and commences when the trees first start to produce (probably year 4). If 'the effective life' is taken as 13 to 30 years, the establishment costs are allowed to be written off over 8 years. Capital costs subject to usual depreciation rules such as machinery, sheds and irrigation, are treated separately. Expenditure after establishment is deductible, subject to its nature.

A purchaser of an established orchard can claim any write-offs still available.

The value of the crop harvested but unsold at 30th June each year must be accrued in that year at the cost of production.

There are many 'grey' areas and sound professional advice, development of a taxation strategy and good record keeping should be essential components of your business plan.



Quality management

The Australian macadamia industry has developed an enviable reputation over the years for producing a consistent, safe-to-eat, high quality product. This has enabled Australian macadamias to establish a competitive edge and to maintain a price advantage on world markets.

However, customers in Australia and overseas are also seeking assurance that the on-farm and processing practices meet their requirements for assured food safety and quality. To maintain and strengthen market position, the industry is responding through implementing quality management systems for assurance of product safety and quality in all sectors of the supply chain.

Macadamia Industry Approved Supplier Program

An Approved Supplier Program involves suppliers putting in place practices that their customers require for quality assurance. The Macadamia Industry Approved Supplier Program (MIASP) is a package of practices macadamia growers will need to implement to satisfy customer requirements. MIASP is HACCP-based.

The MIASP is not a new set of practices. It is a blending of the various recommendations and documentation from COSOP, MacMan, and processor pre-season reports and delivery reports into a single program. It is referenced to the horticulture industry *Freshcare Code of Practice*. The MIASP integrates these resources into a single structure of practices and documents for an on-farm food safety and quality management system. The MIASP is recognised by processors and endorsed by the Australian Macadamia Society. As yet, there are no auditing arrangements, but the program is designed to enable third-party auditing, if the industry chooses this path.

The MIASP requires growers to keep records on practices relating to food safety and quality. It seeks to ensure these practices are a part of routine on-farm activities. In the event of a food safety issue, the recording system needs to be auditable to enable traceback to the origin of the problem. Customers may also want to see that growers are following the program requirements.

On-farm practices addressed in the MIASP include:

- Controlling food safety hazards in chemical, fertiliser and water use;
- Controlling safety hazards from sites, employees, storage and transport;
- Product and handling specifications;
- Product identification and traceability;

NOTE

Further information about the MIASP can be found in the publication *Approved Supplier Manual : On-farm Macadamia Quality and Food Safety Management* published by the Australian Macadamia Society and NSW Department of Primary Industries.

- Training requirements;
- Auditing and corrective action;
- Documentation control.

The MIASP has been developed with a training course, training workbook and user manual designed to provide information about QA and assist growers to package and record the relevant information.

The MacMan farm recording system has been updated to ensure that any additional records required for the MIASP are included. MacMan is the preferred industry recording system for the MIASP.

MacMan

The MacMan recording system was first released in 1999. Available in hard copy diary and computer software program formats, it provides a convenient record keeping system for managing information required for on-farm quality management. Thus, MacMan is a tool to support other quality management systems, it is not a quality management system in itself. Growers can use MacMan to keep up-to-date records of their growing, harvesting and sorting practices, which impact on nut quality and safety. This information can also be used to assess farm performance.

MacMan is regularly updated to include any changes or resources needed for recording on-farm quality management activities, and growers are encouraged by the Australian Macadamia Society to use it. Training and support in the use of MacMan is also available.



See *Record keeping* and the *MacMan software* on page 79 for more detailed information on the software and how to obtain it.

ISO Quality management in macadamia processing

Quality management system standards were introduced to the Australian horticulture industries in the early 1990s and Australian macadamia processors were some of the first businesses to adopt the international ISO 9002 standard into their operations.

ISO 9002 is an international quality management standard. It was originally developed for manufacturing industries but increasingly is used for other product and service industries. It has many requirements that a business must satisfy to demonstrate that all aspects of the business that impact on the quality of products and services provided to customers are controlled. These systems help the processors manage their operational efficiency and assist with maintaining maximum global marketing opportunities with customers who require these standards.

Hazard Analysis Critical Control Point (HACCP)

In recent years, increasing consumer and customer concern over food safety issues has encouraged many processors to develop HACCP Plans to focus on food safety in their operations. The Hazard Analysis Critical Control Point (HACCP) method is an internationally recognised, systematic approach to identify, evaluate and control hazards to product safety and quality, before they occur.

HACCP was implemented mainly to ensure food is safe to eat, but HACCP has also been applied to ensure customer quality requirements are met. The HACCP approach is focussed on preventive practices to control food safety and product quality rather than relying on end-point detection of problems. HACCP is widely used in the food industry as the preferred system for food manufacturers and processors to manage food safety.

Processor HACCP systems can control the risks that occur at the processor facility, from receipt of nut-in-shell to dispatch to their customers. However, to be assured that the product can consistently meet the food safety and quality demands of their markets and customers, the processors need to know about on-farm practices that can potentially impact on kernel safety and quality and how growers manage them.

On-farm quality management—COSOP

NOTE

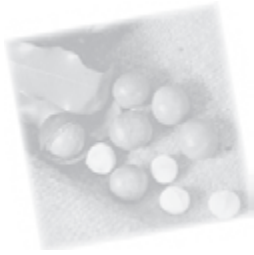
COSOP is available from the Australian Macadamia Society. See page 186 for contact details.

In 1992, the Australian Macadamia Society released the Macadamia Industry Code of Sound Orchard Practices (COSOP). COSOP is a best practice guide for growers for managing orchards and nut quality up to the point of consignment to the processor. The introduction of COSOP was timely as a support mechanism to the many macadamia processors who were then developing their ISO9002 systems. While focussed on nut quality issues, COSOP contains many practices that are central to controlling food safety risks.

COSOP was updated in 2000 to include a greater focus on food safety, environmental management and workplace health and safety issues, as well as greater emphasis on the on-farm risk management practices required. This was necessary because of the increasing food safety concerns in key macadamia markets, which required processors to have documented assurance by growers that sound on-farm practices were in place.

Through COSOP, pre-season reports on farm activities (as part of the supply contract offer), and delivery reports with each consignment, have been increasingly adopted. Pre-season reports provide processors with important information they need for assurance about on-farm food safety practices such as pesticide application practices, fertiliser use, harvesting practices and on-farm storage of nut-in-shell.

COSOP, unlike HACCP, is not normally auditable but it has provided a reference for sound orchard practices, contributed to the control of safety and quality issues, and established the foundations for the Macadamia Industry Approved Supplier Program (MIASP).



Record keeping and the MacMan software

Record keeping is an essential part of good farm management. Records allow trends to be observed, orchard performance to be fine-tuned, and better long-term decisions to be made. They are also essential for quality management systems and to satisfy legislative requirements. MacMan is a specialised software package designed to provide a simple and powerful recording system. This section provides an overview of record keeping and the Macman software.

Record keeping

Accurate and ordered recording of information on the farm is essential for good business management. It is also a legal requirement for taxation purposes, chemical use legislation, Workplace Health and Safety audits, approved supplier accreditation and quality assurance certification systems. The Macadamia Industry Approved Supplier Program involves suppliers (that is, macadamia growers) keeping sufficient records to demonstrate that their practices are meeting customer quality and food safety requirements.

Types of information that may be recorded as part of your farm management include:

- preharvest (pest and disease monitoring records, spray program, labour inputs, leaf and soil analysis, soil moisture monitoring, fertiliser and irrigation schedules);
- postharvest (labour, harvesting records, handling and storage logs, chemical usage),
- quality management records.

This information is used to satisfy legal requirements, compare performance from year to year and to establish best farm practice. It also supports the development and updating of your business plan. It can be recorded on a computer where information can be quickly accessed and compared, or it can be recorded in books or on forms and filed in a filing cabinet.

NOTE

The MacMan farm recording computer package is the recommended way of recording and using this information (see below).

IMPORTANT NOTE

It is a legal requirement that all growers using the pesticide endosulfan, maintain a record of each application. It is the responsibility of the grower to collect (either directly or from a person on his/her behalf) and record all of the information required in a special *Endosulfan Spray Record*. The record requires the completion of information on the farm and applicator, crop and pest details, weather conditions at application, and detailed application information.

Growers may use MacMan or their own computer-generated forms or special forms available from the Australian Pesticides and Veterinary Medicines Authority or other chemical agencies.

MacMan

MacMan is a simple yet powerful recording and reporting system to monitor and improve nut quality and orchard profitability. It is designed to give macadamia growers a quick and easy way to keep important farm records and produce a wide range of useful reports. It also provides a recording system to satisfy nut processors' food safety and quality assurance information requirements.

MacMan consists of:

- A simple, standardised computer based and paper based recording system;
- A benchmarking system that enables growers to analyse performance results from their own farms and to confidentially compare these against other growers and industry standards.

MacMan development

The development of the MacMan farm recording system began in 1997. The Australian Macadamia Society recognised the need for on-farm quality management and approached the Department of Primary Industries & Fisheries to work with them to build a system to enable growers to record key food safety and quality management information. In addition, it was intended that growers would be able to use this information to identify where they could improve their efficiency and productivity.

Since then, the MacMan team of software programmers and extension staff, with the support of Horticulture Australia Limited, has worked closely with a steering group of key growers, consultants, processors, staff of NSW Department of Primary Industries and the Australian Macadamia Society to develop a farm recording system to meet the needs of the range of growers within the Australian macadamia industry. Since the first release of the software in 1999, the program has regularly been updated as the focus groups identify further needs within the industry.

What can you record in MacMan?

MacMan enables you to keep all of the important management records for your macadamia farming enterprise. These include details about the following:

- Farms, blocks and plantings. A planting is the lowest level of recording in MacMan. Plantings enable you to record jobs or harvest yields in part of a block if you wish.
- Employees.
- Contacts. This includes customers and suppliers of goods and services.
- Machinery.
- Pests and diseases. MacMan also provides you with information about the major Australian macadamia pests and diseases, including life cycles, habits and damage, host plants and distribution, monitoring methods, biological and cultural controls, and pictures of the pests and diseases and damage caused.
- Chemicals such as fertilisers and pesticides. MacMan also enables you to keep a chemical stock inventory linked to your job records.
- Storage vessels, such as silos or bins.
- Water sources, such as creeks, dams and bores.
- All the jobs performed on a macadamia farm. This also includes all labour, contract, machinery and chemical costs and products involved. You can also create your own job categories if you wish.
- Employee time sheet records.
- Variable costs. Although MacMan is an agronomic recording program, it also has a simple financial recording system that is very useful in calculating costs of production. You can also import data from farm accounting software into MacMan.
- Harvest yields.
- Post-harvest handling. This includes dehusking and sorting, resorting, transferring nuts between storage vessels and dispatching nuts to customers.
- Factory results.
- Monitoring for pests and diseases, leaf and soil analyses, and water quality.
- Weather information, such as rainfall, temperature and relative humidity.
- The timing of important growth cycle information such as flowering, leaf flushing, mature nut drop and premature nut fall.

Reports

One of the features of the MacMan farm recording software is the ability to produce a wide range of reports. There are currently more than 70 styles of reports in MacMan to suit the needs of macadamia growers. These include both tabular and graphic reports. The graphic reports include a number of highly visual trend, bar and pie charts that enable you to see and compare important information at a glance.

The reports can also be exported to a number of common file formats, including Adobe Acrobat Portable Document Format (.pdf), Microsoft Excel (.xls) and Rich Text Format (.rtf). This is particularly useful if you wish to send the reports by electronic mail.

Some of the reports in MacMan include:

- **Delivery report.** Many macadamia processors require a delivery report addressing key food safety and nut quality issues at the start of each session and to accompany each consignment. The data stored in MacMan is used to generate delivery reports that allow traceback to the orchard.
- **Cost of production report.** MacMan can calculate your costs of production for a particular farm, block or planting and for a particular time frame.
- **Nut-in-shell storage estimates report.** This report provides you with a current balance estimate of the nut-in-shell in each of your storage vessels and the date each of the storage vessels was last emptied.
- **Weather, pests and spray overlay chart.** This report provides you with a picture of what is happening in your orchard with regard to pest and disease management. It enables you to overlay your weather data (rainfall, temperature and relative humidity) with your pest monitoring results and your spray events.
- **Leaf and soil analysis monitoring charts.** This enables you to graph and compare results of different nutrients and locations. Further work is also planned to overlay this information with yield and quality results and fertiliser applications.
- **Production trend graphs.** These graphs enable you to compare harvest yields and factory results (for example, NIS, sound and unsound kernel) from different seasons and from different parts of your farm.

Best practice groups

The Australian Macadamia Society and the MacMan team are forming best practice groups with interested growers in all major macadamia-growing areas. The groups enable growers to compare their results from data recorded in MacMan. The growers can then analyse the results and identify where they can improve their productivity and efficiency.

Members of best practice groups have used data recorded in MacMan to identify where they could make improvements in their harvesting and post-harvest handling practices by comparing and analysing their yield and quality results and their costs of production in areas such as:

- Harvesting and postharvest handling practices;
- Fertiliser, pest, disease, soil surface and canopy management.

Training and support

Training and support in the use of MacMan is provided to Australian macadamia growers. Each Australian macadamia grower is entitled to attend

training sessions that are held regularly in all major Australian growing regions. A telephone and electronic mail support service is also provided free of charge to Australian growers.

MacMan-net discussion group

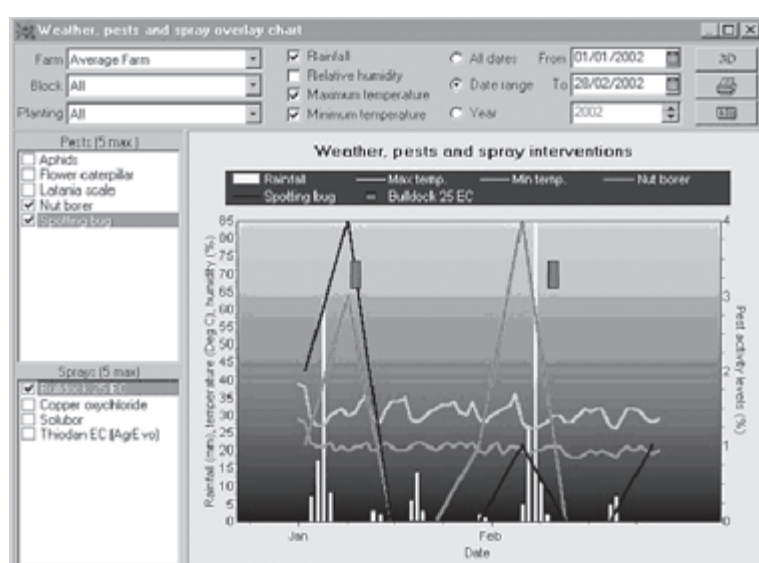
The MacMan-net discussion group is a forum where growers can share information about MacMan or macadamia farm management in general through electronic mail. Contact the MacMan team for information about subscribing to the group.

Farm diary

The MacMan diary is designed to enable users who prefer to use a paper based system rather than a computer to keep the same records as the MacMan software. The two systems are complementary to enable growers who do not use a computer for farm recording at this stage to switch easily from the diary to the software when they are ready. Many growers also prefer that their staff record information by hand and then have one person enter it into a computer on a regular basis.

Crop loss protocols

The crop loss protocols were developed to provide practical and reliable on-farm crop loss assessment procedures in order to explore management and profitability. Three protocols have been developed. Two examine 300 NIS and 300 nut-in-husk (NIH) respectively, and provide a picture of total crop losses. The third protocol examines 100 NIS from the reject pile and identifies the major causes of crop loss. Results can be reconciled in MacMan. The protocols are available as a spreadsheet or in print form from the Australian Macadamia Society.



An example of the weather, pests and spray overlay chart

Further information

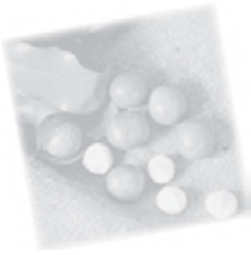
For further information about the MacMan farm recording system, contact the MacMan team:

E-mail: macman@dpi.qld.gov.au

Phone: (07) 5441 2211

Fax: (07) 5441 2235

MacMan website: www.dpi.qld.gov.au/macman



Understanding the macadamia tree

The aim of macadamia growing is to consistently produce a large crop of high quality kernels. To achieve this, it is essential to have a good basic knowledge of what governs nut production and quality.

Important features of the macadamia tree

The macadamia is an evergreen, medium to large tree, growing to a height of up to 15 m. It produces a number of vegetative flushes per year (see photo) with peaks in spring and late summer. In the main commercial species *Macadamia integrifolia*, the leaves are arranged in whorls of three (see photo). A whorl is a ring of leaves originating at the same point or node on the shoot. In the species *Macadamia tetraphylla*, the leaves are arranged in whorls of four. Hybrids between the two species can have combinations of three and four leaves per whorl. Leaves often have spiny toothed margins and short petioles (5 to 15 mm long). Three buds are arranged longitudinally in the axil of each leaf. Multiple branches and/or flower racemes may therefore be produced from each leaf whorl or node.



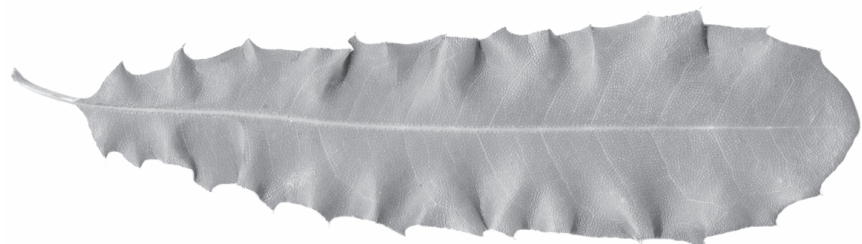
Vegetative flush

A mature tree may produce many thousands of flower racemes each year. The pendulous racemes, 10 to 15 cm long and bearing approximately 200 to 400 individual creamy to white flowers (or pink for *M. tetraphylla*), are borne on hardened wood in spring. Less than 5% of the flowers set nuts and many of these fall off in the first 5 to 6 weeks after fertilisation.

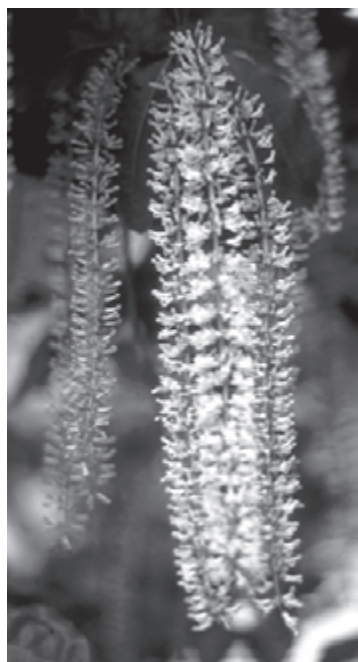
Nuts mature in 5 to 6 months, when most fall naturally. Depending on the variety, it may take several more months before all mature nuts drop. Botanically, there are two ovules or immature seeds formed in each nut, but only one generally develops to produce a typical round NIS.



Whorl



Typical leaf



Flower raceme



Nut (in husk)



See *Canopy management* on page 160 for more detail on principles of light distribution.

In some varieties however, both ovules develop in a small percentage of nuts to produce twin nuts. These are undesirable commercially as they are difficult to crack without damaging the kernel. Mature nuts usually, but not always, fall when the fibrous husk is still green. As the husk dries, it splits along a single suture line to release the nut, which consists of a hard, thick, stony, light tan shell enclosing the kernel. Darkening of the inside of the husk gives a good indication that the kernel is mature (more than 72% oil) and ready for harvesting.

Annual growth cycle

Macadamia trees have a cyclic, seasonal pattern of vegetative growth, flowering and nut production that is responsive to the environment. By monitoring this growth cycle in your orchard, and scheduling cultural operations at the appropriate stage of the cycle, the balance between vegetative growth and cropping can be maintained for optimum yield of sound kernel.

Vegetative growth

The growth and production of macadamia trees, like other tree crops, is directly proportional to interception of radiant energy from the sun. Leaves convert the radiant energy into carbohydrates that are used for growth and maintenance in the tree. Maximum light interception occurs with a completely closed canopy but operational efficiency in the orchard dictates the use of hedgerows with a 2 m wide alley for machinery access. For example, in an orchard with hedgerows and a 2 m wide alley, incident light interception is an acceptable 90% to 95%.

The carbohydrates produced by the leaves from radiant energy are either used for growth or accumulated in the tree. The seasonal pattern of carbohydrate storage consists of a general accumulation in autumn and winter and depletion in spring. This is because during nut development in spring, insufficient carbohydrate is produced by photosynthesis to meet the high demands of nut growth and oil accumulation, and the tree needs to draw on its reserves. At other times, excess carbohydrate is stored in leaves, stems and root tissue from where it can be mobilised to support other tree growth functions. Since developing nuts have the highest priority for carbohydrate, tree reserves have to be sufficient to meet this need otherwise nut yield and quality can be affected. Carbohydrate accumulation in autumn and early spring is important for the replenishment of reserves taken by the previous crop and to support the development of the new crop.

Macadamia leaves may live for many years but they are most productive (maximum photosynthesis) soon after they reach full size and harden. For trees to remain healthy, vigorous and productive, it is necessary to replenish this supply of young, actively growing leaves. Careful management of the health and vigour of the trees is therefore very important. Compare this with trees affected by the decline disorder. Here, trees have sparse foliage and when a flush

occurs, it lacks vigour and the leaves produced are often small and unhealthy. As a result, the tree's capacity to produce carbohydrate through photosynthesis is very limited, the root system is deprived of energy needed for healthy growth, and the above parts of the tree are, in turn, starved of water and nutrients. It is a slow and difficult process to reverse this downward spiral.

Research has shown that the timing of vegetative growth flushes has a profound effect on yield and quality of nuts. Maximum yields are obtained when trees flush in late winter/early spring (August/September in southeast Queensland). This maximises leaf photosynthetic capacity leading up to the period of oil accumulation, which is the period of high energy demand. This late winter/early spring flush then hardens in spring (October/November in southeast Queensland) and the trees are vegetatively dormant during oil accumulation. This timing of the flush is very important for two reasons:

- The active flush in late winter/early spring builds up a good supply of carbohydrate for the oil accumulation period to follow;
- The lack of vegetative growth during the oil accumulation period means that there is nothing to compete with oil accumulation in the nuts. This maximises nut yield and quality.

A smaller late summer/early autumn flush (March/April in southeast Queensland), when oil accumulation is largely complete, is a prerequisite for a good crop the following season.

Flushing is influenced more by temperature and rainfall (or irrigation) than by nutrition. Flushing appears to be inhibited by low temperatures in winter and by excessively high temperatures in summer. Mild water stress suppresses normal flushing. As soon as water is applied to trees under stress, flushing occurs. Consequently, in some situations, water management may be used to manipulate the timing of seasonal flushing. If this flushing can be manipulated into the desired flushing pattern above, higher yields may be possible.

Flowering

Potential yield is determined by the number of flowers produced, effective pollination and retention of pollinated nuts. Any event that interferes with these processes may limit yield. Floral buds initiate in autumn but remain dormant over winter. They recommence growth in late winter/early spring. In southeast Queensland, flowering usually commences in August, peaks in mid September and is complete by mid October. Exact timing depends on variety, location and climatic conditions. Flowering is earlier in north Queensland and later in northern New South Wales. Some varieties such as HV A4, HV A16 and HAES 741 have a short flowering cycle, while others such as HAES 246, HAES 783 and HAES 842 have a prolonged flowering cycle.

Nut production

Nuts set in early October (southeast Queensland) and reach maturity 5 to 6 months after nut set. Maximum fresh weight is achieved at about 18 weeks after nut set (fertilisation).

Premature nut drop occurs in three stages:

1. fall of unfertilised flowers;
2. rapid fall of the initial set of small immature nuts between 3 and 8 weeks after nut set;
3. fall of larger immature nuts from 10 weeks after nut set onwards. High temperatures, moisture stress and competition for resources exacerbate nut fall at this stage.

Kernels are usually mature 21 weeks after nut set (southeast Queensland) and 24 weeks after nut set (northern New South Wales). Nuts of some varieties commence dropping in mid February. The kernel is marketable (mature) when it floats in tap water (more than 72% oil). Maturity is hastened in warm climates and delayed in more temperate climates. Although the nuts of most varieties are mature at much the same time (by early March), some varieties do not drop mature nuts until late in the season. These varieties have a greater risk of pest and disease carryover.

Root growth

Little is known about root growth patterns in macadamia but a healthy, active root system is obviously essential to ensure water and nutrients do not limit healthy vegetative growth, and hence nut yield and quality. As root tips produce growth regulators, which help maintain a balance between shoot and root growth, a dense surface mat of feeder roots is desirable for healthy tree growth.



Growth cycle

A typical growth cycle for trees in southeast Queensland is shown in Figure 23. Seasonal conditions, particularly temperature and rainfall, influence the cycle. The pattern is earlier and accelerated in the tropical north and later and elongated in more temperate southern areas.

Soil removed to show the extensive mat of feeder roots under a healthy tree

Operation	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June
Crop cycle	Leaf growth	Peak flowering	Spring flush			Nut growth and oil accumulation			Summer flush		Flower initiation for next crop	
	Nut drop			Premature nut fall				Nut drop				

Figure 23. Growth cycle for trees in southeast Queensland

The timing of orchard operations in relation to the growth cycle is covered under *Implications for management* later in this section and in the *Crop production handy guide*.

Environmental effects on growth and flowering

Temperature

The optimum temperature range for growth and photosynthesis is 20 to 25°C. Low day temperatures suppress vegetative growth. Low night temperatures (12 to 14°C) promote flower initiation and delay raceme development, but ultimately result in more intense flowering. On the other hand, high night temperatures (above 20°C) inhibit flower initiation and raceme development. Warm nights during flowering, and warm days but mild nights during oil accumulation appear to provide the best potential for high yields.

The bark and new flush on young trees is particularly susceptible to frost damage but severe frosts can also kill mature trees. Late frosts in August/September are likely to damage flowers on older trees. Cool temperatures, combined with high humidity during flowering, provide ideal conditions for infection by blossom blight disease. Constant high temperatures (greater than 30 to 35°C) tend to inhibit vegetative growth and may induce leaf yellowing. This has the potential to reduce production, especially under conditions of low humidity and moisture stress.

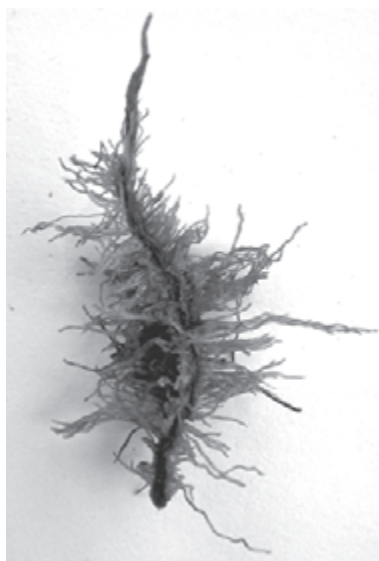
The number of heat units accumulated during oil accumulation account for the higher oil content of Australian macadamia kernels, compared to other major producing countries such as Hawaii.

Soil moisture

The macadamia has several features that help it to survive drought. These include:

- hardened leaves resistant to wilting;
- special proteoid roots that increase the surface area for absorption of water and nutrients from infertile soil.

However, vegetative growth is suppressed, and nut yield and quality reduced by moisture stress at sensitive stages such as flowering, nut development and particularly oil accumulation. Rain (or irrigation where available) in February/March, coinciding with a peak of vegetative flush, is associated with high yields in the following year.



Proteoid roots



Wind damage in a poorly protected site

Soil drainage

A deep, fertile, well-drained soil provides the best conditions for tree growth. Drainage is necessary to promote healthy root growth, prevent root rot diseases, and to allow access for machinery for cultural operations and harvesting. Trees can survive inundation for several days provided the water recedes quickly and the soil is well-drained.

Wind

As the macadamia is susceptible to wind damage, wind protection is recommended. Adequate protection can generally be achieved from strategically placed natural forest surrounds, but in highly exposed sites, planted windbreaks may be necessary. Once dense hedgerows are formed, trees tend to provide mutual protection and there is less need for windbreak protection. Very high, dense windbreak trees may be counter-productive, as these tend to create turbulent wind flow and eddies that potentially cause more damage than in unprotected trees. Ideal windbreaks allow laminar wind flow over the orchard surface. Early tree training, including training to a central leader and removal of branches with narrow crotch angles, may help minimise damage later on. When major limbs are lost during strong winds, the tree responds by filling the gap with new vegetative growth. This may upset the vegetative to reproductive balance and suppress yields until the balance is re-established.

Implications for management

Establishment and management of young trees

The influence of environmental conditions on growth has important implications for orchard establishment and management. Here are the important management issues:

- Select a warm, well-protected, relatively frost-free site. Macadamias are not suited to continuous high or low temperatures. Safe limits to the mean temperature range are 31^oC maximum to 9^oC minimum, with a maximum diurnal fluctuation of 10^oC. Short periods of higher temperatures can be tolerated without major effect.
- Use only deep (minimum 0.5 m), well-drained soils to avoid later problems with root growth and diseases. In small orchards where mechanical harvesting is not an issue, mounding along the row may be used to improve the drainage of marginal soils.

- Design and construct orchard drainage systems carefully to provide all-weather access to the orchard.
- Choose a well-protected slope or provide wind protection to avoid wind damage.
- Start with healthy nursery trees.
- Ensure the trees get the best start by carefully preparing the planting site, using good planting techniques, and providing optimum conditions for early tree growth.
- Planting can be carried out at any time but protection is necessary in frosty or hot, dry conditions.
- Spacing of trees within and between rows should allow for tree habit, tree vigour, soil type, climate, access for machinery, spray penetration into the canopy, and air flow to reduce humidity at flowering. With the tendency towards denser planting for quicker returns, it needs to be recognised that the trees soon become crowded, requiring pruning and possibly tree removal.

Management of bearing trees

Understanding the growth cycle and the way it is influenced by weather and other factors is important in maintaining the appropriate vegetative/reproductive balance for high nut yield and quality. Here are the important management issues.

Nutrition

- Use leaf and soil analyses, together with interpretation by an experienced consultant, to identify what fertilisers are required.
- Calculate rates of fertiliser carefully, as too much may promote excessive vigour, which may be detrimental to flowering, yield and quality. A good place to start is to calculate rates on the basis of replacing nutrients removed with the crop, adjusted for leaching and other loss factors.
- Apply fertiliser so that it is available at appropriate times in the cycle.

Nitrogen. Apply in frequent small doses throughout the year. If this is not convenient, apply the bulk in April to June, split into several applications, particularly where leaching is likely. Avoid applying all or nearly all of the nitrogen in summer. The aim is to have a high nitrogen level in late spring going into the major nut growth and oil accumulation period, and a high nitrogen level in autumn to promote a strong autumn flush to replenish the carbohydrate reserves for the next crop.

Phosphorus. As it moves slowly through the soil profile, apply at any time, preferably before rain.

Potassium. As it is needed for nut growth and kernel development, apply in late winter and spring.

Liming materials. Apply with caution. As macadamias are tolerant of acid soils, a soil pH of 5.0 to 5.5 (1:5 water test) is optimum. As soil pH approaches 7.0, other nutrient deficiencies are induced.



See *Fertiliser rates using the nutrient replacement concept* on page 117 for more detail.

Trace elements. As copper and zinc deficiencies commonly cause abnormal leaf and branch growth, apply before the major leaf flush in spring. As boron is important for pollination, flower development and early nut growth, apply during flowering and early nut growth.

Irrigation

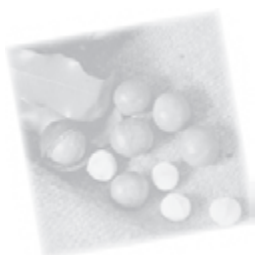
Pay particular attention to those parts of the cycle most sensitive to water stress. Critical times are nut set (fertilisation), nut development, and particularly oil accumulation. Use moisture monitoring systems such as tensiometers and capacitance probes to guide the frequency and amount of water applied.

Pruning

Once the young trees have been skirted and trained to a central leader, they require minimal pruning. Once tree growth begins to restrict access, mechanical pruning is necessary to maintain the 2 m wide alley between the rows and access under the trees for harvesting machinery. This is particularly important in high-density orchards. Commence pruning early and trim trees regularly to avoid removing a large portion of the canopy at any one time. This adversely affects production by unbalancing vegetative growth and cropping.

Other orchard operations

- **Pollination.** Research suggests that cross-pollination has beneficial effects on nut set, nut size, kernel recovery and yield. Consequently, interplant at least two varieties in alternating sub-blocks of between 4 and 10 rows. Also encourage the activity of native and commercial bees.
- **Orchard floor management.** A combination of canopy shading and the impact of mechanical harvesters often result in large areas of bare soil under the trees. This exposes the shallow root system to high temperatures, with a detrimental effect on yield. Two options for overcoming this are recommended. Either use a shade-tolerant, under-tree ground cover such as sweet smother grass or add organic matter such as composted nut husk under the trees. Note that organic matter, if not properly managed, can interfere with harvesting and increase the risk of germination and mould in fallen nuts. These problems can be reduced by adding organic matter after the last harvest with a view to it being sufficiently broken down by the time mature nut drop occurs in the following season.



Selecting varieties

Because macadamias are a long-term crop, selecting varieties is a key to long-term profitability. In addition to selecting varieties for the main characteristics of yield and quality, consideration must also be given to their ease of management and how well they satisfy processor and consumer needs. This section will help you make a sound decision on the best varieties to select for your orchard.

What makes a good variety?

A good variety has a range of desirable tree and nut/kernel characteristics. These are listed in Table 13.

Table 13. Desirable tree and nut/kernel characteristics

Desirable tree characteristics	Desirable nut and kernel characteristics
<ul style="list-style-type: none"> • Robust, compact and open growth habit • Resistant to wind damage • Tolerant of sub-optimal nutrition, soils and environments, but responsive to good management • No sticktight nuts • No pre-germination on the tree or ground • Tolerant of major pests and diseases • Short-harvest nut-drop season, largely complete (85 to 90%) by mid August, before flowering for the next crop begins • Begin bearing by the third or fourth year from planting out • Consistently high yields of 2 t/ha of sound kernel (equivalent to 5t/ha NIS at 40% sound kernel recovery) from 10 years onwards (This is achievable and higher than the current industry average, but will be dependent on good management) 	<ul style="list-style-type: none"> • Sensory quality must be acceptable to processors, marketers and consumers • Uniform in colour and free from discolouration • Even colour after roasting • Regular, round kernels, weighing 2 to 3 g • Regular, round NIS • No NIS less than 18 mm in diameter • NIS remains in husk after it falls from the tree • Husk separates readily from NIS in dehusker • No husk adhering to the shell • High and stable first grade kernel (over 96%) • Sound kernel recovery in excess of 36% • High % whole kernel • Consistent kernel quality with a low percentage of appearance defects

A process for selecting varieties

Variety performance can vary significantly depending on environment, soils and management and thus it is difficult to accurately predict how a variety will perform in a new orchard.

The main feature used in selecting varieties is yield performance in properly-managed variety trials in a region similar to that of your own orchard. This data is shown in the tables under *Variety performance by region* at the end of this section. High performing varieties are normally identified as those with a high and consistent yield of sound kernel from mature trees (10 years old), assessed over at least three seasons.



See *Choose varieties and tree spacing* on page 23 for details of a process for selecting varieties. Refer to this in conjunction with the notes here.

However, don't rely on this alone. Other features which need to be considered are:

1. A substantially better kernel recovery, first grade kernel and % whole kernel than current commercial variety standards (36%, 96% and 50% respectively).
2. Freedom from major undesirable tree and nut characteristics such as sticktight nuts, pre-germination and processing problems and very late nut drop patterns that may favour pest and disease carryover.

Then combine this information with other sources of information such as local knowledge from other growers, consultants, processors and nurseries. A note of caution however, rely more on actual yield and quality data and experience rather than unsubstantiated perceptions or opinions.

Some additional considerations

- Production can be increased by planting at high density a smaller-tree variety with a high yield of sound kernel per square metre of canopy area (area projected horizontally, within the drip-zone). This strategy should be considered if you are contemplating high-density systems.
- Sound kernel yield per square metre of canopy area may be used as a rough indicator of long term yield per hectare. However, it is not appropriate to extrapolate yield per tree to yield per hectare directly, as many complex assumptions have to be made.
- Many of the new varieties have very late drop patterns that are undesirable from a pest and disease management perspective. Early drop patterns help break the pest or disease cycle and make their control easier. If you are in an area susceptible to serious pest and disease problems, it is desirable to choose varieties that drop the crop before the next season's flowering.
- In wet areas, mid-season varieties that drop after the wetter part of the year, but before next season's flowering, may be desirable.
- Think ahead to anticipate variety attributes that may be potentially valuable in the future. For example, varieties with a high percentage of whole kernels may attract an industry premium in the future. Consumer preferences will influence future preferred varieties. Because processors and purchasers have to consider issues such as roasting quality, taste, flavour and appearance defects in setting their prices, it is important to seek their opinions on what varieties they see as unacceptable or likely to incur a price penalty in the future.

NOTE

The tables in *Variety performance by region* on pages 100 to 102 show sound kernel yield per square metre of canopy area.

Characteristics of the main varieties

Legend to abbreviations in variety tables:

- KR – kernel recovery
- G1K – first grade kernel (floated in tap water)
- HV A – Hidden Valley A varieties
- HAES – Hawaii Agricultural Experiment Station varieties

IMPORTANT

The industry comments listed for each variety are a compilation of comments from a number of key growers and consultants from a range of macadamia growing districts. Some are based on limited observation and experience with that variety. As a result, some comments may be contradictory. Please accept the comments as opinions only and seek additional local expertise.

HV A₄

Industry status	Widely planted in the 1990s in Queensland and NSW
Yield	Very early bearing; best kernel yields in NSW
Quality	Nuts 6.4 g, thin shell, shiny golden brown colour; kernels 2.8 to 3.3 g, larger in NSW; 42 to 47% KR; greater than 97% G1K; approximately 44% wholes
Sensory quality	Texture and flavour acceptable but below average (lowest rating of the new varieties), relatively bland flavour, attractive cream kernels
Flowering pattern	Very heavy, short, late flowering
Nut drop pattern	Mid-season (May-August)
Defects	Dehuskers may need to be adjusted to avoid damage to the large nuts
Husk spot susceptibility	Only slightly susceptible
Tree features	Medium size, spreading to rounded, open canopy; can be planted closer giving potentially higher early yields per hectare; susceptible to wind damage in exposed sites; requires careful attention to nutrition management
Industry comments	Very precocious with large nuts of high kernel recovery; often produces out-of-season flowering; young trees prone to trunk canker in NSW; can decline at 8 to 9 years; performs better in southern areas and away from the coast (better than A16); needs special nutrition and high standard of management; some concerns over flavour and roasting properties; large nut and thin shell; requires dehusker adjustment in some cases; characteristic raised crest may not be pre-germination; questions over the raw flavour but acceptable roasted and salted; some processors prefer that HV A series varieties are kept separate from HAES Hawaiian varieties

HV A₁₆

Industry status	Widely planted in the 1990s in Queensland and NSW; still being planted
Yield	Early bearing; best kernel yield in Queensland
Quality	Nuts 6.3 g, thin shelled, oval; kernels 2.4 to 2.9 g, larger in NSW, uniform and attractive; 39 to 42% KR; greater than 97% G1K; approximately 44 to 51% wholes
Sensory quality	Texture and colour good (above average), overall acceptability and flavour 'acceptable', slightly bland
Flowering pattern	Moderately intense, condensed, late flowering
Nut drop pattern	Very late (May to November)
Defects	Late dropping (nuts hang on trees long after they are mature); prone to sticktight where trees are stressed; dehuskers may need adjustment to avoid damaging nuts
Husk spot susceptibility	Moderate to highly susceptible, exacerbated by the late nut drop pattern
Tree features	Small, moderate to dense canopy, upright, with willowy branches; can be planted closer, giving potentially higher early yields per hectare
Industry comments	Hardy; suits high-density planting; very late nut fall a major disadvantage to some growers; nut drop exacerbates susceptibility to husk spot; germination may be a problem late in season north of Gympie; consider removing branches to improve air flow and light penetration in NSW; in future, may need to be harvested separately; some discolouration after roasting; early trials indicate that ethephon can be used successfully to drop nuts

HV A29

Industry status	Released to industry by Hidden Valley Plantations in 1991; relatively new variety
Yield	Early bearing
Quality	Nuts 6.2 g, uniform; kernels 3.1 g; 38% KR; 98% G1K; approximately 32% wholes
Sensory quality	Not assessed
Flowering pattern	Short, mid-season flowering
Nut drop pattern	Mid-season (April to July)
Defects	Not yet properly assessed
Husk spot susceptibility	Susceptible
Tree features	Large size, very upright tree; very vigorous; susceptible to wind damage in exposed sites; very open canopy means easier spray penetration
Industry comments	Early observations suggest: looks very good in southern production areas; may be an alternate bearer; good cropper; subject to discolouration, immaturity, some germination; very large kernel

HV A38

Industry status	Released to industry by Hidden Valley Plantations in 1991; relatively new variety
Yield	Early bearing
Quality	Nuts approximately 6.7 g, uniform; kernels approximately 2.7 g, slightly flattened, cream; 37.5% KR; 98% G1K; approximately 41% wholes
Sensory quality	Not assessed
Flowering pattern	Short, mid-season flowering
Nut drop pattern	Mid-season (April to August)
Defects	Kernel discolouration, depending on season
Husk spot susceptibility	Susceptible
Tree features	Medium size, very upright tree; very vigorous; needs early tree training and pruning to size; susceptible to wind damage in exposed sites; very open canopy means easier spray penetration
Industry comments	Should be treated with some caution; very susceptible to stress and discolouration including on the suture ring; high percentage of immaturity and discolouration; variable roasting; kernel quality doubtful for various reasons; suitable variety for close planting; some years performs inconsistently; most variable variety; susceptible to husk spot; high yield could justify planting; early trials indicate ethephon can be used successfully to drop nuts

HV A203

Industry status	Not yet widely planted
Yield	Early bearing
Quality	Nuts 5.6 g, variable kernel recovery, sometimes low, oval; kernels 2.1 g, uniform and attractive; 33 to 34% KR; 89 to 97%G1K; approximately 43% wholes
Sensory quality	Not assessed
Flowering pattern	Moderately intense, condensed, late flowering
Nut drop pattern	Early
Defects	Not yet properly assessed
Husk spot susceptibility	Not yet assessed
Tree features	Small to medium, semi-compact to open, rounded tree canopy
Industry comments	None available at this stage

HV A268

Industry status	New variety, not yet widely planted
Yield	Early bearing
Quality	Large nuts 8.2 g, uniform; kernels 3.4 g; 37 to 38% KR; 89 to 96% G1K; approximately 36% wholes
Sensory quality	Not yet assessed
Flowering pattern	Short, mid-season flowering
Nut drop pattern	Mid-season (April to July)
Defects	Not yet properly assessed
Husk spot susceptibility	Not yet assessed but appears susceptible
Tree features	Rounded, spreading, semi-compact to slightly open tree canopy
Industry comments	Very large kernel; well shaped tree

HAES 246

Industry status	Widely planted in the 1960s and 1970s; still some current planting, particularly in NSW and southeast Queensland
Yield	Reliable, but not early bearing; best yields in NSW and southeast Queensland
Quality	Nuts 6.8 g, moderate flecking, with open micropyle, kernels 2.0 to 2.7 g, larger in NSW; 31% to 37% KR; less than 96% G1K; approximately 45% wholes
Sensory quality	Highly rated for flavour, texture and overall acceptability, colour slightly variable between sites
Flowering pattern	Extended, heavy flowering
Nut drop pattern	Mid-season (April to August)
Defects	Pre-germination (on the tree); basal kernel discolouration; open micropyle
Husk spot susceptibility	Highly susceptible
Tree features	Medium to large spreading/rounded tree, moderately dense canopy, suitable only for wider tree spacings; susceptible to wind damage; tree produces much leaf litter causing potential problems with harvesting
Industry comments	Heavy consistent cropper; described as a ‘cash cow’ for many farms; the basis of the early Australian industry; very average at Hidden Valley (Queensland) – not as good as in NSW; lower roasting quality; can leave on ground for longer periods than other varieties (less likely to germinate under wet conditions); heavy leaf fall can be a problem at harvest; susceptible to wind damage; good but variable yields; some concern about shelf life; appears to have greater than 36% KR closer to the coast.

HAES 344

Industry status	Most common variety in Australia; widely planted in 1980s/early 1990s; no longer being widely planted
Yield	Early bearing; best yield in central and southeast Queensland
Quality	Nuts 6.9 g, round, dull shell with moderate flecking; kernels 2.2 g, larger in NSW; 32 to 35% KR; approximately 97.2% G1K, variable; approximately 35 to 46% wholes
Sensory quality	Average flavour and overall acceptability; texture acceptable but less crunchy than other varieties; kernels tends to be darker (beige light brown and two-tone) than other varieties
Flowering pattern	Mid-season flowering, medium in length; light flowering some years
Nut drop pattern	Early-season nut drop (April to July); later in NSW (May to August/September)
Defects	Lowest kernel recovery of recommended varieties; prone to nutborer attack
Husk spot susceptibility	Moderately tolerant
Tree features	Medium-large, upright, dense, conical tree; dense foliage can result in poor spray penetration
Industry comments	Consistent performer in Qld; precocious; early nut fall; low kernel recovery a disadvantage; susceptible to macadamia nutborer – control difficult because of tight bunches; yield tends to be erratic in some environments; may need higher standard of management; doesn’t flower under (some) stress conditions; good roaster; favourable sensory feedback; susceptible to husk spot in a hot climate; more susceptible to excessive heat and abnormal vertical growth disorder (AVG) than other varieties

HAES 66o

Industry status	Widely planted in the 1970s and 1980s; current plantings rare
Yield	Early bearing; best yield in NSW and southeast Queensland
Quality	Nuts 5.4 g, pronounced flecking; kernels 2 g, larger in NSW; 35 to 39% KR, lower in north Queensland; 96 to 98% G1K, lower in north Queensland; approximately 36 to 41% wholes
Sensory quality	Good flavour, soft texture, mostly cream and beige in colour
Flowering pattern	Mid-late, variable flowering
Nut drop pattern	Very early-season nut drop (April to June)
Defects	Germinates on tree in wet conditions, large number of undersized, reject nuts
Husk spot susceptibility	Slightly susceptible
Tree features	Medium-large, upright, moderate to dense canopy, turkey's neck; more open than 344
Industry comments	Good variety in the past – under-rated; early nut fall; lot of variation in nut size particularly when stressed; small nuts; nuts dehusk on ground making finger-wheel harvesting difficult; tendency to germinate; prone to brown centering

HAES 705

Industry status	Relatively new variety; very few plantings to date
Yield	Medium to high
Quality	Nuts 7.0 to 7.7 g; round but slightly irregular; light brown with irregular, light tan blotches; kernels 2.3 to 2.8 g; good kernel characteristics; 34.8 to 35.5% KR; 96.4 to 99.0% G1K; approximately 40 to 52% wholes
Sensory quality	Acceptable flavour, texture and colour
Flowering pattern	Late to very late flowering
Nut drop pattern	Very late
Defects	Late nut drop
Husk spot susceptibility	Not yet assessed
Tree features	Small to medium, open, upright tree
Industry comments	None available at this stage

HAES 741

Industry status	Widely planted, particularly in Queensland from the late 1980's to the present
Yield	Not early bearing but in some seasons, young trees crop well; performs better as trees mature; best yield is in central and southeast Queensland
Quality	Nuts 6.2 g, variable size, some small, round and smooth; kernels 2.3 g, full, slightly dull, larger in NSW; approximately 36 to 38% KR, lower in north Qld; greater than 97% G1K; approximately 36% wholes
Sensory quality	Above average overall acceptability and flavour, slightly below average texture, attractive cream to beige kernels
Flowering pattern	Condensed, late flowering, shy flowering in some areas in some seasons (dry autumn/winter)
Nut drop pattern	Early (April to June)
Defects	Some basal discolouration of kernels
Husk spot susceptibility	Very susceptible, impact reduced by early nut drop
Tree features	Medium-large, upright, moderate to open, turkey's neck particularly when young, becoming more dense with age, performed well at northern sites (heat tolerant)
Industry comments	Reliable; hardy; wind-resistant; the most popular of the old varieties; does not crop well under 7 to 8 years; variable cropping in NSW with low production in northern NSW; performs well in Queensland except some problems with nut setting in Bundaberg; early nut fall a major advantage with many growers; appearance is ordinary; some basal discolouration

HAES 781

Industry status	Relatively new variety; very few plantings to date
Yield	Not precocious; medium to high yields; may be variable across sites; lower in hot environments
Quality	Nuts 6.6 to 8.2 g, round, slightly flecked with distinct groove (not the suture); can be variable mainly on flat at hilum end of shell; kernels 2.6 to 3.0 g, good kernel characteristics; 35 to 39% KR, 91.5 to 98.8% G1K; approximately 41 to 51% wholes
Sensory quality	Excellent texture, good flavour and good overall quality
Flowering pattern	Light, late flowering
Nut drop pattern	Long, late nut drop; prone to sticktight
Defects	Prone to open micropyle
Husk spot	Susceptibility not yet assessed
Tree features	Large, vigorous, open, rounded, moderately upright tree; moderately dense canopy; has low heat tolerance with chlorotic leaves produced under hot conditions but this does not seem to adversely affect yield, at least in some environments
Industry comments	Quite a good yield performer but the tendency to sticktight might be a problem

HAES 783

Industry status	Relatively new variety; very few plantings to date
Yield	Not early bearing; high yields in Queensland
Quality	Nuts 6.4 g, even size, round, some white flecks; kernels 2.4 g, larger in NSW; good kernel characteristics; 40% KR, lower in north Queensland; 97 to 98% G1K, slightly lower in north Queensland; approximately 50 to 54% wholes
Sensory quality	Good texture, flavour and overall acceptability, colour variable (cream, beige, light brown and two-tone)
Flowering pattern	Extended flowering, more intense late in the season
Nut drop pattern	Extended nut drop, very late (June to September)
Defects	Late nut drop, especially in southern districts
Husk spot susceptibility	Tolerant
Tree features	Medium to large, moderately dense, spreading tree
Industry comments	Good cropper but with very long, late nut fall with some sticktight (a disadvantage); performed well in NSW

HAES 814

Industry status	Relatively new variety; minor plantings from mid-1990s following performance in regional variety trials
Yield	Early bearing; high yields in NSW and central Queensland
Quality	Nuts 4.4 g, round; small kernels 1.8 g, larger in NSW; 37 to 39% KR, lower in north Queensland; 63 to 87% G1K, variable, higher in north Queensland; approximately 34 to 37% wholes
Sensory quality	Acceptable but generally low rating, flavour similar to 344, but slightly higher incidence of off-type flavours, kernel colour good, cream to off-white
Flowering pattern	Short, late
Nut drop pattern	Mid to late (May to August)
Defects	Low first grade and whole kernel (with poor nutrition); prone to sticktight in stressed trees
Husk spot susceptibility	Slightly susceptible
Tree features	Small, upright, open canopy, large leaves
Industry comments	High to very high level of immaturity (up to 40% both in Queensland and NSW); low first grade kernel (may be acceptable in NSW); very precocious; small tree suited for high density planting; prone to leaf mottling; may require high standard of nutrition; consistent size; may dehusk in the tree; small nuts may not be picked up by harvester; stresses readily; small half kernels have reduced value in the market

HAES 816

Industry status	Relatively new variety, very few plantings to date, mainly in NSW
Yield	Not early bearing; high yields in NSW and central Queensland
Quality	Nuts 6.9 g, round, pale in colour; kernels approximately 2.9 g but 3.4 g at Clunes, round, uniform kernel; 42 to 45% KR, lower in north Queensland; 96 to 98% G1K, lower in north Queensland; approximately 53 to 58% wholes
Sensory quality	Highest rating for texture, flavour and overall acceptability, kernel colour slightly variable
Flowering pattern	Light, late
Nut drop pattern	Early to mid-season (March to June)
Defects	None apparent
Husk spot susceptibility	Slightly susceptible
Tree features	Medium to large, moderately upright, moderately dense, pale green leaves with no spines
Industry comments	Variable yield performance in different sites (caution – investigate performance locally): performs well at Childers; roasting reasonable; slightly susceptible to insect damage (twig-girdler and leafminer); may be slightly susceptible to canker (but less than A4); early to mid-season nut fall may be an advantage but up to 10% sticktight has been observed in NSW; may require careful nutrition management

HAES 835

Industry status	Relatively new variety; very few plantings to date
Yield	Medium to high
Quality	Nuts 5.7 to 6.3 g; round but slightly irregular; brown with irregular, light tan blotches, mainly on hilum half of shell; kernels 2.0 to 2.4 g; good kernel characteristics; 34.9 to 35.9% KR; 98.4 to 99.9% G1K; approximately 65 to 69% wholes
Sensory quality	Not yet assessed
Flowering pattern	Early to mid season
Nut drop pattern	Early
Defects	Variable micropyle size, but this may not be a big problem
Husk spot susceptibility	Not yet assessed
Tree features	Medium to large, moderately dense, semi-upright, spreading tree
Industry comments	An under-rated variety with good overall performance and no major problems; worthy of further assessment

HAES 842

Industry status	Relatively new variety; increased plantings from mid-1990s following good performance in regional variety trials
Yield	Early bearing; high kernel yields in Queensland and NSW; performs particularly well in central Queensland; appears to be more tolerant of high temperatures than most other commercial varieties
Quality	Nuts 5.8 g, even size, slightly flat and oval; kernels 2.1 to 2.5 g, larger in NSW; 36 to 41% KR; 94 to 98% G1K, variable; approximately 50% wholes
Sensory quality	Acceptable texture and flavour and overall acceptability, colour slightly variable but acceptable (cream, beige, light brown and two-tone)
Flowering pattern	Heavy flowering over a long period
Nut drop pattern	Extended, mid-to late-season (April to September)
Defects	Up to 10% hang late, may pre-germinate
Husk spot susceptibility	Slightly susceptible
Tree features	Medium-large, moderately upright tree; canopy open when young becoming more dense as the tree matures
Industry comments	Hardy; fairly precocious; good yields but not as good as 816 and 849 in NSW; seems suited to warmer areas; long, late nut fall a disadvantage; slight pre-germination; darker kernel colour (growers penalised); not enough planted in NSW to properly define

HAES 849

Industry status	Relatively new variety; increased plantings from mid-1990s, particularly in NSW, following good performance in regional variety trials
Yield	Not early bearing; high yields in Queensland and NSW
Quality	Even nuts 6.4 g; large; uniform kernel, 2.8 g, larger in NSW; 40 to 46% KR; approximately 95% G1K, lower in north Queensland; approximately 56 to 60% wholes
Sensory quality	Excellent texture, flavour and overall acceptability, kernels beige to light brown with a tendency to two-tone
Flowering pattern	Light, condensed, late flowering
Nut drop pattern	Extended, mid to late-season (May to October)
Defects	Up to 10% hang late, may pre-germinate
Husk spot susceptibility	Very susceptible
Tree features	Medium to large, spreading; moderately dense canopy, moderately vigorous tree
Industry comments	Good yields enhanced by high kernel recovery; late nut fall but marginally earlier than 842 and Daddow; pre-germination is a major defect; darker colour; high levels rejected due to discolouration; susceptible to twig-girdler and husk spot

Daddow

Industry status	Been around for a long time but significant plantings only since mid-1990s
Yield	Early bearing, high yields, particularly in Queensland
Quality	Nuts 6.4 g, even, tea colour, heavily striped and a very prominent suture; kernels 2.4 g, good kernel characteristics; 37 to 40% KR, lower in north Queensland; 92 to 99% G1K, variable; approximately 42% wholes
Sensory quality	Good overall acceptability, good kernel colour, acceptable but slightly below average texture and flavour
Flowering pattern	Moderately heavy, mid to late-flowering
Nut drop pattern	Long, mid to late season nut drop (May to September)
Defects	Very dense foliage; long, late nut drop; slightly prone to nutborer
Husk spot susceptibility	Very susceptible
Tree features	Medium size, slightly spreading, very dense canopy; prone to mottling of older leaves
Industry comments	No major defects; very hardy and reliable yield performance; suited to marginal conditions; late nut fall but acceptable; prone to leaf mottling; may have higher nutritional requirements; not stress-tolerant in poor soils; like most late-dropping varieties, a considerable level of germination has been observed

Variety performance by region

The data listed in Tables 14 to 19 is derived from regional variety trials, which have been conducted over more than 10 years at six locations in Queensland and northern NSW. The tables list the best yielding varieties at each of the six locations, together with standard kernel recovery and first grade kernel figures. The data tables are as follows:

- Table 14: Central NSW (Warrell Creek/Nambucca site)
- Table 15: Northern NSW (Clunes site)
- Table 16: Southeast Queensland – southern (Forest Glen site)
- Table 17: Southeast Queensland – northern (Wolvi site)
- Table 18: Central Queensland (Rockhampton site)
- Table 19: North Queensland (Walkamin site)

Further information on the identification characteristics of the varieties (which includes some useful additional information for selection) is contained in the book *Macadamia Variety Identifier* published by the Department of Primary Industries and Fisheries.

Note that growers may elect to choose varieties outside those listed where other desirable characteristics suit their farming system. For example, varieties with high yield of first grade kernel per square metre of canopy area for high-density plantings; varieties with late nut drop to spread workloads; varieties with early nut drop to assist in husk spot management by breaking the disease cycle. Similarly, growers may elect to reject some of the varieties listed because of concerns about defects and other problems listed earlier under the variety profiles.

Table 14. Best yielding varieties for central New South Wales, based on variety trial performance at Warrell Creek

Variety	A29	246	A4	A38	A268	A203	344
Yield NIS ¹ (kg/tree)	25.0	22.0	15.8	19.0	17.7	18.5	17.4
Yield sound kernel ¹ (kg/tree)	10.0	8.5	7.5	7.4	6.8	6.7	6.5
Cumulative yield (years 4-10) sound kernel (kg/tree)	42.7	32.1	33.0	30.3	31.7	29.1	25.9
Yield sound kernel ¹ (kg/m ² canopy)	0.45	0.42	0.47	0.41	0.43	0.44	0.38
Average canopy dia. (m) at year 10	5.3	5.1	4.5	4.6	4.5	4.4	4.7
Kernel recovery ² (%)	38.4	36.0	46.1	37.3	38.3	34.3 ³	34.7
First grade kernel ² (%)	92.3	88.0	98.7	98.1	88.8	89.2	93.3

¹Yield of mature trees (average of years 8 to 10) @ 10% moisture

²Data from years 4 to 10

³A203 may be worth considering in other areas where it is reported to have much higher KR

Table 15. Best yielding varieties for northern New South Wales, based on variety trial performance at Clunes

Variety	246	842	344	849	816	814*	783	781	Daddow	705	A16 ³
Yield NIS ¹ (kg/tree)	25.1	20.9	24.9	18.2 ⁴	17.8	20.4	19.4	20.2	22.0	21.2	10.2
Yield sound kernel ¹ (kg/tree)	8.6	8.3	8.1	7.8	7.7	7.6	7.6	7.5	7.5	7.5	4.0
Cumulative yield (years 4-14) sound kernel (kg/tree)	59.9	53.3	52.6	60.9	56.5	48.1	50.2	59.0	52.3	51.0	35.0
Yield sound kernel ¹ (kg/m ² canopy)	0.29	0.40	0.34	0.27	0.40	0.58	0.34	0.26	0.34	0.42	0.29
Average canopy diameter (m) at year 14	8.1	7.0	7.5	6.7	6.2	5.8	6.9	8.2	7.7	6.7	5.7
Kernel recovery ² (%)	37.1	41.1	34.6	46.2	45.1	38.3	40.7	39.5	37.7	37.7	41.7
First grade kernel ² (%)	95.1	96.8	91.7	95.1	96.2	87.3	96.6	94.1	91.8	93.2	95.6

¹Yield of mature trees (average of years 12 to 14) @ 10% moisture

²Data from years 9 to 14

³Local experience suggests A16 performs very well at Clunes. Should be considered despite results of this trial

⁴Suggestion that production may have been reduced by collection of budwood from 849 at this site

*Although good yielding, not recommended because of quality defects

Table 16. Best yielding varieties for southeast Queensland– southern, based on variety trial performance at Forest Glen

Variety	A29	A38	A268	A16	A203	344
Yield NIS ¹ (kg/tree)	19.8	18.5	18.1	14.5	15.3	15.0
Yield sound kernel ¹ (kg/tree)	7.3	6.9	6.7	6.1	5.0	4.9
Cumulative yield (years 4-10) sound kernel (kg/tree)	40.0	39.2	36.6	35.6	30.4	26.6
Yield sound kernel ¹ (kg/m ² canopy)	0.36	0.37	0.39	0.46	0.36	0.31
Average canopy diameter (m) at year 10	5.1	4.9	4.7	4.1	4.2	4.5
Kernel recovery ² (%)	36.9	37.4	36.9	37.4	32.8 ³	32.5
First grade kernel ² (%)	97.1	98.3	96.3	97.6	95.8	95.9
Whole kernels ² (%)	30	56	36	46	43	44

¹Yield of mature trees (average of years 8 to 10) @ 10% moisture

² Data from years 4 to 10

³ A203 may be worth considering in other areas where it is reported to have much higher KR

Table 17. Best yielding varieties for southeast Queensland–northern, based on variety trial performance at Wolvi

Variety	246	344	781	835	842	783	849	A16
Yield NIS ¹ (kg/tree)	24.2	24.4	21.6	20.2	18.4	17.2	15.5	15.5
Yield sound kernel ¹ (kg/tree)	8.4	7.8	7.7	7.3	6.9	6.9	6.5	6.2
Cumulative yield (years 4-14) sound kernel (kg/tree)	47.1	46.6	45.5	45.0	41.7	39.5	45.3	39.0
Yield sound kernel ¹ (kg/m ² canopy)	0.33	0.28	0.17	0.12	0.31	0.38	0.33	0.31
Average canopy diameter (m) at year 14	5.7	6.1	6.9	6.0	5.7	5.0	5.3	4.9
Kernel recovery ² (%)	35.0	32.4	37.0	37.1	36.9	39.1	43.8	40.4
First grade kernel ² (%)	92.3	96.8	97.1	99.0	98.7	98.1	95.7	97.4
Whole kernels ² (%)	44.4	34.9	46.5	66.7	48.3	54.4	55.9	50.3

¹Yield of mature trees (average of years 12 to 14) @ 10% moisture

² Data from years 9 to 14

Table 18. Best yielding varieties for central Queensland, based on variety trial performance at Rockhampton

Variety	741	816	344	842	705	Daddow
Yield NIS ¹ (kg/tree)	21.6	14.3	18.2	14.7	12.5	11.2
Yield sound kernel ¹ (kg/tree)	8.0	6.6	6.1	5.3	4.8	4.6
Cumulative yield (years 4-14) sound kernel (kg/tree)	55.0	43.6	45.2	52.9	36.8	41.2
Yield sound kernel ¹ (kg/m ² canopy)	0.24	0.16	0.23	0.23	0.22	0.12
Average canopy diameter (m) at year 14	7.0	7.6	6.9	7.0	6.1	6.5
Kernel recovery ² (%)	37.6	45.9	33.4	38.1	38.0	40.2
First grade kernel ² (%)	98.6	97.8	97.6	94.1	97.2	99.2
Whole kernels ² (%)	37.7	57.7	44.8	51.1	43.7	43.4

¹Yield of mature trees (average of years 12 to 14) @ 10% moisture

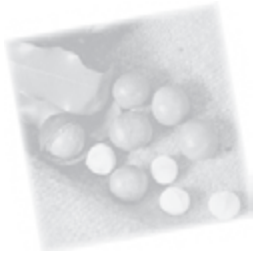
² Data from years 9 to 14

Table 19. Best yielding varieties for north Queensland (Atherton Tableland), based on variety trial performance at Walkamin

Variety	Daddow	705	A16	783	741	660
Yield NIS ¹ (kg/tree)	24.8	25.6	19.0	21.2	19.5	19.2
Yield sound kernel ¹ (kg/tree)	8.3	7.7	7.5	6.9	6.2	6.1
Cumulative yield (years 4-14) sound kernel (kg/tree)	60.7	53.6	59.0	54.9	43.4	37.9
First grade kernel ¹ (kg/m ² canopy)	0.25	0.27	0.29	0.20	0.23	0.23
Average canopy diameter (m) at year 14	7.6	7.9	6.5	7.3	7.1	7.6
Kernel recovery ² (%)	34.7	32.1	39.1	35.4	33.4	33.0
First grade kernel ² (%)	98.7	95.3	99.3	93.8	94.5	93.9
Whole kernels ² (%)	42.1	37.7	51.3	50.1	35.6	38.2

¹Yield of mature trees (average years 12 to 14) @ 10% moisture

² Data from years 9 to 14



Nutrition management

Applying fertiliser without knowing whether it is needed or not may lead to excessively low or high levels of some nutrients and nutrient imbalance. Blanket fertiliser applications also fail to recognise that different varieties, different blocks of trees and different soil types have different fertiliser needs. Consequently, they tend to provide too much nutrient for some and too little for others.

The modern and responsible approach to fertilising relies on regular monitoring of soil and plant nutrient levels so that nutrients are kept at optimum (or acceptable) levels. This approach also helps avoid excessive fertiliser use, which apart from deleterious effects on tree growth and production, can have serious consequences for the environment through leaching and contamination of water systems. This is particularly important as the build-up of nitrates and phosphates in watercourses arising from agricultural activities is coming under more scrutiny.

Three different monitoring tools are used:

- **Pre-plant soil analysis.** This ensures that the soil is suitable for the crop, and should consist of both a chemical analysis and a physical appraisal of the soil. Chemical analysis is used to ensure that nutrients are within the adequate range before planting. It is particularly important to allow for the adjustment of insoluble nutrients such as calcium and those with limited mobility such as phosphorus. These are difficult to adjust once the trees are in the ground. In phosphorus-fixing soils, it is desirable to concentrate phosphorus fertiliser in the planting hole to reduce the rate of fixation. Physical properties of the soil have a profound effect on root development, soil aeration and on infiltration of water. Corrective measures such as deep ripping to break up hardpans and applying gypsum to improve soil structure should be carried out before planting.
- **Annual leaf analysis.** This allows the fertiliser program to be fine-tuned each year to keep all nutrients within the optimum range. It allows variables such as the season, the crop load and the condition of the tree to be taken into account.
- **Regular (annual/biennial) soil analysis.** This monitors soil pH, major nutrients, and the important balance between pH, calcium, magnesium and potassium to ensure they are maintained within optimum ranges.



See *Consultants and contract services* on page 187 for details.

Because of the complexity of soil chemistry and nutrition, it is highly recommended that expert soil nutrition consultants be used to help guide fertiliser management in the orchard.

Understanding soil fertility

Good soil health is a balance of physical, chemical and biological activity. A good balance optimises the soil’s ability to store and cycle water and nutrients, decompose organic matter, inactivate toxic compounds, suppress pathogens, enhance the efficacy of beneficial microbes (particularly at the root surface or rhizosphere) and protect water quality. Good soil health is fundamental to productive and profitable growing as well as playing an important role in the long-term sustainability of the orchard and the demonstration of good environmental stewardship.

Physical soil health

Physical properties of the soil such as soil structure, texture, bulk density, porosity, and plasticity, have a profound effect on soil health and thus on the health of the tree. These properties influence the water infiltration rate, and consequently the effective utilisation of rainfall and irrigation. They also influence susceptibility to soil erosion, soil aeration, development of hardpan layers and tendency to crusting. Well-aerated soil with low bulk density has low resistance to root growth, and encourages healthy root systems.

Chemical soil health

Soils must have adequate levels of essential nutrients, some of which should be within acceptable ratios to support optimum plant growth. More detail on the nutrients is contained later in this section in *Understanding the important nutrients*.

Soil pH

Soil pH provides one of the most valuable indicators of soil health. Soil pH is a measure of soil acidity or alkalinity and is measured on a scale from 0 to 14. A pH of 7.0 is neutral; below this the soil is acid and above it, alkaline. The pH scale is a logarithmic scale; soil with a pH of 5.0 is 10 times as acid as a soil with a pH of 6.0. The acidity or alkalinity of soil is important in influencing the availability of essential mineral nutrients for plant growth. Some are less available at strongly acid pH levels while others are less available at alkaline pH levels (Figure 24). Below pH 4.5, some mineral toxicities can occur from the soil solution becoming saturated with minerals such as aluminium and manganese. Levels of calcium and magnesium also fall. On the other hand, when soil pH rises over 6.5 (more alkaline), many mineral nutrients become fixed and plant deficiencies may develop. In general, trace elements such as boron, copper, iron and zinc are most affected by high soil pH. Nevertheless, some krasnozem soils with pH above 7.0

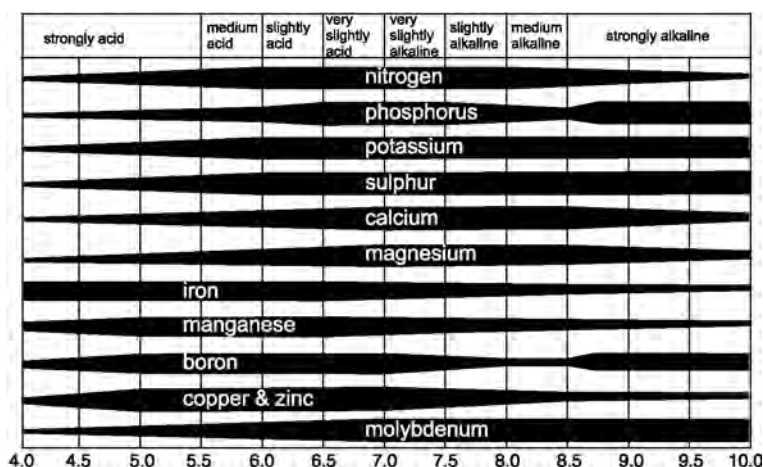


Figure 24. Effect of soil pH on nutrient availability

NOTE

Further information on soil pH is available in the Conservation and Land Management (CaLM) and NSW Agriculture *Soil Sense* information sheets *What is soil pH?, How to interpret your soil test, Why worry about acidity?* and *Which liming material is best?*

may support healthy, productive macadamia orchards, despite iron deficiency being common.

Soil pH can be measured either in water or in calcium chloride, the latter generally being 0.5 to 0.8 pH units lower than if tested in water. For macadamia, soil pH is best kept between 5.0 to 5.5 (1:5 water test) and 4.5 to 5.0 (calcium chloride test).

Effective Cation Exchange Capacity (ECEC)

Effective cation exchange capacity (ECEC) measures the ability of the soil to hold cations (positively charged ions) including calcium, magnesium, potassium, sodium and aluminium. It is a valuable indicator of chemical fertility of the soil and the availability of nutrients to the soil solution for plant growth. The sum of the five positively-charged ions or cations is known as the effective cation exchange capacity.

Cations are held in the soil on the surfaces of clay colloids, organic matter and humus and the quantity held is determined by pH, clay content and soil type, as well as the organic matter and humus content. Typically, sands have CEC's of 1 to 5, loams 4 to 10, clay loams 6 to 15, and clays 5 to 40. The CEC level in clay soils depends largely on soil pH.

The balance between cations should fall between certain limits:

- Calcium (Ca) should always be present in the greatest amount and constitute 50 to 80% of the ECEC. As pH decreases, levels of Ca fall rapidly.
- Magnesium (Mg) is normally the second most plentiful cation, accounting for 10 to 50% of the ECEC. Figures greater than 20% are normally only found in heavy black and grey soils formed on basalt.
- Potassium (K) typically accounts for 2 to 10% of the ECEC, the lowest amount of the desirable cations (Ca, Mg, and K). The amount of K in sandy soils is generally quite low.
- Sodium (Na) is an undesirable cation normally present in small quantities. Larger amounts are only found in saline soils or those formed from marine sediments. Clay loams and clays with greater than 5% Na have problems with water movement through the soil.
- Aluminium (Al) is also an undesirable cation, only present in toxic forms where pH falls below 5.0 (1:5 water). Al toxicity causes root damage and reduces growth. Although sensitivity varies with different plants, macadamia appears to be reasonably tolerant.

In the past, considerable emphasis was placed on the Ca/Mg ratio being between 4 and 6, although variation between 1 and 10 is quite acceptable, especially since many Australian soils have high subsoil Mg levels. This is generally not detected in soil analysis as soil samples are usually taken no deeper than 15 cm.

NOTE

Further information on cation exchange capacity is detailed in the CaLM and NSW Agriculture *Soil Sense* publications *Cation Exchange Capacity* and *How to interpret your soil test.*

NOTE

Further information on soil organic matter can be found in the CaLM and NSW Agriculture *Soil Sense* publication *Soil Organic Matter*.

Organic carbon and other indicators of soil chemical health

Organic carbon is a measure of soil organic matter, made up of any living or dead plant and animal material in the soil. Organic matter is a highly desirable constituent of the soil. Benefits of increasing the level of organic matter in the soil include improving soil structure, drainage, and water retention; providing nutrients such as nitrogen, phosphorus and sulphur; and increasing the cation exchange capacity. Organic matter can be increased by promoting growth in the inter-row area and under the canopy with under-tree ground covers like sweet smother grass or by applying bulk organic material, as long as this does not interfere with management operations such as harvesting. Organic carbon values of more than 4% are regarded as high, 2 to 4% as medium and 1 to 2% as low.

In addition to organic carbon (referred to as total carbon), other good indicators of good soil health include labile carbon content ('active' carbon), microbial biomass C, total N and pH buffering capacity.

Biological soil health

The biological balance of healthy soils helps suppress the build-up of soil-borne pathogens such as *Phytophthora* and maintains a stable ecological balance in the soil. There are many ways to indicate the biological health of soil, including microbial biomass, microbial activity, bacterial and fungal biodiversity, the ratio of free-living to plant parasitic nematodes and earthworm density. Enzymes produced by microorganisms play a key role in the oxidation and release of inorganic nutrients from organic matter.

Nematodes and earthworms are one or two steps higher in the food chain than fungi and bacteria and are good indicators of the physical, chemical and biological health of soil. For example, the proportion of free-living to plant parasitic nematodes is a useful ecological indicator of the functionality of the detritus food web, because it indicates the balance between the various groups feeding on plant roots, and those feeding on bacteria, fungi and other nematodes. Because of their relatively short generation times, nematodes can respond quickly to changes in food supply or other changes in the soil.

Excessive use of copper in orchards can have a major, and undesirable, effect on soil biota. Care should be taken to avoid excessive use of copper sprays.

HINT

Nutrient concentrations in the sections that follow are generally expressed in mg/kg. Note that 1 mg/kg is equal to 1ppm (part per million).

Understanding the important nutrients

NITROGEN (N)

Function	<p>The most important nutrient for tree growth.</p> <p>A key component of chlorophyll (the green pigment in leaves), which is why nitrogen deficient trees are light green or yellow.</p> <p>An essential requirement for the synthesis of plant hormones, which control tree growth.</p>
Behaviour in soil and plant	<p>Very mobile in the soil and leaches very readily, particularly in high rainfall areas. May have to be topped up with small applications after extended periods of rain.</p> <p>Very mobile within the tree. New vegetative growth has a strong demand for nitrogen and, because of its mobility, it is moved from the old leaves to young leaves during periods of rapid growth.</p> <p>Too little nitrogen reduces photosynthesis and hence growth, causes early leaf fall and reduces fruit set and yield. Too much promotes excessive vigour and reduces flowering, especially if applied in large doses.</p>
Fertiliser forms	<p>Urea (46% N)</p> <p>Sulphate of ammonia (Gran-Am®, 21% N).</p> <p>Potassium nitrate (13% N and 38% K).</p> <p>Calcium nitrate (15% N and 18 to 19% Ca)</p> <p>Calcium ammonium nitrate (CAN, 27% N and 8% Ca)</p>
Management	<p>In young trees, nitrogen is applied regularly to rapidly develop the leaf canopy. When trees start bearing, its use should be related to the level of production (nutrient replacement). Nitrogen is best applied in as many applications as practicable throughout the year. During summer, small applications of nitrogen are needed to meet the high demand during nut development and oil accumulation. However, heavy applications of nitrogen to bearing trees at this time should be avoided as this can promote vegetative growth, and reduce nut yield and quality. Excessive applications of nitrogen (particularly in the ammonium form) can also increase soil acidity.</p>

PHOSPHORUS (P)

Function	<p>Essential for energy metabolism in maintenance and growth.</p> <p>Particularly important for root growth, flower initiation and nut set.</p>
Behaviour in soil and plant	<p>Only a small proportion of soil phosphorus is generally available for tree uptake.</p> <p>In some soils such as krasnozems and red earths, phosphorus is tightly fixed. Most macadamias in NSW are grown in these soils. The fixing of phosphorus near the surface reduces its availability to the tree and predisposes it to losses from soil erosion.</p> <p>Relatively immobile in the soil and not readily leached.</p> <p>Very mobile in the plant, moving readily in both an upward and downward direction.</p> <p>Excessive soil levels may induce iron and zinc deficiencies. Iron deficiency is common in soils where sugar cane has previously been grown. The iron to phosphorus ratio in leaves (Fe:P) is a reliable indicator of tree health. A Fe:P ratio of less than 0.07 is often associated with phosphorus-induced iron deficiency (chlorosis).</p> <p>Proteoid roots are induced to form under low soil P conditions. These roots are adapted to enhance the uptake of the sparingly available P by greatly increasing the root surface area available for absorption, and by producing specialised root exudates that make P more available to the tree.</p>
Fertiliser forms	<p>Superphosphate (9% P, 11% S, 20% Ca).</p> <p>Triple superphosphate (19% P, 2% S, 18.5% Ca).</p> <p>Diammonium phosphate (DAP, 18% N, 20% P, 2% S).</p> <p>Monoammonium phosphate (MAP, 12% N, 22% P, 3% S).</p> <p>Rock phosphate (phosphorus content varies according to source; check content before calculating rates).</p>
Management	<p>Monitor soil and leaf levels regularly, and apply phosphorus fertilisers only where required. Leaf phosphorus levels often fall rapidly as the tree commences to crop and may be hard to maintain in older bearing trees.</p>

PHOSPHORUS (P) continued...

In phosphorus-fixing soils such as the krasnozems, extractable soil phosphorus levels above 100 mg/kg using the Colwell soil test may be required for optimum nut-in-shell production. In most other soils, the optimum level for macadamias is about 85 mg/kg, based on field trials calibrated to yield. Pot trials with a wide range of soils, however, indicated adequate soil P at 50 mg/kg calibrated to seedling growth. Many productive orchards fall between this range

Because of its slow movement through the soil profile (except in white sands), it is best applied in non-irrigated orchards before the summer rains to help with its movement into the soil.

POTASSIUM (K)

Function	Several important roles, but the most important appears to be regulation of water balance. It achieves this by influencing water movement and controlling the opening and closing of stomata (water pores on leaves). Another important function is the synthesis and movement of starches, sugars and oils. In this role potassium has a direct effect on nut yield and quality.
Behaviour in soil and plant	Very mobile in the soil and readily leached, particularly in sandy soils. Very mobile in the plant, readily moving in all directions. However, because it is not required to a great extent by leaves, new growth flushes do not draw large amounts of potassium away from the nuts. Peak potassium requirements occur during nut growth and oil accumulation.
Fertiliser forms	Potassium sulphate (sulphate of potash, 41% K, 16.5% S) Potassium chloride (muriate of potash, 50% K, 50% Cl) Potassium nitrate (38% K, 13% N)
Management	The availability of potassium should be considered in relation to that of other nutrients, such as calcium and magnesium. An excess of one of these nutrients can reduce the availability of others. For example, excessive applications of potassium fertilisers can induce a magnesium deficiency.

CALCIUM (Ca)

Function	Plays an important role in cell division and cell development in new leaves, nuts and root tips.
Behaviour in soil and plant	Relatively immobile in the soil. Mobile within the tree in an upward direction towards the leaf tips with little remobilisation downwards. High soil levels may reduce uptake of manganese, zinc, boron, copper and phosphorus.
Fertiliser forms	Calcium sulphate (gypsum, 18 to 20% Ca, 14 to 18% S). Calcium nitrate (18 to 19% Ca; 15% N). Calcium carbonate (lime, 35 to 40% Ca). Calcium and magnesium carbonates (dolomite, 12 to 15% Ca, 8 to 12.5% Mg). Calcium ammonium nitrate (CAN, 8% Ca, 27% N).
Management	The availability of calcium should be considered in relation to that of other nutrients, such as potassium and magnesium. An excess of one of these nutrients can reduce the availability of others. Since lime is insoluble, and gypsum relatively insoluble in water, they should be applied before the wet season to help with incorporation. Before buying any liming material, check the neutralising value, fineness and calcium and magnesium content. Finer particles of lime react faster. Fine agricultural lime with 98 to 100 percentage fines (particles less than 0.25 mm in diameter) is recommended. The choice of calcium product depends on the effect required. Lime is normally used when soil pH and calcium levels are both low. Dolomite is normally used when soil pH, calcium and magnesium levels are all low. Gypsum is normally used when pH is within the desired range, but the soil calcium level is low.

MAGNESIUM (Mg)

Function	An essential component of chlorophyll (the green pigment in leaves) where it helps trap light energy, converting it to chemical energy used to produce sugars (photosynthesis). Also regulates the uptake of other plant nutrients and is essential for many biochemical cellular functions.
Behaviour in soil and plant	Relatively mobile in the soil and is absorbed by roots, mainly through passive diffusion. High soil concentrations of ammonium, potassium and calcium may compete with magnesium for uptake, leading to magnesium deficiency. Very mobile within the tree, moving readily from old leaves to new leaves under deficient conditions.
Fertiliser forms	Magnesium sulphate (Epsom salts, 9.5% Mg). Calcium and magnesium carbonates (dolomite, 8 to 12.5% Mg, 12 to 15% Ca). Granomag (magnesium oxide, 54% Mg).
Management	The availability of Mg should be considered in relation to that of other nutrients, such as Ca and K. An excess of one of these nutrients can reduce the availability of others. Because of the links between pH, ECEC, Ca, Mg and K, base the calculation of rates and timing of these nutrients on leaf and soil analysis, and on the balance of cations. Corrective application is generally only necessary once every few years. Aim to keep the pH between 5.0 and 5.5 (1:5 water test). All liming materials are best applied in autumn. The choice of magnesium product depends on the effect required. Dolomite is normally used when soil pH, calcium and magnesium levels are all low. Granomag is normally used when pH is within the desired range, but the soil magnesium level is low.

SULPHUR (S)

Function	An important component in proteins and chlorophyll.
Behaviour in soil and plant	Relatively mobile in the soil. There is little impact from other nutrients on the uptake and movement of sulphur absorbed by roots. Movement in the tree is mainly upwards. Once incorporated in proteins, it cannot be remobilised for use in other parts of the plant in times of deficiency.
Fertiliser forms	Sulphate of ammonia (Gran-Am®, 24% S) Superphosphate (11% S) Single superphosphate with sulphur (26.1% S) Gypsum (14 to 18% S) Elemental sulphur (98 to 100% S)
Management	There are no specific management strategies for sulphur fertilising in macadamias. Under normal circumstances, fertilisers commonly used (superphosphate, sulphate of ammonia, sulphate of potash and gypsum) generally contain enough sulphur to meet tree requirements. If leaf S levels are low, select these fertilisers to use in the fertiliser program.

Trace elements

Trace elements are extremely important although only small quantities are usually required. Trace elements most likely to be deficient are boron, copper, zinc and iron.

BORON (B)

Function

An important role in cell division and cell growth. Important in areas of the plant where cell development is significant (for example, flowers, nuts and shoot and root tips).

Important role in root health.

The range between boron deficiency and toxicity is narrow, so careful management is required.

Behaviour in soil and plant

Very mobile in the soil and is easily leached from acidic soils, and rendered unavailable in calcareous (alkaline) soils and in very wet or dry soils.

Not very mobile within the plant, with any movement occurring in an upwards direction with little remobilisation downwards. Consequently, in most Australian growing environments, trees require a constant supply of boron throughout the year from small, but frequent applications.

Fertiliser forms

Borax (11% B).

Solubor (21% B).

Boric acid (17% B).

Note: Often incorporated into N:P:K mixes (e.g. North Coast Macadamia Mix®).

Management

Use leaf and soil analysis to monitor boron levels. Take care with application rates as there is a fine line between deficient and toxic boron levels. To apply boron evenly and to avoid toxicity with soil application, it is best mixed in water and sprayed on the ground. Alternatively, use soluble forms (Solubor, boric acid) and apply by fertigation. Must be a ready supply from either the soil or foliar sprays. In situations of B deficiency, foliar boron sprays have been shown to increase yields of nut-in-shell, kernel recovery, first grade kernel and mean kernel weight. However, foliar applications provide temporary relief only. Hence, follow-up sprays and soil applications are needed.

If an application is due and the orchard has received very little rain or irrigation since the last application, postpone the application until substantial rain or irrigation is received.

ZINC (Zn)

Function

An essential role in the production of enzymes and plant hormones. Hence it is required for new growth, which is distorted when deficiency occurs.

Has a regulatory role in the uptake of water.

Necessary for normal chlorophyll formation.

Behaviour in soil and plant

Not very mobile in the soil. It has been shown that mycorrhiza assist with the root uptake of zinc in other tree species.

From research in other species, it is known to be not very mobile in the tree. Tends to accumulate in roots.

Deficiency is reasonably common, particularly on soils with high pH or where heavy applications of lime have been made. High soil phosphorus levels also inhibit the uptake of zinc. There is evidence in red krasnozem soils that macadamias take up little if any soil applied zinc.

Fertiliser forms

Zinc sulphate heptahydrate (23% Zn).

Zinc sulphate monohydrate (36% Zn).

Zinc oxide (80% Zn).

Management

In red krasnozem soils where there is evidence of inhibition of uptake from the soil, foliar sprays of zinc and urea are recommended, where leaf analysis suggests a deficiency. This is best applied to the summer leaf flush. Where deficiency is severe, re-apply to the winter/spring flush and developing nuts.

In other soils, there should be sufficient uptake from soil applied zinc to overcome a deficiency. However, concentrating the zinc in a band around the dripline of the tree is recommended to assist with uptake. Foliar sprays may be used as a supplement where necessary.

COPPER (Cu)**Function**

Involved in the transfer of energy in various tree processes such as photosynthesis and nitrogen metabolism.

Also important in the production of lignin, which provides strength to the growth of lateral branches.

Behaviour in soil and plant

One of the least mobile elements in the soil and not easily leached.

Not readily mobile within the tree, though if present in sufficient quantities, it will be translocated from older to younger leaves.

Copper deficiency is normally only a problem in leached, sandy soils receiving high nitrogen, or where soil phosphorus is very high.

High levels of soil copper may induce an iron deficiency.

Fertiliser forms

Bluestone (copper sulphate pentahydrate, 25% Cu).

Copper is also available in several fungicides including copper oxychloride and copper hydroxide. If copper fungicides are regularly used for control of diseases such as husk spot, then there is generally no need to use copper fertilisers.

Management

Routine sprays of copper-based fungicides for husk spot control generally prevent copper deficiency from developing.

IRON (Fe)**Function**

Critical function in the production of chlorophyll (the green pigment in leaves).

Behaviour in soil and plant

Generally an abundant element in the soil, where it is relatively mobile.

Not very mobile within the tree.

Generally associated with either high soil pH (greater than 7.0 on 1:5 water test), high levels of soil phosphorus, or high levels of soil manganese.

Fertiliser forms

Iron sulphate (23% Fe). For use in all situations.

Iron chelate or iron EDDHA (5 to 15% Fe, for example Sequestrene 138®). For use in soils with a pH greater than 7.0.

Management

Iron deficiency can be corrected by lowering the pH with sulphur or by using sulphate of ammonia instead of urea for nitrogen requirements. However, where high soil phosphorus levels cause the iron deficiency, this is ineffective. Foliar sprays of iron chelate and soluble ferrous sulfate may help in this situation.

A program for nutrition management

A detailed program for managing nutrition has been outlined throughout the *Growing the crop* chapter of this handbook. In brief, the program involves:

Before planting

Do a complete soil analysis before planting to adjust pH and the relatively immobile nutrients (phosphorus, calcium, zinc and copper) to appropriate levels. These nutrients are best worked into the entire root zone before planting.

Young, non-bearing trees

Wait until young trees have begun to put on new growth and then fertilise little and often from September to May. Young trees have a high requirement for nitrogen and phosphorus, the latter heavily dependent on soil type, but a relatively low requirement for potassium until bearing commences. Use soil analysis as a guide to fertiliser rates. Spread fertiliser in a broad ring around the tree, extending 50 cm beyond the edge of the canopy (dripline). Keep the

fertiliser 10 cm away from the trunk to avoid collar burn. Alternatively, apply through the irrigation system where available (fertigation).

Bearing trees

Base all fertiliser applications on leaf and soil analysis, together with an allowance for nutrient removal (see later in this section). In addition, factor in the tree vigour when calculating nitrogen requirements, to maintain tree health under sustained heavy cropping. Similarly, higher levels of nutrition are required for some varieties, such as the HV A series. Spread fertiliser over the whole orchard area with most directed under the tree canopy where feeder roots are concentrated. Alternatively, apply through the irrigation system where available (fertigation).

Leaf and soil analysis

Details on sampling for soil and leaf analysis are outlined in the *Growing the crop* chapter of this handbook. It was recommended there that because the processes of sampling, analysis and interpretation are complex and require specialist skills, growers engage the services of an experienced local nutrition consultant. They will manage the analysis, interpret the results and make fertiliser recommendations appropriate to each orchard. Ensure that consultants are using the services of a reputable laboratory with quality-assured accreditation for the analysis. However, to help growers understand what is involved in the interpretation, some basic information is provided here.

Understanding leaf and soil analysis results

Tables 20 and 21 show soil and leaf nutrient levels that are considered optimum for macadamia.

Table 20. Optimum soil nutrient levels for macadamia.

Element (extraction procedure shown in brackets)	Optimum soil levels
pH (1:5 water)	5.0 – 5.5
pH (1:5 CaCl ₂)	4.5 – 5.0
Organic carbon (Walkley-Black)	more than 2.0% C
Nitrate nitrogen (1:5 aqueous extract)	more than 15 mg/kg
Sulphate sulphur (phosphate)	more than 20 mg/kg
Phosphorus (Colwell)	85 mg/kg P
Potassium (exchangeable)	more than 0.5 meq/100 g K
Calcium (exchangeable)	more than 5 meq/100 g Ca
Magnesium (exchangeable)	more than 1.6 meq/100 g Mg
Sodium (exchangeable)	less than 2% exchangeable cations
Aluminium (exchangeable)	less than 5% exchangeable cations
Chloride (1:5 aqueous extract)	less than 200 mg/kg Cl
Conductivity (1:5 aqueous extract)	less than 3 dS/m
Boron (hot calcium chloride)	1 – 2 mg/kg B
Total cation exchange capacity	preferably more than 7
Cation balance (%)	calcium 50 – 80 magnesium 10 – 50 potassium 2 – 10 sodium less than 2 aluminium less than 5

Note that soil nutrient levels in analyses vary from laboratory to laboratory depending on extraction procedures used. Hence it is important to relate the result to the extraction procedure. These are listed for each nutrient in Table 20. Note also that most soil tests do not measure total nutrient content, but rather use various solutions to extract ‘available’ fractions of the nutrient from the soil. To be meaningful, this amount of extracted nutrient should preferably be calibrated to yield and leaf content of the nutrient. Apart from phosphorus trials on three soils in Queensland, there is no such calibration specifically for macadamias. The optimum soil levels for other nutrients are therefore extrapolated from other research and local experience.

Table 21. Recommended leaf nutrient levels

Nutrient	Deficient	Low	Recommended	High
Nitrogen (%)	<1.2		1.4 – 1.5	
Phosphorus (%)	<0.05	0.05 – 0.08	0.08 – 0.10	>0.1
Potassium (%)	<0.40		0.4 – 0.7	>0.7
Sulphur (%)		<0.16	0.16 – 0.25	>0.25
Calcium (%)	<0.4	<0.4 – 0.5	0.5 – 0.9	>0.9
Magnesium (%)	<0.06	0.06 – 0.07	0.07 – 0.10	>0.1
Sodium (%)			<0.02	
Chloride (%)			<0.05	
Copper (mg/kg)	<3	3.0 – 4.5	4.5 – 10	
Zinc (mg/kg)	<5		6 – 15	>50
Manganese (mg/kg)	<20	20 – 100	100 – 1000	>1500
Iron (mg/kg)			40 – 200	
Boron (mg/kg)	<20	20 – 40	40 – 75	>100

Note that the leaf nutrient ranges shown in Table 21 apply to leaves analysed by the dried tissue technique. Levels do not apply to results obtained from sap analysis techniques.

Tables 22 and 23 provide broad guidelines for interpreting leaf and soil analysis results. The tables use a concept known as ‘replacement rates’ which is explained after the tables.

Note that except for phosphorus on three Queensland soils, there has been little research on responses of macadamia to soil nutrient levels. Soil type should be taken into account when applying the following tentative recommendations, particularly for pH, ECEC, Ca, Mg, K, Na, Al and Colwell P. Krasnozems often have different requirements and responses to other soil types.

Table 22. Interpreting soil analysis results

Element	Optimum levels	Interpretation
pH (1:5 water)	5.0 - 5.5	5.5 about ideal. Note: pH measured in CaCl ₂ is usually 0.5-0.8 units lower than that measured in water. If below 5.0, toxic soluble Al levels may increase and Ca and Mg fall. In these cases, apply dolomite or a limestone/Mg blend if calcium:magnesium ratio (in this table) is close to 3-5:1 and magnesium concentration is less than 1.6meq/100g soil. Otherwise use lime. pH levels up to 7.0 appear to present no significant problems, although above pH 6.5, induced Fe deficiency may occur in white and red sands, loam soils and black earths, particularly when the soil is low in Fe and/or high in P.
Organic carbon-%C (Walkley-Black)	> 2.0	If less than 2, use green manure crops, mulches, organic manures. Values >4% are regarded as high, 2-4% medium and 1-2% low.
Nitrate nitrogen-mg/kg (1:5 aqueous extract)	> 15	Note: nitrate nitrogen analysis of soils is notoriously unreliable because soil nitrate is very mobile in the soil. If carried out, samples should be frozen before dispatch. If < 15, apply at replacement rates + 30%. If 20-30, apply at replacement rates. If > 30, apply less than replacement rates.
Phosphorus-mg/kg P (Colwell)	85	Note: a level of 85 mg/kg is suitable for loams, red sands and black earths but for white sands and loams with bleached A ₂ horizons, values of 50mg/kg may be adequate. Krasnozems often have levels above 85 mg/kg. Colwell extractable P, yet leaf P levels are often below 0.08. Soils in the Bundaberg area often have soil P levels of 40-70mg/kg. If < 60, apply at rate of 25kg/ha P. If 60-85, apply at replacement rates. If > 100, no application is necessary (except for krasnozems—seek specialist advice).
Potassium-meq/100g K (exchangeable)	>0.5 (2-10% of ECEC)	If < 0.5, apply at replacement rates + 20%. If 0.5-1, apply at replacement rates. If > 1, no application is necessary.
Calcium-meq/100g Ca (exchangeable)	>5.0 (50-80% of ECEC)	In white and red sands, and often in loams with bleached A ₂ horizons, soil Ca may be adequate at 2-3 as ECEC levels are only 4-5. On black earths, Ca may be as high as 20-30meq/100g. If < 5 and pH < 5.0, apply lime at up to 2.5t/ha on light sandy soils and up to 5 t/ha on heavier soils. If magnesium levels are also low, use dolomite or a limestone/magnesium blend instead. If soil pH >5.0 and calcium levels are low, apply gypsum at 1 to 2 t/ha. If > 5 and pH is > 5.0 (1:5 water), no application is necessary.
Magnesium-meq/100g Mg (exchangeable)	> 1.6 (10-50% of ECEC)	Similar soil type interpretation to that for Ca (above). If < 1.6, with pH less than 5.0, apply dolomite at up to 2.5 t/ha on light sandy soils, and up to 5 t/ha on heavier soils. If the pH is satisfactory and magnesium levels are low, apply magnesium oxide at 100 to 200 kg/ha.
Sodium-meq/100g Na (exchangeable)	< 1 (<5% of ECEC)	If > 1, check quality of irrigation water and height of water table.
Chloride-mg/kg Cl (1:5 aqueous extract)	< 200	If > 200, check quality of irrigation water and height of water table, and use sulfate forms of potassium fertiliser.
Conductivity EC _{se} *-dS/m (1:5 aqueous extract)	< 3	If > 3, check quality of irrigation water, fertiliser rates and height of water table.
Boron- mg/kg B (hot calcium chloride)	1 - 2	If < 1.0, check leaf analysis level to see if overall deficiency is confirmed. Follow recommendations there.
Total cation exchange capacity	>2, preferably higher	Total ECEC is heavily dependent on soil type. Typically, sands have ECECs of 1-5, loams 4-10, clay loams 6-15 and clays 5-40, the latter depending on pH. See pH, calcium, magnesium and potassium above.

*Saturated extract equivalent

Table 23. Interpreting leaf analysis results

Element	Adequate levels	Interpretation
Nitrogen (% N)	1.4 - 1.5	If within desired range, use nutrient replacement to determine rates of application. If below desired levels, apply additional N. NB. Recent surveys indicate higher leaf N levels (1.6-1.8%) in high-yielding orchards, particularly in the krasnozems of northern NSW. Hence, the adequate range may be adjusted to include these levels.
Sulphur (% S)	0.16 - 0.25	Rarely out of range. HV A varieties may have lower levels.
Phosphorus (% P)	0.08 - 0.10	It is hard to increase leaf P of mature trees above 0.06% and P applications have little effect on leaf P levels. If within desired range, no action necessary. If below or above desired range, use soil analysis results and/or nutrient replacement to determine rates of application.
Potassium (% K)	0.40 - 0.70	If below desired level, either insufficient potassium or competition from high levels of calcium and/or magnesium for uptake. Use soil analysis results for potassium, calcium and magnesium to determine rates of application. Remember that potassium levels fall as the crop load increases on the tree, so timing of sampling is important when interpreting analysis results. If within or above desired range, use soil analysis results and/or nutrient replacement to determine rates of application.
Calcium (% Ca)	0.50 - 0.90	Ca continues to accumulate as leaves age so younger leaves will have lower levels. Drought may influence Ca levels. It is suggested that 0.4% Ca may be adequate for younger leaves. If below desired range, either insufficient calcium, low soil pH, or an imbalance with potassium and/or magnesium. Use soil analysis results for potassium, calcium, magnesium and pH to determine type of fertiliser and rates of application. If within or above desired range, no action necessary.
Magnesium (% Mg)	0.07 - 0.1	If below desired range, either insufficient magnesium, low soil pH, or an imbalance with potassium and/or calcium. Use soil analysis results for potassium, calcium, magnesium and pH to determine type of fertiliser and rates of application. If within or above desired range, no action necessary.
Zinc (mg/kg Zn)	6 - 15	If below desired range, high soil pH, excessive phosphorus or excessive nitrogen may be indicated. Evidence suggests that soil-applied Zn is not effectively taken up by macadamias, particularly in krasnozem soils. Apply a foliar spray of zinc sulphate heptahydrate at 15kg/1000L/ha (1.5% solution) plus 1kg urea to the summer growth flush. Where deficiency is severe, re-apply to the winter/spring flush. In other soil types, band zinc sulphate monohydrate at a rate of 3 g per square metre of canopy cover in a band 30 cm wide around the dripline of the tree. If within or above desired range, no action necessary.
Copper (mg/kg Cu)	4.5 - 10	Rarely out of range if copper fungicide sprays are used. Where leaf symptoms indicate copper deficiency, use foliar sprays.
Sodium (% Na)	less than 0.02	If more than desired level, check quality of irrigation water and soil analysis results.
Chloride (% Cl)	less than 0.05	If more than desired level, check quality of irrigation water and soil analysis results.
Iron (mg/kg Fe)	40 - 200	Rarely out of range except where heavy applications of lime, dolomite or phosphorus have been made.
Boron (mg/kg B)	40 - 75	If below desired range, apply up to four foliar sprays of Solubor at 1g/L between September and March (B is immobile in the plant so repeat sprays are necessary) and spread 3 g of borax or 1.5 g of Solubor per square metre of soil surface evenly beneath the trees. Boron can become toxic so check leaf levels two months later before any further applications are made. B may be readily leached from the soil. If within or above desired range, no action necessary.
Manganese (mg/kg Mn)	100 - 1000	Only likely to be deficient on white sands. If below desired range, apply a foliar spray of manganese sulphate at 100g/100L to the spring flush.

Note that apart from some research on N at one site, most of the leaf nutrient standards are based on survey and field observation, and not on calibrated yield responses. Local monitoring of yield responses to leaf nutrient levels is recommended to refine the tentative recommendations in Table 23.

Fertiliser rates using the nutrient replacement concept

Once nutrients requiring adjustment have been identified, the next step is to calculate the rates of fertiliser that need to be applied. For the main nutrients, use the nutrient replacement concept below in conjunction with Tables 22 and 23. This bases nutrient and fertiliser application rates on the amount of nutrient removed by the crop, adjusted for expected losses of nutrient through leaching and soil fixation.

Nutrient removal by the crop has been calculated from research and is shown in Table 24.

Note that the rates of nutrient replacement in Table 24 have been adjusted using the following rules of thumb for normal (not excessive) leaching, erosion, soil fixation and other losses:

- nitrogen rates increased by 30%
- potassium rates increased by 20%;
- calcium rates increased by 10%;
- magnesium rates increased by 25%.

These allowances are appropriate in most situations but since soil type and weather conditions vary so much, loss estimates may need to be refined. For example, **in very sandy soils, nitrogen rates could be increased by up to another 20%, and in krasnozems soils, phosphorus rates should be increased by up to 100%.**

Table 24. Nutrient removal by the crop (tree nutrient removal + adjustment for leaching and other losses) with varying crop yields

Crop yield (t/ha)	Requirements for full replacement of lost nutrients (kg/ha)					
	NIS at 10% m.c.	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
2		27	2.5	22	1	2
4		55	5	44	2	4
6		82	7.5	66	3	6

A simple computer program (Excel format), to help calculate the amount of fertiliser to apply based on a nutrient replacement system, is available from NSW Department of Primary Industries.

Fertiliser choice

Nutrients can be applied either as straight inorganic (synthetic), mixed inorganic, or organic fertilisers, with both the rate and timing being important. The nutrient content of a fertiliser is displayed on its label. Mixed fertilisers are usually described by their ratio of nitrogen: phosphorus: potassium (N:P:K) and there is a wide range available. Special mixtures can also be made to suit particular requirements. Some mixed fertilisers also contain trace elements, such as copper, zinc and boron.

Inorganic fertilisers are recommended as they produce a more predictable and timely response. Macadamia trees respond well to organic fertilisers, which are useful in improving soil structure, organic matter levels and microbial

activity. Their chemical composition, however, is variable and often low in some nutrients such as potassium. They are recommended as supplements to inorganic fertilisers. Organic materials such as poultry manure and nut husks are best applied as soon as harvesting is complete. Do not apply raw animal manures within four months of the start of nut drop and until after the completion of harvest to reduce the risk of microbial contamination of nuts. Husks should be composted to reduce the spread of the husk spot fungus.

Straight inorganic fertilisers are preferred to mixed inorganic fertilisers as they can supply each nutrient as required. They are also generally cheaper per unit of nutrient. Mixed fertilisers are more convenient to use but may cause a nutrient imbalance by oversupplying a particular nutrient.

Another important issue in the selection of fertilisers is how much they will contribute to soil acidity and soil salinity. If the soil is acid, choose the least acidifying fertiliser available – see Table 25. Most mixed fertilisers are based on sulphate of ammonia and therefore acidify the soil.

Table 25. Acidifying effect of common fertilisers

Fertiliser	Acidifying effect
Sulphate of ammonia	highly acidifying
MAP	highly acidifying
DAP	acidifying
Urea	acidifying (neutral if no leaching)
Superphosphate	non acidifying
Calcium ammonium nitrate	non acidifying (basic)
Sodium nitrate	non acidifying (basic)
Potassium nitrate	non acidifying (basic)
Muriate of potash	non acidifying (basic)

If salinity is a problem, choose fertilisers with the lowest salt index – see Table 26.

Table 26. Salt index of common fertilisers. (A measure of contribution to osmotic potential in the soil solution. For comparison, common salt has a salt index of 154).

Fertiliser	Salt index
Muriate of potash	114
Urea	75
Potassium nitrate	74
Sulphate of ammonia	69
Sulphate of potash	46
DAP	34
MAP	30
Gypsum	8
Superphosphate	8
Lime	5
Dolomite	1

Note that urea is readily converted to ammonia in the soil, often within a couple days of application. If the urea is not washed into the soil by rain or irrigation, large losses of N can occur through volatilisation of the ammonia.

Fertigation

Fertigation (application of fertiliser through the irrigation water) is recommended and has many advantages over the manual application of solid fertilisers. It uses less labour, gives more efficient nutrient uptake and fertilisers can be applied more regularly and conveniently. With efficient fertigation, annual rates of nitrogen and potassium can generally be reduced by up to 25%. Fertiliser can be added during every irrigation if desired, but fertigation every 2 to 4 weeks is generally most practical.

The effectiveness of fertigation is dependent on the effectiveness of the irrigation system. The full advantages of irrigation and fertigation only become evident if the irrigation system is designed correctly to meet tree requirements and to distribute water and fertiliser evenly. Irrigation output must be uniform across the block to fertigate accurately. Where fertigation is being used on sloping land, pressure compensating emitters (either mini-sprinkler or drip) are required and application should be avoided at the end of an irrigation because of uneven drainage of lines. For these reasons, seek professional advice from an experienced irrigation designer when planning the system.

Before starting, get a water-testing laboratory to analyse the irrigation water. Make sure an iron test is included to assess the potential risk of iron blockages.

Fertilisers used in fertigation must be highly soluble to avoid pump damage and pipe blockages. Mixtures of fertiliser must also be compatible to avoid precipitation which can block sprinklers and also cause root damage. For example, calcium and phosphate fertilisers mixed at high concentrations often form precipitates. The most suitable fertilisers for fertigation are urea, calcium nitrate, potassium nitrate, potassium chloride and technical grade monoammonium phosphate (MAP). Several commercial soluble fertilisers that supply a range of nutrients are also suitable.

Because of the corrosive nature of many fertilisers, the components of the irrigation system that come into contact with corrosive solutions should consist of stainless steel, plastic or other non-corrosive materials. Concentrations of total nutrients in the mainline should not exceed 5 g/L. Always mix fertilisers in a sufficient volume of water. If fertilisers are not completely dissolved and mixed prior to injection into the system, varying concentrations will be applied or blockages may occur within the system.

The majority of injectors available can generally incorporate automatic operation by fitting pulse transmitters, which convert injector pulses into electric signals. These signals then control injection of preset quantities or proportions relative to the flow rate of the irrigation system. Injection rates can also be controlled by flow regulators, chemically resistant ball valves or by electronic or hydraulic control units and computers. Older systems rely on either:

NOTE

Because fertigation is limited to highly soluble fertilisers, and is effective in applying fertiliser to the irrigated zone only, some ground applications of fertiliser may also be necessary.

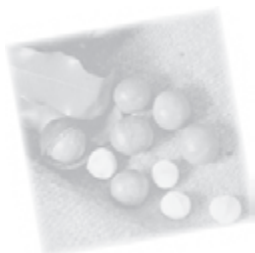
- Venturi suction from a tank with the flow rate controlled by a gate-valve;
- Direct injection into the suction line of the irrigation pump (beware of impeller corrosion);
- Pressure differential (PD) drums, where some mainline flow is bled off through a pressure drum containing a concentrated fertiliser solution, before being injected back into the main line as a dilute fertiliser solution.

Suitable anti-siphoning valves or non-return valves should be installed where necessary to prevent backflow or siphoning of water or the fertiliser solution into fertiliser tanks, the irrigation supply, household supply or stock supply.

Fertigation increases the quantity of nutrients present in an irrigation system and this can lead to a buildup of bacteria, algae and slime. These should be removed at regular intervals by injection of chlorine or acid through the system. Chlorine injection should not be used while fertiliser is being injected as the chlorine may tie up nutrients making them unavailable to the trees.

Injection can start any time after the system is fully operational (that is, it has reached operating pressures and is flowing, and all air is out of the irrigation lines). Merck nitrate test strips can be used to follow a dose of potassium nitrate through a system to give direct and visual indications of the time it takes to inject and then flush the system. Systems should always be flushed of nutrients before irrigation is completed. During the irrigation season, it is important to monitor:

- pH effects over time in the root zone,
- soil temperature effect on nutrient availability,
- corrosion and blockages of outlets, and
- reaction with salts in the soil or water.



Irrigation management

Although irrigation is only recommended where annual rainfall is less than 1200 mm or where it is unevenly distributed throughout the year, in these locations it can significantly improve nut yield, size and quality.

Research has shown that, even though mild water stress at all stages of the growth cycle reduces tree growth, its effect on yield and nut quality depends on the particular stage when the stress occurs. Stress in April (when floral initiation occurs and the trees are normally vegetatively dormant) has little or no effect on yield or quality. Stress during flowering and early nut set and development (August to November) can reduce yields. This period often has high temperatures, low humidity and low rainfall which collectively, may lead to significant moisture stress. As nuts set and develop, yield and quality become increasingly sensitive to water stress. Yield and quality are most sensitive to stress during the latter stages of maturation (December to February) when oil is accumulating in the kernel. The extent of damage to yield and/or quality depends on the severity and duration of the stress. Where water supply is limited, it should be conserved and applied at these critical stages.

Supply and demand for water in the orchard

Only a small, but essential, proportion of the tree's water requirement is used for growth of stems, leaves, roots and nuts. The majority is lost through transpiration (evaporation through the small pores or stomata on the leaf surface). This water movement through the tree is essential for carrying nutrients from the roots and for cooling sunlit leaves that would otherwise get sunburnt.

Plant water use (transpiration) depends on supply and demand – the ability of the soil to supply sufficient water to the roots, and the demand for water determined by weather conditions, the size of the canopy, and the resistance to water loss from the leaves. The stomata have the ability to close when water supplies are limiting (block off the pores), hence decreasing water loss.

The demand for water

Water evaporates from leaves that contain about 80% water into the relatively 'dry' atmosphere. The demand for water is higher in sunlight when:

- humidity is low (drier atmosphere);
- temperature is high;
- wind speed is high; and

- the leaf area (which provides the evaporative surface for water loss from the tree) is greater (up to a certain leaf area above which water use does not increase further).

When water in the leaves is less available, and at night, the stomata close to reduce further loss of water to the atmosphere. The water status of trees that are under some water stress during the day will often recover at night.

As water is lost from the leaves via transpiration, tension develops between water molecules in the leaf and this tension is transmitted through the xylem (the conduit linking leaves, through the stem, to the roots, where there is generally an abundance of water in well-managed orchards). This tension ‘draws’ water up from the roots to the leaves.

The supply of water

An optimum supply of water in the soil is needed for healthy and productive trees. Too much water will result in waterlogging and the tree will die from lack of oxygen for the roots. After rain or irrigation, excess water percolates down through the soil, allowing air to enter the large pores between soil particles. At this point the soil is at field capacity and a large amount of water is held loosely in the smaller soil pores and around soil particles. Much of this water is available to the tree. However, some of the water is not available because it is held too tightly around the soil particles. When all the available soil water is used by the tree, and only the unavailable, tightly held water is left, the soil is at the wilting point – the point where plants would start to wilt. Soils of different texture (different particle sizes) and structure hold different amounts of available and unavailable water (Table 27). In poorly structured soils, as soil particle size and soil pore size decrease, the amount of available soil water declines and root growth is impeded because soil particles tend to be more tightly packed together.

Table 27. The amount of water held in different soils. Note that this is an approximate guide only.

Water held in the soil (mm water/m depth of soil)*			
Soil texture	At field capacity	At wilting point	Available soil water
Sand	90	20	70
Loamy sand	140	40	100
Sandy loam	230	90	140
Sandy loam + organic matter	290	100	190
Loam	340	120	220
Clay loam	300	160	140
Clay	380	240	140
Well structured clays	500	300	200

* 1 mm water = 1 L/m²

In addition to the amount of water in the soil, the supply of water to the tree is determined by the extent and density of the root system, and the movement of water through the soil (hydraulic conductivity).

Plants with deep root systems have access to a larger reservoir of soil water and a dense mat of fibrous roots will more effectively exploit soil water reserves. However, a dense mat of roots can reduce the water holding capacity of the soil by roots filling up soil pore spaces where water is normally stored. Roots cannot grow in dry soil and tend to proliferate in moist soil.

The amount of water that is stored in 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 is different for different soils (Table 28). Information on infiltration rate is important when planning the irrigation system. The irrigation delivery system should not exceed the infiltration rate for the soil being irrigated.

HINT

Get an experienced irrigation consultant to do an infiltration test on your soil before design and installation of the irrigation system.

Table 28. Water infiltration rates for different soils

Soil type	Infiltration rate (mm of water/hour)	
	Flat ground	Sloping ground
Deep sands, aggregated silts	More than 20	8
Deep loamy sands	10-20	5
Loams and sandy loams and soils low in organic matter	5-10	3
Clay loams (including krasnozems soils)	5	2
Clays	Less than 5	Less than 2

Irrigation essentials

A good irrigation system

The first essential of efficient irrigation is an adequate water supply and an irrigation system capable of delivering the required amounts of water to each tree when needed, without waste. Research has shown that mature HAES 344 macadamia trees at 8 m x 4 m spacings use up to 55 L water per day at Bundaberg in summer, hence 0.5 ML/ha is needed to provide a months storage for irrigation—equivalent to up to 5 ML/ha/year. Ask a qualified irrigation expert to prepare an irrigation design and plan.

The two preferred irrigation systems (minisprinklers with a microspray feature, and drip or trickle tape) are detailed in the *Growing the crop* chapter of this handbook. Whatever system is used, it must be able to supply water to a depth of at least 75 cm, the depth of the bulk of the root zone.

A monitoring system

The second essential of efficient irrigation is a system of monitoring how much water the trees need and when. Water use can generally be reduced without affecting yield or nut quality. It also helps ensure that sufficient water is applied at critical times without overdoing it at other times.

A range of equipment and techniques is available for monitoring soil moisture and scheduling irrigation (Table 29). The most common are the soil-based systems using tensiometers or soil capacitance probes such as the

EnviroSCAN® and C-Probe®, and these are recommended. Most of the feeder roots of macadamia trees are in the top 30 cm of soil, so soil water monitoring devices used for irrigation scheduling need to concentrate on this part of the soil profile. Nevertheless, macadamia roots extend down to 4 m or more, depending on soil type, so the tree may have access to additional soil water at depth. As soil moisture monitoring can be complex, we recommend you seek expert advice, particularly when setting up the system.

Table 29. Comparison of main soil moisture monitoring systems

System	Advantages	Disadvantages
Tensiometers	Relatively cheap Easy to install yourself Easy to read yourself	Labour intensive to collect and record data Require regular maintenance Can be inaccurate in extremely wet or dry soil Not accurate in very sandy soils Indicates when to irrigate; not necessarily how much to apply
Soil moisture sensors, e.g. gypsum blocks	Relatively cheap Easy to install yourself Easy to read yourself	Labour intensive to collect and record data. Requires a digital meter to be brought to each sensor site to take readings Can be inaccurate in extremely wet or dry soil Indicates when to irrigate; not necessarily how much to apply May only last up to 18 months because of breakdown of gypsum
Neutron probe	Portable, can be moved around sites	Not suitable for continuous monitoring As equipment is expensive and radioactive, generally need to use a consultant Less accurate in sandy soil unless sampled frequently, but accurate once calibrated for a particular soil Need special training course and license
Portable capacitance probes e.g. Gopher®, Diviner®	Relatively cheap compared to permanent capacitance probes Reasonably accurate at all depths and for all soils Lightweight and portable Easy to operate and interpret Indicates both when to water and how much to apply	Manual reading required Labour intensive to collect and record data
Non-portable capacitance probes e.g. EnviroSCAN®, C-Probe®	Automatic continuous monitoring Accurate at all depths and for all soils Enables rapid reading and recording of results Indicates both when to water and how much to apply	Expensive Needs skill in interpreting data – training and support Computer required Not portable
Evaporation pan	Inexpensive, no in-field measurement needed because the system uses weather data to predict irrigation requirements Regular schedules can be developed in advance Invaluable when planning the orchard to estimate annual requirements and peak demand needs	Less accurate as it ignores soil variability and the performance of the irrigation system Cannot accurately assess the effectiveness of rainfall received Requires evaporation and rainfall data Error can build up; actual soil moisture needs to be checked periodically

Tensiometers

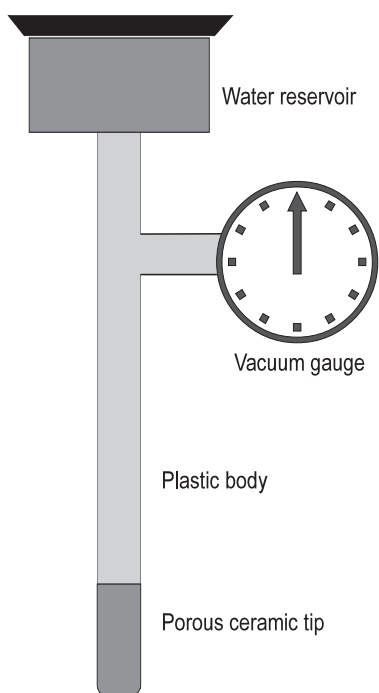


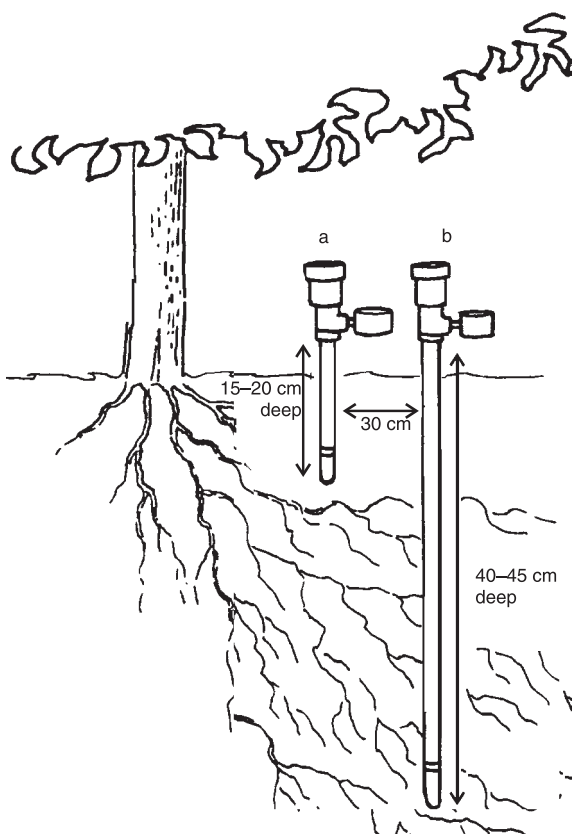
Figure 25. Parts of a standard tensiometer

Tensiometers, provided they are well sited and maintained, are a relatively cheap and effective way of monitoring soil moisture. Tensiometers consists of four basic parts – a hollow tube filled with water and algacide, a ceramic tip, a water reservoir and a vacuum gauge which reads water tension on a scale of 0 to 100 centibars (cb) or kilopascals (kPa) (Figure 25). Gaugeless tensiometers, read using a special handpiece, are also available. While the tubes are cheaper, the handpiece is expensive, but these systems should be considered if you intend to purchase more than eight tensiometers. Some handpieces enable the readings to be kept and graphed on a computer.

In saturated soil, the vacuum gauge on the tensiometer displays 0 kPa. As the soil dries, water moves from inside the instrument, through the porous ceramic tip, into the soil creating a vacuum inside the tube. The gauge measures this vacuum and readings may go as high as 90 kPa. When the soil is re-wetted after rain or irrigation, water moves from the soil back into the tensiometer and the vacuum in the tube decreases and gauge readings fall.

Monitoring sites

Tensiometers are installed at monitoring sites throughout the orchard once trees are established. Use at least one monitoring site for each variety or block. At each site, install two tensiometers — one shallow, the other deep. Position the shallow tensiometer (30 cm long) in the major root zone with its tip 15 to 20cm deep, and the deep tensiometer (60cm long) with its tip 40 to 45cm deep. Place tensiometers on the north-eastern side of trees, inside the dripline and where they will receive water from the micro-jets/minisprinklers or trickle. Ensure tensiometers are installed at the same distance from the micro-jets/minisprinklers in all blocks. Where trickle systems are used, keep the tensiometers at least 15 cm from the trickle tube. Placement of tensiometers is shown in Figure 26.



Installation

Assemble tensiometers and fill with good quality water to which algacide has been added. Adding a dye to the water also makes it easy to observe the water level. Leave them to stand in a bucket of water at least overnight, but preferably for a day or two.



Tensiometers are more reliable if a vacuum pump is used to remove any air from the tensiometer body and gauge. Make sure the pump fits snugly over the fill point on top of the tensiometer. Top up the tensiometers with more water if neces-

Figure 26. Tensiometers in place, (a) in major root zone and (b) below most roots

sary and use the vacuum pump to remove air bubbles. They are now ready to install.

Carry tensiometers to the installation site with the tips either in water or wrapped in wet rags. Do not touch the porcelain tips with the fingers as grease from the fingers can block the fine pores. To ensure reliable monitoring, there must be good contact between the soil and ceramic tip. Soil should also be compacted around the tube so there are no easy pathways for water to flow directly from the soil surface to the tensiometer tip.

Tensiometers should be installed in the tree line to give consistency of readings over the years and to avoid damage due to normal orchard operations. To install the tensiometer, follow these instructions in conjunction with Figure 27. Dig a hole to the required depth. A 50 mm (2 inch) auger is ideal for this. Place the tensiometer in the hole, over to one side. The next step is critical. Good contact between the ceramic tip and the surrounding soil

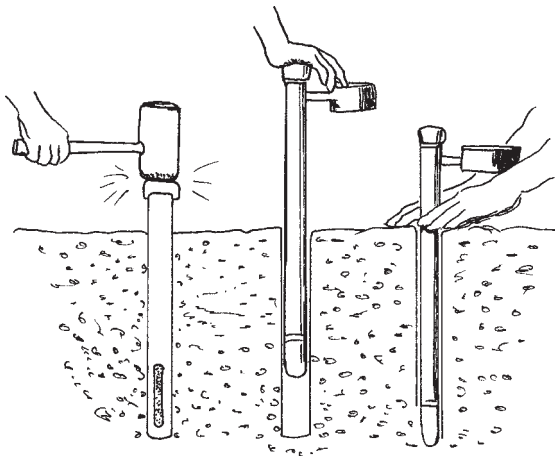


Figure 27. *Installing deep tensiometers*

is most important. Take the most crumbly, moist soil from the dirt pile and pack it around the tip at the base of the hole. A piece of 10 to 15 mm diameter dowel is useful for packing. Don't over-compact the soil into plasticine, but remove large air gaps. Continue replacing and packing soil until the hole is filled. It doesn't matter which soil you use after you have packed the first 5 cm above the tip. Friable topsoil from a few metres away can be used to create a slight mound around the tensiometer. This minimises the risk of water draining down beside the tensiometer, leading to false readings. Covers made from silver/blue insulation foil can be placed over the tensiometers to minimise temperature fluctuations and algal growth. The gauge can be left exposed for easy reading.

The tensiometers are now ready to operate. Use the vacuum pump to remove air bubbles. Tensiometers may take a few irrigation cycles to settle down, so don't take too much notice of the readings for the first few days. During this period, air gaps may appear in the tensiometer. Simply refill with algacide-treated water. Within a week of installation, readings should rise and fall with irrigation or rainfall. Clearly mark tensiometer locations to avoid damage by tractors and other equipment.

Reading

Lightly tap the gauge before reading. Read at the same time each day, preferably early in the morning, (before 8am) when there is little water movement in the soil or plant. It is best to read tensiometers daily for the first few weeks to get a feel for the system. Thereafter, read at least twice a week. The shallow tensiometer indicates when to water. The deep tensiometer indicates when the right amount of water has been applied.

Irrigating using tensiometers

During the high-demand nut development/kernel filling stage (December to February), start watering when the shallow tensiometer reads 20 kPa (sandy soils) and 30 to 40 kPa (loam and clay loam soils). Stop watering when the reading falls to 10 kPa (Figure 28).

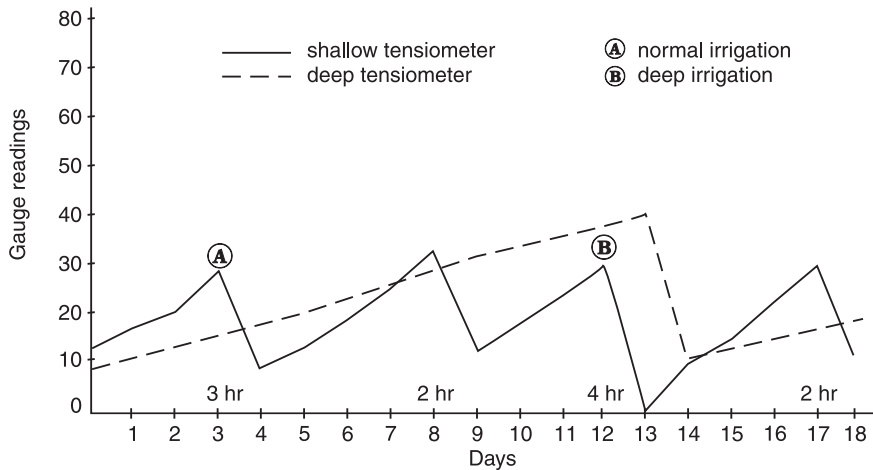


Figure 28. A sample chart showing tensiometer readings on a daily basis

Stop watering when the reading falls to 10 kPa (Figure 28). Monitor the trend of the deep tensiometer. If its readings continue to rise immediately after irrigation, not enough water has been added. If its readings fall to less than 10 kPa soon after irrigation, too much water has been added (Figure 28). Slightly lower readings should be used for drip systems.

Once a week, using the vacuum pump, remove any accumulated air and check that the gauges are working properly. Refill as required.

Capacitance probes

Capacitance probes measure the dielectric constant of the soil and consequently its water content. They are available in two forms: a portable version with brand names such as the Gopher® or Diviner® and a non-portable version with brand names such as the EnviroSCAN® or C-Probe®.

Portable versions (Gopher®; Diviner®)

These consist of a probe on the end of a rod, which is passed down 50 mm diameter PVC access tubes to determine the moisture content of the soil. A reading is taken at 100 mm intervals down the access tube and recorded by a hand-held logger. Soil moisture readings can be measured on site or downloaded into a computer and calculated later. The logger can handle up to 99 sampling sites. The machine measures soil moisture in millimetres and can be used to estimate when to water and how much to apply.

Non-portable versions (EnviroSCAN®; C-Probe®)

These are continuous moisture-monitoring devices consisting of multiple sensors mounted on probes with slots every 10 cm to accommodate the snap-in sensors. The probes are then placed within vertical PVC access tubes installed semi-permanently in the orchard. The probes are generally left in place for the season and then moved to another tube or site as required. However, a probe can be moved from tube to tube to record readings at several different sites. Sensors are positioned on the probes to provide readings at specific depths. Measurements from the sensors are relayed at set times along a cable to a data logger for recording. Data from the logger are downloaded to a computer every few days to show water use and to provide

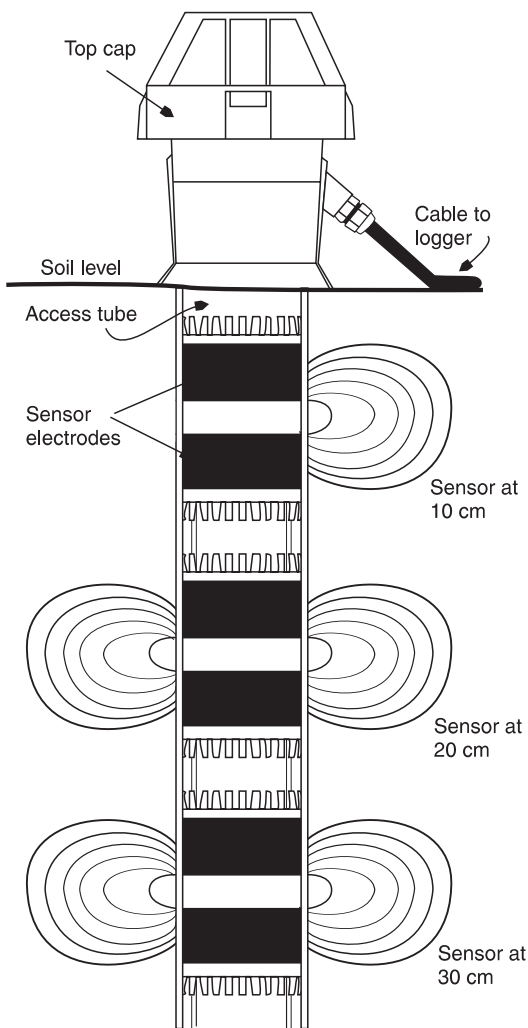


Figure 29. Diagrammatic representation of an EnviroSCAN® probe

recommendations for watering. Figure 29 is a diagrammatic representation of the EnviroSCAN® capacitance probe.

For macadamia, two probes are recommended for a block but the number of sites depends on variability in soil and varieties. The first probe should have sensors at 10, 30, 50 and 100 cm, and the second probe with sensors at 10, 30, 50, 100 and 150 cm to monitor losses from deep drainage. When setting up probe sites it is very important that water distribution patterns from the irrigation system are known and that the probes are positioned appropriately. The equipment can be hired from some consultants. As installation of probes and interpretation of the data requires some skill, we recommend consultants are used to set up the system and provide at least initial advice.

Irrigation scheduling based on evaporation

Because the water requirement for trees is largely determined by atmospheric demand, a common way of determining irrigation needs is to use evaporation from a Class A pan and a crop factor that estimates the relationship between pan evaporation and actual tree water use. It allows for canopy size and resistance by the canopy to transpiration. The water requirement calculated in this way estimates the irrigation required for mature crops only.

Research conducted in a lysimeter at Nambour between 1991 and 1995 provided data that enables a crop factor to be calculated for macadamia. The total water use per tree (L, watered to field capacity weekly) was divided by the canopy surface area (m², an index of evaporative leaf surface) to give mm of water used per square metre of canopy. This was then divided by corresponding A pan evaporation (also expressed as mm water) to give crop factors of 0.7 during spring, 0.8 in summer, 1.1 in autumn and 1.0 in winter. During the critical oil accumulation stage, a crop factor of 0.8 is therefore appropriate for macadamia.

Consequently, we can make a calculation for water need as follows:

$$\text{Water Requirement (L/tree/week)} = 0.56E \times f_1 \times R \times T$$

Where:

- E = weekly evaporation in mm from a Class A pan (Class A pan evaporation figures for three sites are given below. For other sites, figures are available from the Bureau of Meteorology for your district);
- f_1 = crop factor (for macadamias $f_1 = 0.8$ in summer, 0.7 in spring for mature trees);
- the 0.56 represents factors to relate A pan evaporation to that of an open surface of water combined with a climatic factor;
- $R \times T$ = available root area (m²), R being the distance between rows in metres and T the distance between trees in metres.

For example, for a mature hedgerow at 8 m x 4 m spacing, the water requirement in December (A pan evaporation = 42 mm/week) would be = $0.56 \times 42 \times 0.8 \times 4 \times 8 = 602$ L/tree/week. It is better to base the irrigation schedule on actual soil moisture measurements. However, calculating the water requirement as above provides a check to ensure sufficient water is being applied.

Irrigation frequency

The interval between irrigations is calculated using the number of days the tree takes to use the available water in the root zone after irrigation. If the interval between irrigations is too long, trees can be stressed before the next irrigation, and hence water use declines.

$$IT = \frac{W \times T \times D \times F}{R \times T \times Cf \times A_{pan}}$$

Where:

- IT = Interval between irrigations (days)
- W = wetted strip width (m)
- T = Tree spacing along the tree-line (m)
- D = Depth of root zone (m)
- F = Soil Type Factor, depending on soil type (sand = 60, clay = 80)
- R = Row spacing (m)
- Cf = Crop factor (e.g. 0.8), depending on canopy size, etc
- A pan = Average daily pan evaporation (mm/day)

For example, if we assume a wetted zone 3 m wide and a 1.2 m deep root system in a clay soil during December:

$$\begin{aligned} IT &= \frac{0.3 \times 4 \times 1.2 \times 80}{8 \times 4 \times 0.8 \times 9.1} \\ &= \frac{1152}{233} \\ &= 4.9 \text{ days between irrigations} \end{aligned}$$

Hours of irrigation required

$$H = \frac{R \times T \times Cf \times E_{pan}}{I}$$

Where:

- I = Rate of irrigation (L/hr/tree) = Dripper/sprinkler delivery rate x no outlets per tree

Evaporation figures

Average weekly evaporation at Bundaberg, Nambour and Alstonville

	Month	Evaporation (mm/week)		
		Bundaberg ¹	Nambour ²	Alstonville ³
¹ Mean weekly pan evaporation from the Bureau of Sugar Experiment Station, Bundaberg for the 2001-2002 season	Jan	64	40	40
	Feb	50	35	35
	Mar	44	34	31
	Apr	39	29	25
	May/Jun/Jul	22-27	20-24	18-20
² Mean weekly pan evaporation (converted) from the Maroochy Research Station, 11 year average, 1965-1973	Aug	28	24	25
	Sep	35	31	32
	Oct	43	34	36
	Nov	44	44	39
	Dec	50	42	43
³ Mean weekly pan evaporation from the Alstonville Research Station, 27 year average, 1963-2002.				

Useful conversions

Rainfall, evaporation and soil water storage are often expressed in mm but, since only a portion of the orchard (along the tree-line) is irrigated, it is often useful to express water use and storage in litres. Irrigation emitter and dripper discharge is expressed in L/hour and, since the irrigation wetted pattern is restricted to the tree-line, it is more accurate to calculate the volume of the root zone wet in cubic metres rather than in millimetres.

1000 cubic centimetres (cc) = 1 litre (L)

1 cubic metre (m³) = 1000 L

1 m³ = 1000 L

1 millimetre (mm) = 1 litre per square meter (L/m²)

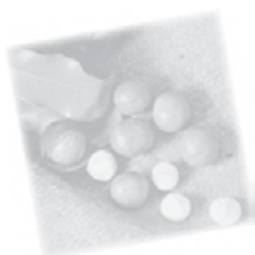
1 mm = 10,000 litres per hectare (L/ha)

100 mm = 1 megalitre per hectare (1ML/ha)

Water use (L/tree) = Water use (mm) x Canopy area (m²)

Tips for managing with limited water

- Eliminate weed competition near trees. Use herbicides rather than cultivation to avoid damaging surface feeder roots and to reduce evaporation losses.
- Keep the inter-row grass sward mown close to the ground.
- If feasible, mulch trees, particularly during the drier spring months, to a depth of 5 cm, covering the area under the trees to just beyond the canopy dripline.
- Don't over-fertilise with nitrogen as the large leaf area produced increases evaporation losses from the tree.
- Irrigate at night when electricity is cheaper and evaporation is minimal.
- Apply water to the active root zone only.
- Install a drip based or trickle system.



Pest and disease management

Being an Australian native, the macadamia tree is susceptible to a wide range of insect pests, several of which are capable of causing a significant reduction in nut yield and quality. Pest management requires regular monitoring of the orchard to determine the presence and severity of pest infestations, and the timely and thorough application of pesticides. Although diseases are fewer in number and generally of less importance than pests, some such as husk spot and trunk canker are serious enough to warrant routine preventative treatments.

An overview of the major pests

Summary of pests

Pest	Where it occurs	Time of year to monitor	Tree part affected	How serious
Spotting bugs (fruitspotting bug; bananaspotting bug)	Fruitspotting bug: coastal Qld and NSW Bananaspotting bug: coastal Qld	September to March	Nuts	Major pest, causes premature nut drop and kernel damage (considered the most important pest)
Macadamia nutborer	Qld and NSW	September to March	Nuts	Major pest, causes premature nut drop and kernel damage
Rats	Qld and NSW	All year in trees, orchard floor and surrounds	Nuts: in trees and fallen	Major pest; can cause severe losses if not controlled
Macadamia flower caterpillar	Qld and NSW Less severe in more elevated locations	July to September	Flower buds and flowers	Major sporadic pest
Macadamia leafminer	Coastal Qld & NSW	Throughout year	Lush new growth	Can be major pest in young trees
Macadamia felted coccid	Qld and NSW	Mainly July to October	Leaves, twigs and stem	Minor to insignificant if clean trees/propagation material used
Macadamia twig-girdler	Qld and NSW	September, December, March	New growth on young trees	Minor pest in older trees. Can be major pest in young trees
Latania scale	Qld and NSW	Young trees: throughout year Bearing trees: September to March	Branches and nuts	Generally minor unless sprays disruptive to beneficials are over-used
Green vegetable bug	Coastal Qld & NSW	September to March	Nuts	Occasionally a major pest in some orchards

Fruitspotting bug (*Amblypelta nitida*) and bananaspotting bug (*A. lutescens lutescens*)

Host plants

In addition to macadamia, both insects attack a variety of horticultural crops including avocado, custard apple, guava, lychee, passionfruit, pecan and citrus. Spotting bugs are usually more severe in orchards surrounded by natural scrub or rainforest.

Life cycle

Both insects pass through seven stages, the egg, five immature stages (nymphal instars) and the adult. Females lay eggs that are placed singly on nuts, leaves or terminal branches. The eggs are often placed on the edges of leaves, and in crevices on nut stalks. The eggs are oval, about 1.7 mm in length, and pale green in colour. After hatching, the nymphs go through five stages, before becoming adults. The adults are capable of mating within 5 days of emergence and can live for up to 6 months, but summer life expectancy is only 2 months. During summer, the eggs hatch in 6 to 7 days and the period required for complete development of the fruitspotting bug (laying of eggs to emergence of adults) is about 40 days. Lower temperatures reduce development rates. The insects pass through three to four generations each year, one in spring, one to two in summer and one in autumn. The adults of the autumn generation live through the winter and commence egg laying in spring. Nymphs may also be found on alternative hosts, especially mock orange (*Murraya paniculata*) during winter.

Nymphs and adults do not move far from the fruit or nuts on which they feed. Both adults and nymphs are very alert and tend to escape observation by hiding behind fruit or leaves when they are approached. It is common to find trees with fruit heavily damaged while adjacent trees are untouched. Intense areas of activity (known as 'hot spots') are well documented. These hot spots can be used to advantage when monitoring for bug activity and may also be useful for targeted spraying.

Other important issues

Most damage occurs in the September to December period. Often, the first indication of spotting bug activity is a patchy, heavy fall of green nuts under the tree. This may be especially noticeable if it occurs before natural nut fall. The fallen nuts need to be dissected and examined to determine whether the fall has been caused by natural thinning or by spotting bug.

Macadamia nutborer (*Cryptophlebia ombrodelta*)

Host plants

In addition to macadamia, the insect also attacks lychee, longan and a range of ornamental plants including bauhinia, bird of paradise tree, cupania, easter cassia, golden rain tree, mimosa bush and poinciana.

Pictures of all pests and their damage are contained in the *Macadamia problem solver and bug identifier field guide*.



Further information on diseases and disorders is available in the book *Diseases and disorders of macadamias* by R.D. Fitzell and further information on insect pests is available in the book *Insect pests of macadamia in Queensland* by D.A. Ironside.

Life cycle

Females lay eggs singly on the surface of the green husk, on the nut stalk, on the stem of the flower raceme, and sometimes on parts of the tree canopy. The scale-like eggs are oval, approximately 1.0 x 0.8 mm in size, and vary in colour from ivory-white when first laid, to red prior to hatching. Fully-grown larvae are up to 20 mm long, pinkish with discrete, dark green spots. They pupate in the damaged nuts or husks and also in sheltered sites in other parts of the tree. The eggs hatch in 4 to 6 days, larval development takes 3 to 4 weeks and moths emerge after a pupal period of 8 to 10 days. In summer, egg laying to moth emergence takes about 5 weeks.

Other important issues

Attacks on immature nuts cause premature nut fall during the December-February period. Early maturing varieties often avoid much of this loss. Husk damage to the mature nuts may cause some reduction in kernel quality. Populations usually begin to increase noticeably in November and December. The most susceptible varieties are those with a soft and thin husk and shell, such as HV A16.

Rats

Rats cause significant losses to the Australian macadamia industry, particularly in older orchards. In individual orchards, losses greater than 30% have been recorded. Most of the damage is caused by the black rat (*Rattus rattus*), which is an introduced species. Several species of native rats also attack macadamias. The black rat is actually a grey-brown colour with a grey-white underbelly that may be tinged with yellow. It can be easily distinguished from native rats, as its tail is longer than its body. Black rats will also voluntarily enter buildings whereas native rats will not.

Management

Rat management begins well before the expected peak damage period from December to February. Baiting as a control measure by itself is not effective. It needs to be implemented strategically and closely integrated with other management procedures.

Control measures include the following:

- Remove any harbourage for rats within or close to the orchard.
- Rats increase in numbers if they have access to a ready supply of suitable food. Ensure no nuts are left on the ground after harvest is completed in order to reduce the food source and discourage a build-up of the rat population.
- Avoid dumping nut waste from grading and sorting in and around the orchard. Compost nut waste (best if done after hammer milling) to ensure it breaks down quickly, or burn it. Ensure safety precautions are taken if burning.
- Avoid long, tangled grass within the orchard and headlands. Short grass in the orchard before and during harvest assists predators such as owls



See page 58 for an illustration of a typical rat bait station and information on the use of other baits in and around farm buildings.

Pictures of all pests and their damage are contained in the *Macadamia problem solver and bug identifier field guide*.



Further information on diseases and disorders is available in the book *Diseases and disorders of macadamias* by R.D. Fitzell and further information on insect pests is available in the book *Insect pests of macadamia in Queensland* by D.A. Ironside.

and hawks. Ensure that orchard verges are kept short and free of undergrowth.

- Regularly remove any rat nests from the trees.
- Bait with the registered rodenticide, coumatetralyl (Racumin®). Handle baits with care and follow the label directions. Prevent all access to the baits by children, domestic animals and non-target wildlife. Place the bait in a locked covered station. Rats prefer the seclusion of covered stations and these also protect the bait from rain.

Macadamia flower caterpillar (*Cryptoblabes hemigypsa*)

Host plants

In addition to macadamia, all known host plants of this insect are Australian native trees belonging to the family Proteaceae. They include non-cultivated macadamias such as *Macadamia ternifolia*, red bottlebrush (*Grevillea banksii*), silky oak (*G. robusta*), *G. pinnatifida*, *G. glauca*, and woody pear (*Xylomelum pyriforme*).

Life cycle

Eggs are white, oval shaped and with an average size of 0.5 mm x 0.3 mm. They are laid singly or in groups of two or three anywhere on the buds or the raceme stem. They are often hidden beneath the small bracts between adjacent bud stalks. Over 400 eggs may be laid on one raceme. Generally, moths prefer to lay eggs on racemes when the buds are about 3 to 7 mm long but may continue to lay when the flowers are at the full bloom stage. The larva goes through five instars during its development. The first instar larva is yellow and about 0.75 mm long. It bores into a floret bud, and during its first two stages, feeds within the bud, mainly on the stamens and pistil. Longitudinal stripes appear on the body of the third instar and become progressively darker during the later stages. The larva is about 12 mm long and reddish brown when mature, though it can vary in colour from light green to a slaty grey.

Mature larvae usually leave the tree and pupate in a silken cocoon in debris on the ground, but some seek out sheltered sites on the tree. The adult is a small, grey moth 6 to 7 mm long, with a wing span of 14 to 18 mm. When at rest, the wings are folded back so that three transverse, darker grey stripes at the tip of each forewing match and appear as inverted V-shaped marks. The moth is nocturnal and most mating and egg laying occurs during the first 4 hours after dusk.

Other important issues

The timing and intensity of infestations in relation to the time of flowering determines the degree of severity of the damage caused to macadamia flowers. Infestation of the main flowering begins with the migration of adult moths from other hosts. The time of migration can vary greatly, but is most common during August. In most seasons, varieties flowering early or over a short period during winter avoid attack, while those flowering later or over a

prolonged period into spring, become heavily infested. Thus the earlier the flowering, the more likely it is that attack by this insect will be avoided.

Macadamia leafminer (*Acrocercops chionosema*)

Host plants

In addition to cultivated macadamia, hosts include the non-cultivated species of macadamia, *Polyosma cunninghamii* and *Stenocarpus salignus*.

Life cycle

Eggs are laid singly, mainly on the upper surfaces of young leaves. As many as 96 eggs have been recorded on one leaf. Eggs are about 0.5 x 0.4 mm in size and oval in shape with a low, rounded profile and a flattened margin. They resemble tiny, glistening water droplets on the leaf. The larva goes through five stages during its development. The first three stages have flattened, blade-like mouthparts that are used to tear apart the leaf cells and suck the sap. The last two stages have biting and chewing mouthparts with which they cut deeper into the leaf. Larvae at first are a pale green colour but become white to bright yellow, sometimes with an underlying dark hue. During the last stage, the larva develops bright red bands. Fully-grown larvae leave the damaged leaves and seek out pupation sites in debris on the ground. Pupation occurs within an oval, flattened, silken cocoon. After moth emergence, the pupal case is left protruding from the cocoon. The adult is brown with prominent silver bands on the forewings and has a wingspan of about 8 mm. It is active mainly at night but is occasionally seen on foliage during the day.

Development from egg to adult takes 19 to 23 days in summer and 50 to 53 days in winter. In summer, the eggs hatch within 3 to 4 days.

Other important issues

Heavy pruning should be avoided, particularly during the first few years of tree life, as such pruning may weaken the tree and intensify the effects of leafminer damage.

Damage is most severe in young trees grown in elevated rainforest areas. Damage is often worst in plantings with internal windbreaks of bana grass.

Macadamia felted coccid (*Eriococcus ironsidei*)

Host plants

Restricted to macadamia.

Life cycle

The female passes through an egg and two crawler stages before becoming an immobile adult. The male, before becoming a winged adult, also has a pupal stage.

The oval-shaped eggs are laid in large numbers within the felted sac of the female. They are 0.2 x 0.1 mm in size, translucent in appearance with a pale

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pink or purplish tinge. When hatching, the lemon-coloured crawlers leave the parent. After the first moult, the insects, which are then about 0.4 x 0.2 mm in size, locate new feeding sites. Prior to the second moult the male crawlers become enclosed in their felted coverings. This covering is elongate, about 0.8 x 0.4 mm in size, white with three longitudinal ridges. The male crawlers moult to form the pupae within their coverings and the winged orange-coloured adults emerge.

The second stage female crawler moults to become an immobile adult. Mating is then necessary before it can develop its felted sac covering. This is white to yellow-brown and averages 0.7 x 1.0 mm in size with a tiny opening at the anal end.

Development is hastened by increasing temperature. The minimum duration for the complete life cycle is 42 days at 20°C. Females began to lay eggs about 4 to 5 days after forming the felted covering. Eggs are laid over an extended period, resulting in considerable overlapping of the generations, with about six generations possible in a year.

Other important issues

Dispersal over long distances is mainly passively via transport of infestations on propagative material such as budwood, cuttings, and potted nursery trees. It is worthwhile to disinfest propagative material to prevent the spread of the insect.

Natural enemies can maintain adequate control. However, when the pest is introduced into new areas, its numbers often increase and it may cause severe damage before its natural enemies can catch up and maintain effective control. In these circumstances, insecticide sprays may be required.

Macadamia twig-girdler (*Neodrepta luteotactella*)

Host plants

In addition to macadamia, the insect attacks many other native proteaceous trees such as *Banksia*, *Grevillea*, *Hakea*, *Persoonia*, *Buckinghamia*, *Stenocarpus*, and *Xylomelum*.

Life cycle

Adult females lay eggs singly in leaf axils, on terminal shoots and in the vicinity of old twig-girdler damage. Eggs are approximately 0.7 x 0.4 mm, yellow when laid and changing to reddish-orange as the embryos develop. The proportion and pattern resemble corn on the cob.

The larvae go through six to seven stages and first instar larvae are about 1.5 mm long, and yellow-orange with a black head. When fully grown, the larvae may be up to 23 mm long. They have a dark brown to black head capsule and a mottled brown body, with longitudinal rows of dark brown dots. At the prepupal stage, the larvae contract and become lighter in colour. Larvae

construct dull brown, silken cocoons (about 12 mm in length) in which the pupae develop.

The life cycle takes from 62 to 84 days. This comprises 7 days for the egg, 39 to 69 days for the larva, and 12 to 17 days for the pupa. During spring and summer, egg laying to adult emergence on trees in the field can take from 3 to 5 months.

Other important issues

The insect is active throughout the year and most damage to macadamia occurs during summer and autumn. The moths are least active during winter. Tunnelling in the husks and kernels causes damage similar to that caused by macadamia nutborer.

Latania scale (*Hemiberlesia lataniae*)

Host plants

In addition to macadamia, known hosts include avocado, bangalow palm and brush box.

Life cycle

The stages of the insect are egg, crawler, two nymphal instars, and adult. The life cycle takes about two months in summer and there are several generations each year.

Other important issues

Continuous use of broad-spectrum insecticides disrupts natural enemies of the scale and encourages scale build-up. Use of these needs to be minimised in well-managed orchards. Also avoid bringing scale into the orchard by using scale-free nursery stock.

Green vegetable bug (*Nezara viridula*)

Host plants

In addition to macadamia, the insect also attacks legumes (such as beans and soybeans), pecan, citrus, tomato, maize, passionfruit and cucurbits.

Life cycle

Female bugs lay clusters of 40 to 80 eggs arranged in parallel rows on host plants. The eggs are pale-yellow, becoming pink with age, about 1.25 mm long, and hatch after about a week. After hatching, the nymphs develop through five stages before becoming adults. The complete life cycle takes about 5 to 8 weeks. There are at least 3 to 4 generations per year. The bug over-winters as an adult and starts laying eggs in spring. It does not normally develop on macadamia, most infestations being the result of the adults migrating into the orchard from adjacent host plants such as soybeans and weeds.

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Further information on diseases and disorders is available in the book *Diseases and disorders of macadamias* by R.D. Fitzell and further information on insect pests is available in the book *Insect pests of macadamia in Queensland* by D.A. Ironside.

Other important issues

Bug feeding produces no external symptoms of damage. Damage is not usually recognised until the nuts have been shelled, when damage on the surface of the kernels is obvious. Most damage occurs from early shell hardening onwards (December onwards in southeast Queensland and northern New South Wales). The lack of external symptoms requires sampled fallen nuts to be cracked to observe the presence or absence of bug damage on the surface of the kernel.

The bug appears to be a more serious problem in northern New South Wales, and may continue to cause damage to nuts beyond the end of the period of spotting bug damage.

Diseases

Trunk canker (*Phytophthora cinnamomi*)

This is an important disease that attacks trees of varying ages. It is an especially important disease of nursery stock and young plantings under 10 years old. The fungus that causes the disease is soil-borne and can be spread in mud, muddy water, soil based potting mix, rain splash, muddy hands, machinery and even dust. It attacks a wide range of plants including pineapples, avocados and native plants such as *Acacia*, *Casuarina* and several *Eucalyptus* species.

The fungus gains entry to the trunk through wounds or natural openings such as growth cracks in immature bark. Diseased trees are commonly found in low-lying areas where water ponds, or in natural drainage lines.

Management

- Since the major infection occurs in young trees, it is best not to buy plants with black, poorly developed root systems. Only obtain plants that have been grown in a sterilised or disease-free medium. Trees should be planted into a low mound.
- Avoid wounding trunks during all cultural practices.
- In the spring, pare back affected bark and thoroughly paint butts with a registered systemic fungicide mixed in white, water-based, flat paint. Repeat in autumn, but not within one month of picking up nuts. Fungicides that can be sprayed onto the foliage to aid in control are also available.
- Trees more than two years old that have been blown over should be replaced – don't attempt to rejuvenate them. Older trees damaged in this way are very susceptible to canker. Consideration should also be given to replanting badly infected young trees.

Blossom blight (*Botrytis cinerea*)

This disease is most prevalent after intense showery periods in spring or when prolonged high humidity persists as a result of fog. It is sporadic but potentially devastating in NSW where yield losses of up to 40% have been reported. It is less significant in Queensland and is rarely seen in trees younger than 10 years of age. The fungus has a wide host range and its powder-like spores can travel on air currents. Light rain or heavy dew can also disperse spores. Outbreaks can occur when showery weather prevails for three or more days and temperatures range from 10 to 22°C. The fungus infects racemes and produces huge crops of grey spores (hence the name grey mould). *Botrytis* spores are dry spores and they can remain viable for several weeks on decaying racemes. This is important when early July flowers become blighted, as this can create an inoculum bank that might infect the main flowering in late August. New infections occur when these spores are washed or blown onto flowers that are at a susceptible stage of development and that have been wet for more than 6 to 8 hours.

The disease commonly occurs when out-of-season or early flowering coincides with cool, showery weather. However, major epidemics occur when similar conditions prevail during the main flowering (late August/September). Blossom blight is more severe in crowded orchards or in high density plantings where trees are shaded.

The susceptibility of flowers depends upon their stage of development, with flowers at the light green to white stage through to when the sepals turn brown being most susceptible.

Management

Monitor the flower racemes and determine when approximately 60% of the main flowering is in the green bud to white flower stages. During this period, monitor weather conditions and consider spraying where temperatures of around 14°C coincide with 10 hours of continual wetness. Warmer and prolonged wet conditions could lead to a severe disease risk. In dry conditions, spraying will generally not be required.

Keep in mind that a large amount of flower loss can be tolerated without significant yield reduction. If blight occurs in the July flowers, be prepared to spray the subsequent flowering. This is because inoculum can carry over into the main flowering period. The aim is to apply fungicide so that it penetrates flowers before the sepals of the flowers start to turn brown.

Thinning out or hedging is encouraged as it reduces the conditions favourable for the disease by letting in more sunlight and improving air circulation. It also promotes nut set on maturing racemes.

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Husk spot (*Pseudocercospora macadamiae*)

Husk spot can cause heavy premature shedding of nuts. The fungus has a long incubation period, making its detection difficult until after the disease has caused premature nut drop. Husk spot has been found in macadamia plantations in all major growing areas of Queensland and New South Wales. There are no reported cases of husk spot in other countries that produce macadamias. It is also unique to macadamias.

Symptoms are evident 12 to 18 weeks after the initial infection, depending upon temperature and variety. Spots are confined to the husk tissue of full sized to mature nuts. There have been no reports of infections on young nuts, twigs, leaves or flowers.

Varieties that are sensitive to husk spot may drop nuts 4 to 6 weeks earlier than non-infected trees. Fallen nuts infected with husk spot may be observed in January to March. These nuts are usually immature, having low oil content, and are unsuitable for processing.

Management

Husk spot can be spread on infected husks carried from farm to farm on machinery. Husks used for mulch pose no disease threat provided they have been composted or dried using hot air. The fungus is killed by temperatures of more than 35°C persisting for more than 10 to 14 days.

Spores are produced on infected husks during damp or humid weather. They are spread by wind and by rain splash during prolonged wet periods. Blowers and sweepers used on mechanical harvesters can also disperse spores through the tree canopy. Varieties differ in their level of susceptibility, with no variety having complete resistance.

Control of husk spot involves the application of protectant and eradicant (systemic) fungicides. Since infection begins 1 to 2 months after flowering, early season applications (when nuts are ‘match head’ to ‘pea size’) are essential for effective control. Applications should be made once a month for three months, beginning in September or early October. Once tan lesions are seen on husks, it is too late for sprays to be effective.

Spot spraying is recommended in areas known to be prone to infection, such as older, denser trees in lower areas where there is less air circulation. Harvest the entire crop as early as possible so that spores on the mature crop are dispersed before next season’s nut set.

Ensure that contract machinery coming onto the farm is clean of all traces of husk. Do not import husk from other farms for mulching purposes unless it is extremely well composted.

Growers who dehusk infected nuts from other plantings should be aware of the possibility of introducing husk spot.

NOTE

There are many other pests and diseases that affect macadamias, but these are generally of minor importance. In some locations and under certain seasonal conditions, treatment may be required. For pictures of these other pests and diseases and their treatment, refer to the *Macadamia problem solver and bug identifier field guide*.

Pest management approaches

Approaches to pest management have changed significantly over recent years. These changes are a response to the need for more cost-effective control methods, as well as the need to reduce chemical reliance.

The traditional approach

The traditional approach to pest management involved routine calendar spraying. This approach had several problems:

- It was a waste of money if pests were absent.
- There was no regard for trees being able to tolerate a small number of pests without significantly impacting upon quality or yield. Often the cost of spraying in these cases was greater than the benefit gained.
- It increased the risk of chemical damage to the crop.
- It relied upon the development of new chemicals to control pests that had developed resistance to chemicals being used. This contradicts the modern reality where fewer new chemicals are being discovered and developed.
- Workers were commonly exposed to a range of chemicals.
- There was increased chemical residue in both the crop and the environment.

The modern approach – Integrated Pest Management (IPM)

The new approach to pest management involves less reliance on chemicals by using complementary techniques in a program, hence the name integrated pest management. There are several key elements:

- Using cultural control measures such as growing less susceptible varieties.
- Using naturally occurring biological control measures such as parasites or predators (often termed beneficials).
- Using a monitoring system to determine pest and beneficial levels and using chemicals only where pest numbers exceed pre-set limits (thresholds).
- Use of sprays that have minimal impact on beneficials ('soft sprays'), and only using these sprays when necessary.

Monitoring pests

Monitoring works by first determining pest action levels – the pest population at which damage is considered of economic importance. The action level is the point at which the cost of damage is approximately equivalent to the cost of control. Pest populations are regularly monitored and control measures are applied only when pest populations approach or reach this level. Monitoring continues throughout the season to allow populations of pests to be managed at or below the action level. Not only are pests monitored, but beneficial



See *Consultants and contract services* on page 187 for details of pest consultants in your district.

insects that attack the pests are also monitored. They may be present at levels that will control the pest, negating the need for spraying.

Monitoring requires skill in observing and identifying pests and beneficials. A good knowledge of the life cycles of the pests is also important, as many treatments require correct timing to give good control. This requires considerable training and experience. **For this reason, we recommend using professional pest monitoring consultants.** These consultants visit the orchard regularly during the season to monitor pest and beneficial populations. After each visit they provide a report on pest status and action required.

Note: Diseases are difficult to monitor in the same way that insect pests are monitored. A disease is microscopic and in most cases, by the time you see symptoms, it is well established and difficult to control. We therefore rely on preventative sprays, or monitoring of environmental conditions to indicate when a disease outbreak might occur. Monitoring of diseases is nevertheless important. For example, grey mould or Botrytis disease, which infects flower racemes, is monitored in the first flowering, and if found at sufficient levels, control in the next flowering may be warranted. Monitoring is useful in detecting obvious problem areas and for evaluating how well your disease prevention program is working.

Do-it-yourself monitoring

If you wish to do monitoring yourself, we suggest you first get some training from a pest consultant or attend formal training. TAFE NSW at Wollongbar runs a course in IPM, which is very useful for those who are starting out in IPM. The main requirements for monitoring are:

Materials

- x10 hand lens;
- Notebook, prepared monitoring charts and pens;
- Paper bags or small bottles and marking pen for samples;
- Sharp pocket knife;
- Roll of coloured plastic tape.

Other

- Commitment and time to monitor at least fortnightly;
- Good eyesight;
- Good knowledge of the pests and beneficial insects.

Monitoring is not difficult. It is just a process of systematic observation and recording.

NOTE

These monitoring guidelines are a general guide only. Some consultants may vary in their approach.

How many trees to monitor

Define your orchard as blocks. A block consists of trees that are managed the same way and are about the same age. Each block should be monitored separately. If you manage your whole farm the same way, then treat it as a block. A block should be no more than 5000 trees in size. When you start out monitoring, you need to monitor enough trees closely so that you feel confident you have identified pest and disease outbreaks and any 'hot spots'. A good start is to monitor 10 nuts per tree, visiting about 5% of trees within a block, while scanning the rest of the block as you move through. These trees need to be chosen randomly. As you gain experience, the size of the sample can be reduced significantly. Many pest consultants work on a sample of 320 nuts per block taking 10 nuts per tree from 32 trees. This has been found to be statistically valid.

How often to monitor

Although monitoring usually occurs throughout the year, the critical period is from August to March. During this period, monitor fortnightly. During the remainder of the year, monitor monthly.

Monitoring procedure

Prepare some monitoring charts to record the results of your monitoring. An example of a monitoring chart is shown in Figure 30.

Each time you monitor, select trees randomly, but from different parts of the block. You need to do this until you are confident you have located 'hot spots' and understand pest movement within the orchard. Once you are confident in monitoring, you can visit 'hot spots' while scanning the rest of the orchard for damage. While moving between selected trees, keep alert and visually scan intervening trees. Inspect nuts on the trees and from the ground, of the selected trees in the block. Cut open nuts and examine the husk, shell and kernel for damage, using your hand lens. If you collect samples for later examination or identification, place them in a paper bag. These are best stored in a cooler, particularly if you are going to be in the field for some time. Mark the bags with the block name and date.

It is best to do monitoring on foot rather than drive, as trees can be inspected more thoroughly. Pay particular attention to the edges of the orchard adjacent to rainforest, windbreaks and watercourses as these are often the areas where pests first enter the orchard.

It is a good idea to transfer your monitoring results to a recording system, such as MacMan, to review the season's results. This will be very useful once you have several seasons' data, as it allows the identification of patterns and 'hot spots' of pest incidence. This will help develop and improve monitoring strategies.

Figure 30. Sample pest monitoring chart

Tree no	Pest or disease						Beneficials			
	FSB	MNB	FC							
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										
11										
12										
13										
14										
15										
16										
17										
18										
19										
20										
TOTAL										
%										

To help with monitoring, pictures of the main pests, their eggs, and beneficial insects are contained in the *Macadamia problem solver & bug identifier field guide*.



Pest monitoring and management guidelines

Spotting bugs

How to monitor

Monitor trees from all areas of the orchard, but pay particular attention to trees adjacent to bushland and known ‘hot spots’ (research has shown bugs will infest the same areas consistently each year). Note any ‘hot spots’ for future monitoring and possible targeted spraying (often termed ‘spot spraying’).

Monitor green fallen nuts for fresh damage. Sample at least 10 freshly fallen nuts from each tree, ensuring that adequate numbers are sampled to determine the presence or absence of bugs. A good method of sampling is to monitor 10 trees in known ‘hot spots’ and then examine trees randomly throughout the rest of the block, ensuring a minimum of 32 trees are monitored. Cut open the nut and separate the husk, shell and kernel. Examine each part for damage, with spotting bug damage appearing as a brown lesion on the inside of the husk. The developing shell may have crinkled areas.

When to monitor

Fortnightly from nut set to shell hardening (usually September until March).

Continue to monitor after a spray application to check spray efficacy and determine when and if another spray application is necessary.

Observe re-entry periods before monitoring again after spraying. Ignore old damage, and base spray decisions on fresh damage only.

Comments

Monitoring of the bugs themselves is difficult, as they are elusive and well camouflaged. Instead, monitor nuts for early signs of damage.

Although small nuts damaged early in the season fall during natural shedding, it is recommended to monitor from nut set because it provides a very good indication of the increasing number of nymphs, and so control can be targeted when needed.

Management

Spray when 4% of nuts monitored have spotting bug damage. Do not spray within 2 weeks of a previous spray (unless that spray for some reason was ineffective).

Parasitism and predation is considered relatively unimportant in regulating spotting bugs in the orchard, because of their continuous movement into the orchard. The assassin bug, spiders and coastal brown ants (*Pheidole megacephala*), have been observed preying on fruitspotting bugs, but generally do not give adequate control.

Macadamia nutborer

How to monitor

Monitor trees throughout the orchard, but pay particular attention to trees adjacent to bushland and known 'hot spots'. Note 'hot spots' for future monitoring.

Monitor at least 10 nuts per tree from 32 trees per block (320 nuts) for **live eggs** especially nuts in bunches, ensuring that an adequate number of trees are monitored to determine the presence or absence of nutborer. Nuts examined will usually be from marble size up (20 mm or greater in diameter), as this is the peak period for nutborer activity. As eggs are easily confused with latania scale, training in egg identification is critical. Cut open nuts, and examine the husk for larvae.

When to monitor

Fortnightly from nut set (September) to March.

Continue to monitor after a spray application to check spray efficacy and determine when and if another spray application is necessary.

Comments

The South African egg parasitoid, *Trichogrammatoidea cryptophlebiae*, may be an effective natural enemy of the macadamia nutborer. Strategies for its conservation and manipulation in macadamia plantations are still being devised, but the monitoring of natural parasitism levels in the eggs of

To help with monitoring, pictures of the main pests, their eggs, and beneficial insects are contained in the *Macadamia problem solver & bug identifier field guide*.



macadamia nutborer is important. The level of parasitism must be taken into account when determining whether or not to spray.

Management

Spraying is necessary if 1%, 2% or 3% of nuts in a sample have **live eggs** present (action level depends on nut development and variety). The 1%, 2% and 3% action levels correspond to 3, 6 and 9 live eggs in the 320 nut sample. The lower thresholds are generally used earlier in the season when the aim is to prevent subsequent generations of the pest.

Macadamia flower caterpillar

How to monitor

Examine flower racemes for eggs and larvae. Damage is often seen as webbing of the flowers, similar in appearance to grey mould (*Botrytis*). Examine randomly selected racemes in each block for eggs or larvae, ensuring that an adequate number of racemes are examined to determine the presence or absence of the pest. Monitor a minimum of 20 racemes with at least one raceme per tree. It is best to pick racemes off the tree to examine closely. As flower caterpillar eggs and larvae are easily confused with those of beneficial insects such as hover flies and lacewings, training in correct identification is critical.

When to monitor

Monitor during flowering (July to September).

Comments

Macadamias flower profusely, with only a small percentage of flowers setting nuts. Therefore a reasonable degree of damage can be tolerated.

Activity of the macadamia flower caterpillar is variable and may be sporadic, and regular monitoring needs to be conducted to determine if control is required. The macadamia flower caterpillar is generally a problem in warm and dry spring conditions. It is rarely a problem in northern New South Wales.

Management

Over 20 different insect species are either predatory or parasitic on the macadamia flower caterpillar. These natural enemies are important in regulating numbers of the pest and may provide sufficient control in seasons of low infestation. Their activity should be encouraged through the minimal use of insecticides or use of softer insecticides.

Spraying is required when:

- 90% of racemes have flower caterpillar eggs or larvae present during raceme emergence (generally up to about mid August in southeast Queensland).
- 60% of racemes have flower caterpillar eggs or larvae present during raceme extension (generally from about mid August to early September in southeast Queensland).

To help with monitoring, pictures of the main pests, their eggs, and beneficial insects are contained in the *Macadamia problem solver & bug identifier field guide*.



- 30% of racemes have flower caterpillar eggs or larvae present during flower opening or anthesis (generally early to late September in southeast Queensland).

Macadamia leafminer

How to monitor

Examine 5 terminals per tree, examining trees widely spaced throughout the orchard. It is best to monitor young trees more closely for this pest as this is where it can be a greater problem. Cut open mines to detect the larvae.

When to monitor

Monitor throughout the year. The most crucial time for monitoring is during the spring, summer and autumn periods when new vegetative leaf flushes are present. Damage is generally more severe in spring and autumn when temperatures are a little cooler.

Comments

The most severe damage occurs in elevated rainforest areas and in plantings protected from the wind. Infestation of young trees can cause severe damage, reducing growth of the trees. Vigilance is required in macadamia nurseries, where low populations can cause serious damage.

Management

Parasitism by a tiny wasp, *Elachertus* sp. (Family Eulophidae), is at times important in regulating macadamia leafminer populations. Control in the field is rarely necessary and is only needed where severe infestations occur.

Macadamia felted coccid

How to monitor

Examine 5 racemes and flushes per tree, ensuring that an adequate number of trees are monitored to determine the presence or absence of the pest. For young trees, the flush is the most important part to monitor. Examine new flush, particularly on the undersides of leaves, and if felted coccid is found, spraying may be necessary. Examine surrounding trees and only spray the trees that have an infestation.

In bearing trees, felted coccid is mainly a problem on the flower racemes, causing distortion of the racemes. Look at 20 trees widely spaced throughout the block and see if you can see any obviously distorted racemes. If 5% of racemes are distorted, then spraying will need to be considered. Note if natural enemy activity is evident.

To help with monitoring, pictures of the main pests, their eggs, and beneficial insects are contained in the *Macadamia problem solver & bug identifier field guide*.



When to monitor

Monitor for the whole year but pay particular attention to the winter pre-flowering period to stop the pest getting into the flower panicles and the spring flush of leaves. It is generally monitored while inspecting racemes and nuts for other pests.

Comments

Macadamia felted coccid is not generally a problem if planting material is pest-free. Inspect trees when they are purchased, and reject infested trees.

If you are propagating plants, disinfest propagative material by dipping it in a suitable insecticide to ensure the pest does not survive.

Management

Natural enemies generally maintain adequate control. However, when the pest is introduced into new areas, its numbers generally increase and cause severe damage before natural enemies get established and exert effective control. In these circumstances, insecticide sprays may be needed.

Macadamia twig-girdler**How to monitor**

Examine 5 terminals per tree, ensuring that an adequate number of trees are monitored to determine the presence or absence of the pest. Record the number of terminals infested on these trees. New flushes are the most susceptible to damage from twig-girdler, so pay particular attention to these.

There are many other caterpillars that can be found on new flushes of macadamias and these are generally not of concern. Most are grazers, causing the loss of a few leaves. It is important to distinguish between twig-girdler and these other caterpillars.

When to monitor

Most damage is observed in the summer and autumn periods. It is therefore best to monitor during September, December and March. Monitor young trees more frequently.

Comments

Twig-girdler is not usually a problem in bearing trees, with some damage being acceptable. It has most impact on young trees, reducing growth by killing the growing tips.

Management

On young trees with a basal trunk diameter of less than 30 mm, apply control measures if more than 15% of the terminals are damaged.

To help with monitoring, pictures of the main pests, their eggs, and beneficial insects are contained in the *Macadamia problem solver & bug identifier field guide*.



Latania scale

How to monitor

Monitor scale levels on nuts fortnightly while monitoring macadamia nutborer and fruitspotting bug. Also visually assess scale populations on twigs and branches as you pass through the orchard. Examine new growth for distortion and discolouration of foliage. Record the presence or absence of scale, and apply control measures on trees where a heavy infestation is found. Note any evidence of parasitoid or predator activity. The most crucial issue in scale management is to avoid excessive use of broad spectrum insecticides.

When to monitor

September to March.

Comments

Avoid excessive use of broad spectrum insecticides which cause disruption of natural enemies. Monitor susceptible varieties. Plant scale-free nursery stock.

Management

Avoiding the use of broad spectrum insecticides will reduce the risk of scale problems developing. Control will only be necessary when very high levels of scale are present.

Hairy caterpillar

How to monitor

Monitor small nuts while monitoring for fruitspotting bug and macadamia nutborer.

Examine 10 racemes containing small nutlets for caterpillar grazing, ensuring that an adequate number of trees are monitored to determine the presence or absence of the pest.

When to monitor

Monitor when nutlets start to form, usually while monitoring for fruitspotting bug and macadamia nutborer.

Comments

Activity of the hairy caterpillar is quite variable, and therefore regular monitoring needs to be conducted to determine if control is needed.

Management

There are natural enemies that are important in regulating numbers of the pest in seasons of low infestation. Minimise the use of insecticides to reduce the impact on these natural enemies.

Control is required when there is obvious damage evident on small nutlets.

To help with monitoring, pictures of the main pests, their eggs, and beneficial insects are contained in the *Macadamia problem solver & bug identifier field guide*.



Green vegetable bug

How to monitor

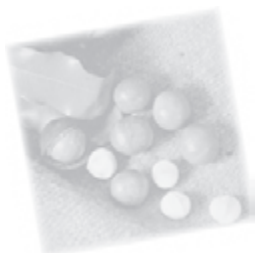
Monitor trees from all areas of the orchard in conjunction with the monitoring for spotting bugs. Monitor green fallen nuts for damage and trees for the presence of adult bugs. Crack the nut; damage appears as circular, whitish lesions on the surface of the kernel.

When to monitor

Fortnightly from nut set (September) to March (the most critical period is from early shell hardening (December) to March).

Management

Spray when 4% of nuts monitored have green vegetable bug damage or when adult bugs are observed. Sprays applied for spotting bugs are effective against green vegetable bug. Where green vegetable bug is active beyond the end of the period of spotting bug damage, additional sprays targeted specifically at this pest may be necessary.



Pesticide application and safety

Although there have been significant advances in the use of integrated pest and disease management systems in macadamias, current technology still depends substantially on the use of chemical pesticides. There are two important aspects of responsible use of chemicals. The first is efficient application so that the effect of each spray on the target is maximised, thereby reducing the number of sprays that may be necessary. The second is safety in use and application so that any impact of chemicals on operators, farm workers and the community in general is minimised.

Basic understanding of spray application

Spray application is a very complex area, but it essentially revolves around two important issues, (1) knowing and understanding the target, and (2) having the necessary equipment and skills to deposit the correct dose of chemical on the target.

Knowing and understanding the target

The first step is to clearly identify what you are targeting and understand what makes it easy or difficult to contact. For example, scales, mites and husk spot disease are essentially stationary organisms, and require very good coverage of the chemical to give effective control. On the other hand, flower caterpillars, fruitspotting bug and, to a lesser extent, macadamia nutborer and thrips move about on the plant surface and have a greater chance of coming into contact with the chemical.

Getting the right dose of chemical to the target

Once you have identified and understood the target, the next step is to ensure the correct dose of pesticide reaches it and makes maximum contact. There are four key steps in this process:

- Starting with the right concentration of pesticide in the tank mix;
- Turning the spray from your tank into droplets;
- Moving them to the target area;
- Depositing them on the target surface.

1. Starting with the right concentration of pesticide in the tank mix

By the end of 2004, every tree crop product label in Australia, including those for endosulfan, should conform to the Australian Pesticides and Veterinary Medicines Authority (APVMA) Tree Crops/Vines Model Label. The model recognises that growers use a wide range of spray volumes and that the chemical concentrations need to be adjusted accordingly. It also recognises

that different sized canopies need different doses of chemical. The label uses the high volume *dilute* (per 100 L) rate, defined as “1X”, as the base point for calculating the rates for lower volume *concentrate* spraying.

Dilute spraying

Use a sprayer designed to apply high volumes of water up to the point of run-off and matched to the crop being sprayed. Set up and operate the sprayer to achieve even coverage throughout the crop canopy. Apply sufficient water to cover the crop to the point of run-off. Avoid excessive run-off. **The required water volume may be determined by applying different test volumes, using different settings on the sprayer, from industry guidelines or expert advice.** Add the amount of product specified in the products *Directions for Use* table for each 100 L of water.

Concentrate spraying

Use a sprayer designed and set up for *concentrate* spraying (that is a sprayer which applies water volumes less than those required to reach the point of run-off) and matched to the crop being sprayed. Determine an appropriate *dilute* spray volume (See *Dilute spraying* above) for the crop canopy. This is needed to calculate the concentrate mixing rate. The chosen spray volume, amount of product per 100 L of water, and the sprayer set up and operation may need to be changed as the crop grows. Do not use a concentrate rate higher than that specified in *the Critical Comments* on the product label.

The ‘required volume’ for dilute spraying


What you will NOT find on the pesticide label is any clear indication as to what VOLUME of spray to use for a *dilute* spray and hence how to calculate the *concentrate* rate.

The appropriate spray volume for *dilute* spraying can be estimated from some measure of the tree or orchard and the nature of the pest. Research into several tree crops has determined that the appropriate *dilute* volume is in the range of 6 to 12 L/100 m³ of canopy.

The current recommendation in macadamias is to consider 6 L/100 m³ of canopy as the *dilute* volume on which to base your *concentrate* rates for both insect pests and husk spot. The recommendation to consider 6 L/100 m³ as the basis for calculating *concentrate* sprays does not mean you must use 6 L/100 m³ of actual spray for effective control. You may, for example, be able to use 3 L/100 m³ and mix at 2X concentration, or 1.5 L/100 m³ and mix at 4X. In general do not use less than 1.2 L/100 m³ or the concentration required will be over 5X. Several pesticides used in macadamias, including Bulldock 25EC® have maximum permitted concentrations of 5X.

2. Turning the spray from your tank into droplets

Spray liquid is turned into droplets at the sprayer nozzle. There are 3 main types of nozzles being used in the macadamia industry today:

 See page 156 for a process to calculate dilute spray volumes.

NOTE

As mentioned above, 1x = the concentration of a chemical at the high volume dilute rate.

- Hydraulic nozzles are the most common and rely on forcing liquid through a small jet at a relatively high pressure of 10 to 30 bar (145 to 435 psi). Higher pressures result in smaller droplets and the smaller the droplet the greater the risk of drift. Experience has shown that the best coverage and penetration is achieved with droplets ranging from 70 to 250 microns (μm) in diameter. Most nozzles will produce a high proportion of this size droplet at 15 to 20 bar (220 to 290 psi). However even at optimum pressure, 15 to 25% of droplets will still be in the 1 to 70 μm range, and prone to evaporation and drift.
- Airshear nozzles rely on spray moving at a low 1 to 2 bar (14 to 29 psi) pressure into a very high speed airstream (250 to 350 km/hr), which rips the liquid apart into small droplets. Faster air and lower flow rate results in smaller droplets. It is difficult to obtain data on droplet size for airshear nozzles but the range of droplet sizes from an airshear nozzle is less than for a hydraulic nozzle. In general, airshear nozzles produce fewer very fine droplets prone to evaporation and drift.
- Spinning disk or cage nozzles were originally designed for aerial application. As the disc or cage spins, liquid fed at low pressure of 1 to 2 bar is thrown outwards and broken into droplets by centrifugal energy. Spinning discs produce a very narrow range of droplet sizes. Droplet size increases with flow rate and reduction in speed of rotation of the discs.

3. Moving them to the target area

Droplets can move from the nozzle to the target in two ways:

- **Under their own momentum.** Droplets leaving fan jets, solid cone jets and cone jets without swirl plates have their own forward momentum. The droplets are basically fired from the nozzle and can travel a short distance on their own – this is how a hosepipe works. An airstream can ASSIST the process.
- **In an airstream.** Droplets leaving hollow cone and CDA spinning disc jets have angular momentum nearly at right angles to the target but very little forward momentum. Droplets from airshear sprayers have no momentum until air hits them.

An airstream is ESSENTIAL for droplets to travel any distance at all.

As orchard sprays consist of water-based droplets, evaporation plays an important role in determining their fate. Where small droplets are used (as is the case with most airblast and misting machines), sprays are best applied in the early morning, late evening or night, when evaporation rates are lowest.

4. Depositing them on the target surface

Droplets reach their final destination in three ways:

- They can travel straight from the nozzle in the airstream and impact the target. Turbulence improves coverage of the underside of leaves as they move in the air.

- They can travel up to the target in the airstream and then settle under gravity. This could be termed ‘drift spraying’. This is what happens once the sprayer has passed the tree.
- They can reach the target and then run off or drip to another position. This may be important in achieving coverage of nut clusters for nutborer and husk spot control.

A good result for both fungicides and insecticides is about 50 to 70 droplets/cm² on both sides of the leaves and nuts. This can be checked using water-sensitive papers.

Spray equipment

Steep slopes on many macadamia orchards means that most growers use low-profile ground-based air-assisted sprayers. On flatter ground, different types of tower conveyors can be added. Use of helicopters or fixed wing aircraft to spray pesticides may be efficient but is now rarely feasible in most macadamia growing areas.

To operate an air-assisted sprayer efficiently:

- If trees are very tall, use the machine in single-sided air-delivery mode for greater spray penetration. Single-sided conveyors are often height adjustable.
- The airstream outlet should be a minimum of about 1 m from the edge of the canopy to allow for unobstructed airflow and droplet dispersal (spraying distance in Figure 31).

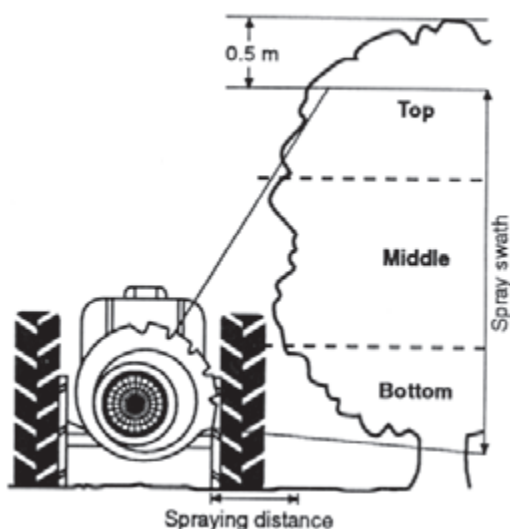


Figure 31. Positioning of spray machine to achieve effective spray swath

- Keep trees to about 6 to 7 m high, to facilitate coverage in the top part of the tree. Coverage at 6 m is rarely more than 30% of coverage at 2 m. More even canopies give more even coverage.
- Trees must be pruned to maintain a suitable alley width to avoid damage to nozzles and fans.
- Set up the machine to spray the largest trees in the orchard. The spray swath (from lowest to highest nozzle) should cover the full height of the tree, but not waste spray in the air space above the tree. Adjust the spray swath so that the top of the airstream is about 0.5 m from the top of the tree (see Figure 31).
- Select and arrange nozzles so that the largest proportion of spray volume is directed towards the top half of the tree. In a variable height canopy, apply 30:50:20% of the spray volume to the Top:Middle:Bottom of the canopy (Figure 32a).

If canopy is even in height, apply 50:30:20% (Figure 32b). It is better to use more nozzles rather than larger nozzles to achieve these differences.

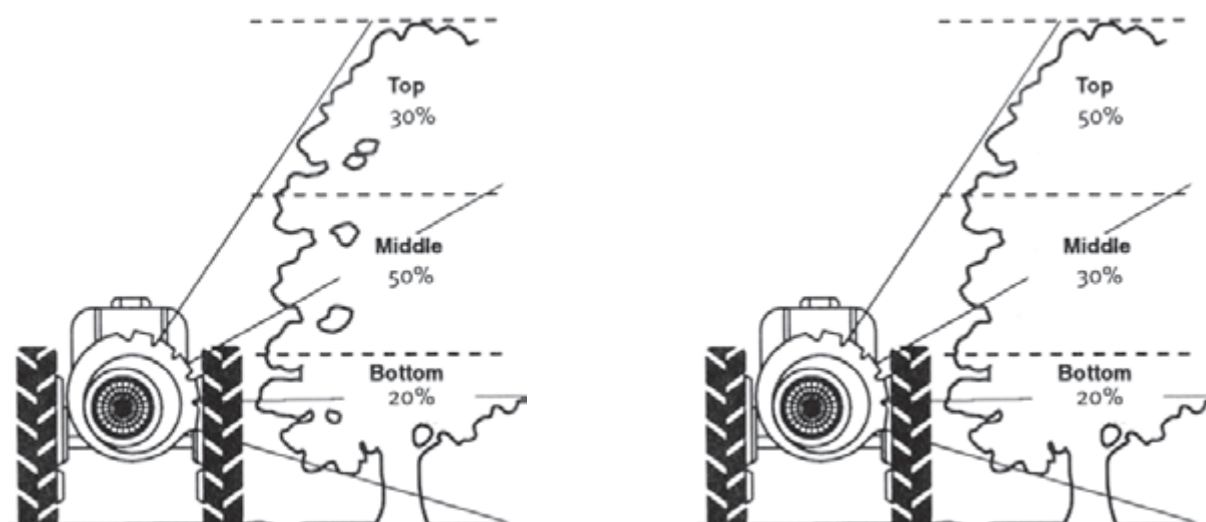


Figure 32. Nozzle selection and arrangement to achieve appropriate spray volume proportions. (a) left: variable height canopy; (b) right: even height canopy)

- Operate the machine first at a ground speed of 2 to 3 km/hr. To ensure coverage is adequate, fill the sprayer with water and check spray penetration using strips of water-sensitive paper at several positions within the tree canopy. If spray coverage is good, it may be possible to spray at a faster speed.

Types of air-assisted sprayers

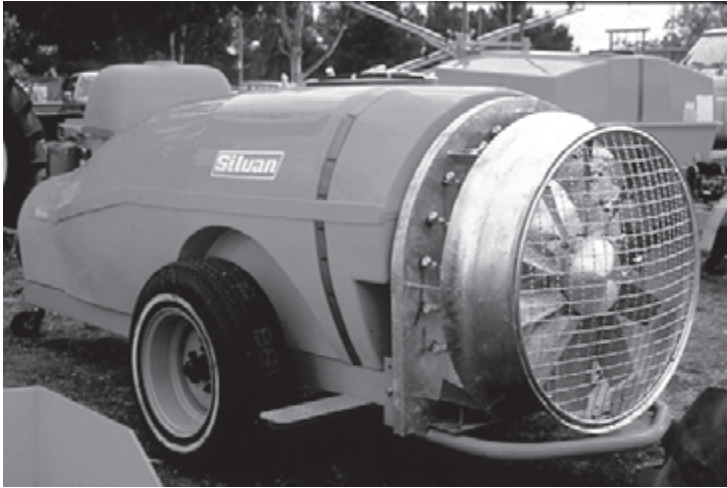
There are three main types of air-assisted sprayers used in the macadamia industry.

Airblast machines

Approximately 70% of macadamia growers use airblast sprayers. Airblast machines are designed to transport droplets produced by hydraulic nozzles in an airstream, produced by a large axial flow fan 800 to 900 mm in diameter. These machines produce high volumes (50,000 to 100,000 m³/hr) of low speed air. They are very versatile and can be operated at low spray volumes (250 to 1000 L/hectare), and also in higher volume mode (2000 to 4000 L/hectare).

Misting machines

Misting machines are designed to transport droplets produced by airshear nozzles in an airstream, generally produced by a smaller centrifugal flow fan. Droplets are produced by airshear nozzles placed in the path of a lower volume (10,000 to 25,000 m³/hour), high speed airstream (250 to 350 km/hr). These sprayers are more suitable for low volume spray applications of 300 to 600 L/hectare or less. Some airshear machines also use electrostatic charges to improve coverage and reduce drift.



A typical airblast sprayer



A typical misting machine

NOTE

Hose kits are available from:

- Australian Macadamia Society, Lismore
 - Northern Rivers Rural Buying Service, Lismore
 - Maroochy Research Station, Nambour
 - Bunaberg Research Station, Bundaberg
-

Controlled Droplet Application (CDA) machines

CDA machines use spinning discs or spinning cages driven by hydraulic motors to produce droplets. The discs, with individual fans behind them, can be separately positioned under or alongside the canopy. CDA machines are dedicated very low volume machines and produce the narrowest range of droplet sizes and least risk of drift. However in some CDA machines, droplets may escape from the airstream resulting in poor penetration of the canopy.

New developments – hybrid machines

Some CDA machines have been modified by switching from spinning disc nozzles to hydraulic nozzles. This retains the advantage of separate highly efficient fans and increases the flexibility of using medium or higher spray volumes. Separate hydraulic fans with hydraulic nozzles are now available as complete purpose-built machines or as add-ons to low-profile airblast sprayers.

Calibration

Sprayer calibration is an essential, and often misunderstood concept which covers both spray volume and pesticide calculations. Calibration should be carried out every year, just like a service of the sprayer. The process of calibration is as follows:

- Check that your pressure gauge is working and that the pressure can be adjusted.
- Check your spray jets for cracks and visible wear and replace as necessary. Clean filters and jets with a toothbrush and detergent, not with wire. Ceramic jets need changing every 3 to 4 years.
- Fill the tank with clean water, set the pressure at 10, 15 or 20 bar and operate the sprayer for a minute or so in a level stationary position to get all spray lines full.
- Check all valves hoses and nozzles for leaks.
- Then EITHER measure each nozzle output for one minute using a hose kit, OR fill the tank to a pre-determined mark, operate the sprayer in a stationary position for one minute and measure the amount of water required to top up the tank again to the pre-determined mark. For a single-sided sprayer, double the figure. This is the total sprayer output in L/min.

- Compare output with the manufacturer's specifications for the jets at your chosen pressure. This will indicate if your gauge is working. If there is a discrepancy, first check your gauge, then check for any blockages in the valves, hoses or jets.
- Check your ground speed. Don't rely on the tractor speedometer. Mark out a distance of 50 to 100 m and, with the sprayer operating, time the speed both up and down hill. Select a gear to produce an operating speed of about 2 to 3 km/hr. From this, calculate the actual speed in km/hr from the following formula:

$$\text{Speed (km/hr)} = \frac{(\text{distance (m)} \times 3.6)}{\text{time taken (sec)}}$$
- Check your coverage using water-sensitive paper or a UV dye.
- Regularly check nozzles, pressure gauge and spray volume to ensure that the desired spray volume continues to be applied. If it increases or decreases, find out why, and act accordingly. You now have the basic information to calculate your spray volumes (per unit canopy, per tree or per hectare) and to calculate the pesticide concentration to use.

For example, assuming:

- The DILUTE spray volume in macadamias is 6.0 L/100 m³
- Trees have 9 m row spacing and 4 m tree spacing, ie. 278 trees/hectare (10,000 ÷ 9 ÷ 4)
- Tree canopy is 4 m long, 5 m wide and 6 m high, ie. 120 m³ of canopy/tree (4 x 5 x 6)
- Your speed is 2.5 km/hr
- Your output is 15.7 L/min per side or 31.4 L/min total output (both sides)

To calculate the DILUTE spray volumes:

- (L/tree) = 6.0 L x 120 ÷ 100 = 7.2 L/tree
- (L/ha) = 278 x 7.2 L = 2002 L/hectare
- To calculate the ACTUAL spray volumes:
- (L/ha) = $\frac{600 \times \text{sprayer output (L/min)}}{\text{row spacing (m)} \times \text{speed (km/hr)}}$
- = (600 x 31.4) ÷ (9 x 2.5) = 837 L/hectare
- (L/tree) = 837 ÷ 278 = 3.0 L/tree
- If the ACTUAL spray volume is less than the desired amount, travel at a slower ground speed or increase jet size or number, and re-calibrate.
- To calculate the RECOMMENDED pesticide concentration:
- If your sprayer is set up for general insect spraying to spray 3 L/tree, ie. 834 L/hectare (3 x 278) you would mix your chemical at 2.4X, ie. 2.4 times the Dilute rate (7.2 ÷ 3).

Records

All users of agricultural chemicals should keep comprehensive records. Calibration and individual spray records provide good evidence of each operation should a dispute arise. Records should include such details as:

- date and time of application;
- chemical used and rate;
- block, pest and area sprayed;
- weather conditions;
- equipment and operating conditions.

In NSW under the NSW Pesticides Act 1999, there is an obligation on users of pesticides to keep written records of every application. There are additional requirements for endosulfan usage in all states.

Pesticide safety

The environment

Always think of your local environment when you are applying pesticides.

There are four main areas where pesticides can pose a threat to the environment.

- Spray drift is generally the result of incorrect sprayer set-up or spraying during inappropriate weather conditions. In areas or conditions where drift is a high risk, use larger jets and lower pressures. Do not spray in high winds or inversion conditions.
- Excessive spray run-off is caused by excessive spray volume or poor direction of nozzles.
- Inappropriate disposal of excess pesticide (both concentrate and dilute) and empty pesticide containers can pollute your land and local waterways. It is essential to ensure that there is no potential risk of pesticides entering watercourses. When using pesticides, never leave pesticide drums or containers at water fill up points, particularly when these are near watercourses or there is a risk of flooding. There are documented methods for the safe disposal but all containers should be triple-rinsed and crushed or punctured. All growers should be aware of their state and local disposal regulations.
- Poor location of your pesticide storage shed, fill up and wash down areas can pollute your land and local waterways. If chemicals need to be stored close to a water source, ensure precautions are in place to handle any accidental spillage or flooding event.

NOTE

drumMUSTER is a scheme designed to safely dispose of empty chemical containers. It is funded by a levy on farm chemical purchases. See page 194 for contact details.

Occupational health & safety

Occupational health and safety is your responsibility. Pesticides can enter the body in three ways.

- **Absorbed through the skin.** Liquids are particularly hazardous and skin exposure, particularly during handling and mixing the pesticide concentrate, may lead to acute poisoning (short-term and severe). Long-term exposure to drift from sprays or by contact with recently sprayed plants may also lead to chronic poisoning (continues over a long time). Dermal absorption occurs when inadequate protective clothing is worn. Try not to re-enter sprayed areas for 12 to 24 hours.
- **Inhaled.** This is an extreme problem with powders, dusts and fumigants. Inhalation of spray droplets may also lead to both acute and chronic poisoning. Inhalation poisoning occurs when a suitable and properly maintained respirator is not worn or where tractor filtration is not effective. If you can smell the spray, then something is not working.
- **Swallowed (ingestion).** Children under the age of five are most at risk from swallowing pesticides. The danger results mainly from inadequate storage security or improper disposal of empty containers. Never put pesticide into any type of drinking bottle.

NOTE

Some chemicals require longer periods before re-entry of people into the orchard is deemed safe. Check chemical labels for details.

Chemical accreditation

Growers must be able to demonstrate that they are meeting their duty-of-care and using pesticides safely and responsibly. One way is to obtain user accreditation under the ChemCert Training scheme. ChemCert accreditation is required for all persons wishing to purchase or use the pesticide endosulfan. In some states, some other pesticides (for example S7's) cannot be bought without current accreditation. Your nut processor or buyer, as part of an on-farm quality assurance program, may require ChemCert accreditation.

ChemCert is a special farm chemical user training course available throughout Australia. Participants undergo the training at a group workshop, complete an assessment at the end of the course and, if they pass, are issued with a statement of accreditation by their state ChemCert organisation (SMARTtrain in NSW). The accreditation is valid for five years.

Safety requirements

All pesticides should be considered potentially hazardous. However, if simple safety precautions are taken, these hazards can be minimised or even eliminated. Correct use, storage and disposal of chemicals will ensure your health and safety and that of others. Here are the main precautions:



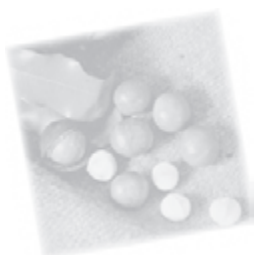
See page 193 for Chemcert contact details.

- **Always read the label before handling.** It provides advice on safe handling, storage and use.
- Obtain and study the Material Safety Data Sheet (MSDS) for each chemical used (chemical suppliers should be able to supply copies). File these in a safe place so they can be quickly referred to in emergencies.
- Use pesticides only as directed. Follow all safety directions, including on the use of safety equipment.
- Keep all chemicals in a secure location, that is in a locked, well-ventilated, well-lit room or in a separate storage area that has an impervious floor and impervious shelving. Store away from foodstuffs and eating and packing facilities.
- Store chemicals in original containers, with labels intact. Never store chemicals in food or drink containers. Re-label if a label comes off the original container.
- Ensure a suitable fire extinguisher and fresh water supply are available close to where chemicals are stored.
- Mix and measure in a level, well-ventilated area. Keep a spill kit, eg. a bucket with a bag of lime and/or sawdust, where chemicals are stored or mixed. Chemical spills should not be diluted with water.
- Place a sign ‘Danger Agrochemicals’ on the chemical store.
- Keep a first aid kit available on-farm and make sure it is in an easily accessible location.
- Do not store personal protective clothing and equipment in a chemical store.
- Do not burn containers. Dispose of empty containers immediately in the correct way.

Key points

Before any spraying make sure that:

- All equipment is in good working order.
- All equipment has been properly calibrated.
- The operator is properly trained and skilled.
- The weather conditions are suitable for spraying.
- The correct personal protective equipment is used.



Canopy management

Productivity of macadamia orchards is fundamentally dependent on maximum interception of light energy. Light interception is directly related to the amount of canopy (effective canopy volume or leaf biomass). The greater the effective canopy volume and the greater the light interception, the greater will be the photosynthetic production of carbohydrates to support the development of vegetative growth and nuts. This is provided that there are no other limiting factors such as high or low temperatures or water stress.

The ideal canopy

The ideal canopy should:

- maximise interception of radiant energy from the sun;
- maximise light penetration through the canopy to maintain optimum fruiting wood for sustainable heavy nut production;
- maximise early returns per hectare to offset the high cost of land;
- minimise energy lost in non-productive respiration such as that associated with excessive vegetative growth (that is, be no larger than necessary to achieve optimum productivity);
- minimise the amount of ‘plumbing’ needed to display canopy foliage for maximum light interception and to supply that canopy with water and nutrients from the roots;
- allow appropriate access for spray application and harvesting equipment, and management of the orchard floor.

Canopy management

The aim of canopy management is to achieve the above ‘ideal’ canopy conditions as rapidly as possible and then to maintain them during the life of the orchard with minimal pruning. Sound canopy management practices depend on an understanding of how the crop develops and the relationship between vegetative growth, flowering and nut production. By planning canopy management to start as early as possible (before orchard crowding occurs), less drastic intervention is needed and, hence, adverse effects on tree growth and production are minimised.

Light energy

Effective canopy management depends on an understanding of the role of leaves in capturing radiant energy from the sun (via chlorophyll) and converting this energy into chemical energy (sugars and more complex

carbohydrates) that is needed for growth and maintenance of the tree organs. During nut development, a large part of the sugars produced by photosynthesis are used directly to support the developing nuts, which have a high energy requirement due to their oil content. At other times of the year, excess carbohydrate is stored in tree tissues such as the wood and bark. These stored carbohydrates are then drawn upon during nut development to supplement those provided directly by current photosynthesis.

Productive macadamia orchards, therefore, depend on having a leaf canopy that captures as much of the radiant solar (sunlight) energy as possible. It is not sufficient, however, for all the sunlight to be captured by the outer leaves. Inner leaves are closer to developing nuts and contribute more carbohydrate to nut development. Thus, these inner leaves should have sufficient light for photosynthesis to support adjacent developing nuts.

In full sunlight, leaves on the outside of the canopy receive more light than they need. Some of it is captured by the chlorophyll in the leaf, some of it is reflected off the leaf surface (contributing to diffuse light) and the rest of the light is transmitted through the leaf. This light, in turn, is reflected, captured, or transmitted through the next leaf layer, and so on. As outer leaves absorb more of the total light available, there is progressively less light available for leaves in the middle of the canopy. The further light penetrates into the canopy, the more productive the tree is likely to be. Thus, canopy management for maximum productivity depends on having sufficient leaf cover to intercept the maximum amount of available sunlight as well as arranging leaves in the canopy so that as much of the available light penetrates through to illuminate inner leaves.

Canopy growth

As the canopy grows and spreads laterally, particularly in high-density plantings, branches overlap and light penetration through the canopy is reduced, although light interception remains high (mainly at the outer surface of the canopy). Because of the lower light environment in the crowded canopy, overlapping branches become spindly with fewer leaves, and trees grow taller.

Flowers are borne in the axils of leaves on mature wood. Flowering may be suppressed inside dense canopies where few leaves, and fewer active buds are present to support flowers. As canopy density increases, the crop tends to be concentrated towards the top of the tree, leaving a 'hollow centre' towards the bottom. This is important for several reasons. It becomes more difficult to get good spray coverage for pest and disease control at the top of the canopy. Air circulation is more restricted in dense canopies, thus predisposing to diseases such as Botrytis. The intense shading from the dense canopy also suppresses inter-row ground cover growth, thereby creating the potential for more soil erosion. It also slows the drying of the orchard floor after rain, and this can delay harvest and result in a deterioration of nut quality.

Young trees grow vigorously but vegetative growth progressively slows as crop load increases. Management that promotes cropping tends to inhibit vegetative growth, which is desirable in mature, bearing orchards. The lateral flowering on mature wood of macadamias is an advantage as light side pruning of the canopy is less likely to remove potential flowering sites. By commencing pruning early, there should be no need for heavy pruning and hence less disruption to the vegetative:reproductive balance and yield.

Canopy light interception

If an orchard had a continuous cover of leaves, with no alleyways between rows, light interception (the amount of radiant energy captured by the tree canopy) would be maximised and no light would be wasted (no light reaching the ground). Such an orchard would be impractical so good orchard management requires a compromise between practical orchard management and achieving optimum light interception. Light interception increases as the ratio between tree height (excluding skirt height) and alley width increases. It approaches a maximum the closer an orchard gets to a continuous cover of leaves. When light interception is near the maximum, the size, arrangement and shape (angle of hedge sidewall) of trees has less influence on the light intercepted. Light interception is greater in north-south rows than in east-west rows.

In denser (hedgerow) plantings, light penetration within the canopy is reduced because of increased light interception by denser foliage cover. As row spacings become narrower, the shape of the hedgerow (angle of cuts) has less influence on light interception. For the same total leaf cover, light interception increases as hedgerow height increases because larger gaps between leaves allow more light to penetrate into the canopy where it is captured (intercepted) by leaves inside the canopy.

Optimum tree size

The optimum tree size is a trade off between maximising light interception and maintaining a manageable orchard that has sustainable yield and quality. There are some guiding principles that growers should take into account when working out the optimum tree size for various orchard layouts:

- Yield of nuts per hectare in macadamia increases up to a high level of orchard crowding, equivalent to 90 to 95% light interception. This corresponds to a hedge height (**tree height less skirt height**) of 6 m and alley widths between 1 and 1.5 m. This is in general agreement with computer models of light interception, which predict that there is only a small increase in light interception beyond 95% when hedge height is greater than 6 m and alley width is 2 m.
- Because yield increases up to a high level of light interception, the main reason for intervening with hedging and topping is to enable access for orchard operations, to achieve good spray coverage and to achieve effective growth of ground cover.

- A 2 m alley width is generally considered the minimum for machinery access.
- Ground cover growth and orchard floor drying, both of which assist orchard access after rain, require adequate light penetration to the orchard floor. Light penetration to the floor decreases as the ratio between hedge height and alley width increases. In a ground cover trial near Alstonville in New South Wales, shade tolerant sweet smother grass (*Dactyloctenium australe*) provided good ground cover in an orchard with a 5.2 m hedge height and a 2 m alley width.
- Effective spray coverage of trees is limited at tree heights greater than 6 m. Allowing for a skirt height of 1.5 m, this corresponds to a hedge height of 4.5 m.
- While hedging and topping trees to meet these management requirements will reduce yield at least in the short term, the economic risk of not controlling tree size is significant.
- Only moderate amounts of nitrogen fertiliser should be applied once trees commence bearing to reduce vegetative vigour. Use the nutrient replacement principles outlined in the *Nutrition* section of this chapter.

Variety selection

High-density orchards of closely planted trees rapidly achieve maximum light interception but require more intensive canopy management practices to maintain the canopy. This can be alleviated by selecting appropriate varieties to suit the orchard environment. For example, where possible, select compact, upright varieties with open canopies for high-density plantings. Large, spreading varieties should only be used for low-density plantings. Macadamia orchards may be planted more densely and require less frequent pruning where tree vigour is lower, for example in cooler or drier areas, on less fertile soils or where moderate amounts of fertiliser are applied.

The search for dwarfing rootstocks is important, as it would allow higher density plantings that maximise light interception early in the life of the orchard. Furthermore, dwarf, compact trees are more easily managed to maintain an ideal canopy that maximises light interception and penetration through the canopy as the orchard matures. However, to date, no dwarfing rootstock has been found.

NOTE

Exercise caution in selecting upright varieties such as HAES 344, that appear more susceptible to Abnormal Vertical Growth (AVG) disorder in some areas.

Tips for developing strong healthy canopies



See *Plant the trees* on page 34 for full details of the things you need to check with nursery trees.



See *Training and pruning* on page 39 for full details on tree training for young trees.



See *Canopy management* on page 51 for full details on canopy management practices for bearing trees.

1. Start with healthy, well-trained nursery trees

2. Train trees carefully during the first four years

The main reason why this is important is that macadamias have a tendency to produce side branches with weak, narrow crotch angles that are prone to breakage in strong winds. As the trunk and side branches increase in diameter, bark growing between the two weakens the union. However, if the angle of the side branch to the trunk is wider, a strong woody attachment forms at the top of the junction. The branch angle depends on the variety and the type of bud from which the branch grows. In the axil of each leaf, there is a series of buds, one on top of the other. The top 'primary' bud usually grows out at a narrow angle whereas lower 'secondary' or bottom, 'tertiary' buds grow out at progressively wider angles. Thus, by selectively pruning, one is able to get side branches growing at wider angles, which are consequently more strongly attached.

3. Start to hedge (side prune), head (top) and skirt trees as soon as required (do not defer)

Hedging (side pruning)

As pruning reduces yield in proportion to the amount of wood removed, commence hedging as soon as growth encroaches on the desired alley width. This allows small amounts of wood to be removed without significant yield loss. From then on, regular, light pruning is recommended. If hedging is left until the inter-row is crowded, severe pruning is required to restore access. This is undesirable for several reasons. It removes many potential flowering sites and produces strong vegetative growth, which inhibits flowering. Also, the efficiency of the canopy is low because the leaves remaining were previously heavily shaded and they do not recover their photosynthetic efficiency quickly. This is only achieved after several growth flushes when new, efficient leaves develop in full sunlight.

Heading (topping)

Start heading or topping as soon as the desired height is reached, since drastically reducing the height of very tall trees is almost certain to result in dense regrowth, reduced light penetration into the canopy, and reduced yields, at least in the short term. Although there is little information on whether the heading cut should be horizontal or at an angle, this is unlikely to have a major influence on light interception. It is more likely to affect light distribution down the side of the hedge as the top of the tree grows more vigorously and tends to shade the lower portion. Cutting the top back at an angle will minimise this effect. Heading also allows better spray coverage for pest and disease control by maintaining the canopy (and target flowers and nuts) within the effective range of spray equipment.

Skirting

Remove branches that are close to the ground that will interfere with cultural operations such as harvesting, weed and pest control. If suspended sprinkler irrigation systems are used, remove any branches that may interfere with water throw.

More drastic measures in canopy management

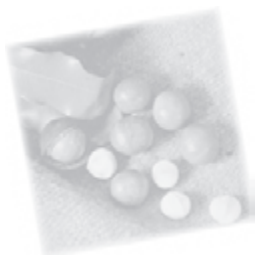
Tree removal

Tree removal is sometimes advocated in high density plantings. Despite claims of yield increases from tree removal in Hawaii and South Africa, trials in Australia have clearly demonstrated that tree removal does not increase yield. It merely results in lost production until the canopy closes again. Hence, there does not appear to be any compelling evidence to support this practice.

Limb removal

Limb removal has been advocated for opening up the canopy to improve light penetration. This is less drastic and less expensive than tree removal, with costs around half of the cost of tree removal when 20 and 30% of the canopy is removed. More than half of the cost is due to disposal of limbs by chipping. However, it does not appear to result in a sustained yield improvement in old mature trees, because the gap is soon reoccupied by a proliferation of regrowth. The gain in better light distribution is offset in the short term by the loss of fruiting wood. The one instance where limb removal is useful is in removing weak branches, particularly those with weak crotch angles that are prone to splitting.

Note that if the removed limbs are chipped, it is preferable to compost them before use around trees. If used fresh, extra nitrogen fertiliser may need to be applied to compensate for the nitrogen used up in decomposition.



Orchard floor management

Orchard floor management is a vital issue in macadamias for the following reasons:

- Maintaining a surface that maximises the pick-up of nuts and minimises the carry-over of old nuts to the following harvest;
- Providing a soil environment to foster the development of a healthy root system and the uptake of nutrients; and
- Controlling runoff water and minimising the potential for soil erosion and the loss of nutrients such as nitrogen and phosphorus from the orchard.

Consequently, it needs to be considered from orchard establishment right through to managing bearing trees.

Orchard establishment

Important issues in orchard establishment include:

- **Controlling overland water flow and runoff.** Uncontrolled runoff causes soil erosion and exposes the surface roots to desiccation. Poor drainage can lead to tree death. A surface drainage system is required to control and direct water flow. It is much easier and cheaper to construct this drainage system before planting the orchard. Remember that drain channels need to be protected by grass or plant cover to prevent scouring. This is normally achieved by the planting of creeping grasses such as carpet grass, kikuyu, couch or sweet smother grass. An annual grass such as millet or oats may also be necessary to provide temporary protection to the channel while the creeping grass is being established.
- **Planting density.** The importance of orchard floor management increases with the density of planting. This is because in denser plantings, less sunlight reaches the orchard floor and it becomes harder to maintain plant cover there. This increases the potential for soil erosion and nutrient loss. An alternative is to use shade tolerant species such as sweet smother grass.
- **Land preparation.** During land preparation, ensure that issues related to orchard floor condition are attended to. For example, remove or bury any surface stones where possible, as these cause excessive wear on finger-wheel harvesters as well as damage dehuskers. Where a subsoil compaction layer from previous cultivation or grazing exists, deep rip along the rows. Ripping may also assist with the drainage of wet areas and springs. Before planting, adjust soil pH and levels of those nutrients such as phosphorus, calcium, copper and zinc, which are more difficult to adjust once the trees are in the ground. Establish a permanent grass cover using carpet grass, kikuyu, couch or sweet smother grass on any



See *Plan the orchard layout* on pages 20 to 22 and *Control water flow within the orchard* on pages 30 to 32 for more detail on the planning and construction of drainage systems.

NOTE

Further information is available in the NSW Agriculture AgNote *Reducing soil degradation and erosion in macadamia orchards*.



See pages 27 to 33 for more detail on land preparation.

disturbed or bare areas to prevent further soil erosion. An interim fast-growing cover crop such as oats in autumn or winter or millet in spring or summer may be necessary to stabilise the soil while the permanent grass cover is being established.

Young trees

The first three to four years of the orchard provide an excellent opportunity to establish a vegetative ground cover and to build up soil organic matter levels.

Maintain the grassed inter-row area and divert slashed grass from it to the tree rows, using a side delivery slasher. The inter-row area is a valuable source of mulch. Do not slash until the grass is 15 to 20 cm high to ensure a sufficient volume is available.

Alternative mulches include coarse straw and composted nut husk. The mulched area should extend to just beyond the canopy dripline. Where herbicides are used, keep the sprayed area along the tree line to a minimum to reduce the potential for soil erosion.



See page 169 for more information on composting.

Bearing trees

When orchards begin to bear, the need to maintain a healthy soil environment and minimise soil erosion and nutrient loss is balanced against the need to efficiently harvest nuts from the orchard floor. As trees crowd in orchards, non-shade tolerant inter-row grasses die out and leave the soil vulnerable to erosion and overland movement of nutrients. There are two main options at this stage:

- A vegetative ground cover grown under the trees as living mulch, or
- The area under the canopy is kept weed free with a combination of imported mulch and herbicide spraying.

Mulching, whether by living mulch or imported mulch, has many advantages:

- Adds organic matter and increases organic carbon (C) levels. Organic matter provides food for soil life and increases stability of the soil so it becomes more resistant to erosion and compaction and holds more moisture;
- Improves soil structural stability, moisture holding capacity and water infiltration;
- Reduces soil moisture loss;
- Helps to control weeds;
- Reduces soil temperature variation, thus reducing soil water loss;
- Protects the soil against erosion;
- Adds some nutrients (slow release);

- Encourages a wide range of beneficial soil organisms (microbes and earthworms), which improve soil health.

Under-tree ground covers

This option has the advantage of enabling mechanical harvesters to enter the orchard more easily following wet weather. Living mulch ground covers need to have the following characteristics:

- Low growing, so that they are less competitive, require less mowing and minimise the number of nuts left behind on each harvest round (height of preferably less than 3 cm during the harvest season);
- Shade tolerant;
- Non-climbing;
- Persistent under regular mowing.

NOTE

Further information is contained in the NSW Agriculture publication *Shade tolerant ground cover in macadamia orchards* and the NSW Agriculture Agnote *Sweet smothergrass – a perennial groundcover for subtropical orchards*.

To date, sweet smother grass has been identified as the most suitable perennial ground cover for Australian macadamia orchards. It is established by runners or turf. Rolls of sweet smother grass can be obtained from some specialist turf suppliers. It is best established before total canopy closure. It can be planted in spring, summer or autumn. It needs to be watered in if there is no follow-up rain. Where irrigation is unavailable, autumn is usually the best time to plant.

Mulching and herbicide use

Sources of mulch include grass slashings from the inter-row area, leaf drop, tree prunings and composted nut husks. Whatever the source of mulch, it needs to be managed so that, at the time of harvesting, a minimum of coarse material remains on the soil surface. This is because coarse mulch can interfere with mechanical harvesting. Even with hand harvesting, mulch needs to be well settled or chopped up finely prior to nut drop. The best time to apply mulch is after harvesting is completed. A layer up to 5 cm deep is ideal.

Slashings from the grassed inter-row area can provide a valuable source of mulch until shading reduces the volume available. Fallen leaves and tree prunings need to be finely chopped up with implements such as offset flail mulchers otherwise they interfere with finger wheel harvesting equipment. This material is best placed on the soil surface under the trees rather than in inter-row areas. If husk is to be applied as mulch, it is recommended that it is composted properly before use.

Herbicides are used to control any weeds that grow through the mulch. Management of herbicides is important, particularly when nuts are on the ground.



See page 41 for more detail on herbicide management.

Tree decline

A condition known as tree decline can occur, particularly in orchards on marginal or eroded soils, or on steeper slopes, or following environmental stress. It can significantly reduce yields and the life of the orchard. Older trees are most affected. Some varieties such as H2, HAES 508 and HV A4 appear more susceptible to the problem. In the case of HVA4, this may be due to its need for additional fertiliser to compensate for its precocious habit.



See page 56 for more detail on treatment of tree decline.

Trees affected usually have a reduced fine feeder root system. Sound cultural practices that sustain soil structure and fertility and provide an environment for healthy root development are important in reducing the incidence of decline. This increases the importance of the effective use of surface drains and vegetative ground cover to limit water flow, thus reducing soil erosion and exposure of surface roots.

Overcoming decline is a slow process. Treat affected trees as soon as symptoms are visible.

On-farm composting for mulch

(Adapted from Jenkins, Abigail and Van Zweiten, Lukas (2003) *How to compost on farm*. NSW Agriculture Agnote DPI-448)

Composting is the breakdown of any organic material into a crumbly, dark, soil-like product in which none of the original material can be easily identified. Various organic waste materials produced by farming such as nut husk, effluent, vegetable waste, stubble and so on can be used to produce compost. Nut husk makes an ideal compost to use as mulch for macadamia trees.

Types of composting include:

- **Vermicomposting** – where worms are used;
- **Passive composting** – where plant waste degrades slowly, for example when mulch is added to soil;
- **Thermophilic composting** – where organic material breaks down rapidly. Here, the compost pile gets hot and sterilises weed seeds and disease organisms.

The information contained below relates to thermophilic composting.

What you need to make good compost

The key elements needed when making good thermophilic compost are:

1. Aeration

To ensure air can move in the compost heap, it is important to turn the pile regularly and include a range of different sized and shaped materials. BUT,

remember that large pieces of woody material will take much longer to break down than smaller ‘chips’.

2. Moisture

Ideally, water content should be 50 to 60% (it feels like a moist sponge but no water comes out when you squeeze it with your fingers). To make sure the pile stays wet enough during the composting process, you may need a water supply to keep moisture up to the pile.

3. Organic ingredients

Good compost must have a balance of carbon-rich (woody material) and nitrogen rich (green leafy matter or manure) materials. The ideal is a carbon:nitrogen (C:N) ratio of about 30:1. Materials can be selected and mixed to achieve this desired ratio. Materials with a C:N ratio significantly lower than this (for example lucerne hay), tend to decompose too rapidly and raise nitrogen levels too high. Materials with a C:N ratio that is significantly higher can cause a nitrogen draw-down effect unless extra nitrogen fertiliser is applied (the material takes nitrogen from the soil in order to decompose, thus starving the tree). A list of materials and their approximate C:N ratios is shown in Table 30.

Table 30. Approximate carbon:nitrogen (C:N) ratios in a range of dried materials (after Handreck, K.A. and Black, N.D. (1994). *Growing media for ornamental plants and turf* (revised edition). University of New South Wales Press; and Jenkins, Abigail and Van Zweiten, Lukas (2003) *How to compost on farm*. NSW Agriculture Agnote DPI-448)

Material	Carbon : Nitrogen (C:N) ratio
Pinus radiata sawdust	500
Cardboard/newspaper	500-600
Eucalyptus sawdust	500-800
Sugar cane bagasse	120
Woody tree prunings	100
Wheat or oats straw	80-100
Sugar cane tops	80-100
Mature leaves/soft tree prunings	50-60
Macadamia nut husk	40
Non-legume hay/corn stalks	35
Horse manure	30
Mill mud (filter press)*	25
Grasses/grass clippings/mixed weeds	15-20
Cow manure	15-20
Lucerne hay	10-15
Poultry litter	10-15
Pig and poultry manure	5-8
Blood and bone	3-5

* Note that this figure is for mill mud only. Some sugar mills blend fly ash with mill mud and this mixture will have a different C:N ratio

4. A suitable area

You will need to dedicate an area to composting for at least three months. The area you identify should be relatively flat and free of stones, tree stumps, drainage lines and weeds (especially bulbous weeds). A good base for the compost pile can be created using crusher dust. There should be enough room for machinery use to turn the compost. The pile should be located so it will not contaminate adjacent land or waterways via wind drift and water runoff.

5. Machinery

If making a large amount of compost, you will need machinery to turn the pile. A front-end loader or excavator is ideal. Alternatively, you may consider hiring a machinery contractor.

6. Cover

You may need to cover the pile if there is excessive rainfall.

Making the compost

1. Constructing the pile

Mix all materials and construct a pile that is between 1.5 and 2 m high and 2 to 3 m wide. It can be as long as required. Using these dimensions, every 1 m in length will make about 3 cubic metres of compost.

Add water so that the pile is wet through but not soaked. Check a sample. It is wet enough if it glistens with water but doesn't drip excess water.

2. Turning the compost pile

After about one week, check the temperature in the pile. It should be between 50 and 65°C (this is now considered a thermophilic compost). Use a shovel to dig a hole in the middle of the pile. You will probably notice steam rising and the compost should feel uncomfortably hot. You can check the temperature accurately with a thermometer or a data logger, which transfers temperature information to your computer.



Preparing nut husk compost on a farm in New South Wales

If the temperature is right, turn your pile about seven days after measurement, or when the temperature starts to decline. If the temperature is above 70°C, turn the pile immediately and reduce pile height to a maximum of 1.5 m.

When turning the pile, ensure the materials from the outside of the pile are placed on the inside. This can be achieved by rolling the pile over using a front-end loader or lifting the pile and dropping in its original place using an excavator.

NOTE

It is important for the compost pile to reach about 60°C to kill any unwanted pathogens and weed seeds and break down all the material properly. It must not get hotter than 70°C as this will reduce the nutrient and carbon value of the compost and kill beneficial decomposer organisms.

3. Monitor the temperature

Keep monitoring the temperature on a weekly basis and turn the pile after the correct temperature has been reached each time. The pile will probably need to be turned at least three times before the compost is ready for use but may need up to six turns, depending on the materials used. Once the pile has stopped producing heat, let it 'cure' for at least two weeks before use.

4. Trouble shooting problems

Some common composting problems and their remedies are shown in Table 31.

Table 31. Trouble shooting problems

Problem	Cause	Remedy
Excess water running off	Compost too wet	Add dry materials or let pile dry out a little
Bad smell	Anaerobic conditions	Add larger materials and turn more often
Ammonia smell	C:N ratio too low	Add extra high-C materials
Clumping	Compost is too wet	Add dry materials and turn
Pile won't get hot after set-up; the compost process does not appear complete	C:N ratio too high	Add high nitrogen materials, but avoid fertilisers such as urea
	Moisture is incorrect Too little oxygen	Adjust accordingly Turn pile

When is the compost ready?

Good quality compost should take about 8 weeks to complete; macadamia nut husks can take up to 12 weeks. It is very important not to use the compost before it is ready as beneficial organisms will not have established, and nitrogen will have been temporarily taken by the decay organisms and be unavailable to the trees. When the compost is ready it has the following distinct characteristics:

- **Smell:** nice earthy smell, with no sour or rotten odours;
- **Feel:** moist and earthy; not wet and sloppy or dry and powdery;
- **Appearance:** original organic materials are not distinguishable. Pile contains dark soil sized particles;
- **Temperature:** pile stops getting hot;
- **C:N ratio:** between 15:1 and 20:1 (a laboratory test for this costs about \$25).

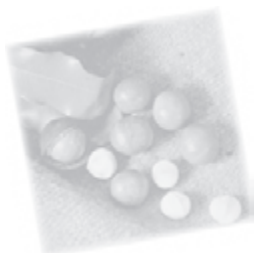
The composting process takes longer if there is insufficient water or too much carbon rich material.

Applying compost

For small farms, compost can be raked out by hand or applied using a manure dropper of about 1 cubic metre capacity, attached to the three-point linkage of a small tractor. The bin can double as a scoop for filling, making this an effective one-person operation. Do not apply compost more than 50 mm deep and do not allow it to build up around the trunk, particularly in young trees.

For larger farms, a mechanical spreader with 3 to 4 cubic metre capacity is required. In some areas, contractors are available for hire. A separate front-end loader is desirable. There are two types of spreader:

- **Disk or twin disk spreader.** This throws compost out behind the hopper and is effective at getting an even coverage to a depth of 30mm. Compost is either thrown out to one side by a single disk or spread both sides using a twin disk. However there is little control over where the compost ends up so it is difficult to limit the compost to a particular area such as the dripline.
- **Belt spreader.** This consists of a large bin with a moving belt for the floor. An opening at the end of the bin allows the compost to exit. The quantity of compost delivered depends on the speed of the belt and the size of the opening. A belt spreader will place the compost in the row in a pile 30 mm or more thick. It may then have to be spread further using a rake or other machinery. The advantage of using the belt spreader is the more accurate placement. The disadvantage is the need for further spreading.



Propagation

Most macadamia trees are propagated by grafting or budding selected varieties onto seedling rootstocks. When establishing an orchard, there is a choice of buying or propagating your own trees. Propagating macadamias, however, is a difficult and specialised operation. For this reason, it is best left to specialist macadamia nurseries. However, a basic knowledge of the process is valuable to assist in understanding nursery tree quality. In addition, topworking existing trees to new varieties may be an option for some growers instead of replanting with new trees.

Terminology

- Grafting** The art of joining parts of different plants together so they unite and form a single new plant: one forming the root system (the rootstock), the other forming the tree canopy (the scion).
- Rootstock** The rootstock (or stock) is the lower portion of the graft below the graft union, from which the root system of the grafted tree develops. A seedling rootstock is a rootstock produced from a seed and a clonal rootstock is a rootstock produced from a cutting.
- Scion** The scion is the upper portion of the graft above the graft union. Initially, it consists of a short section of a branch from a mother tree of the desired variety, containing about three nodes or whorls of well-developed buds that, when grafted onto the rootstock, forms the tree canopy of the grafted tree.
- Callus** When plant tissues are damaged, the cambium layer is stimulated to produce callus tissue of unspecialised (parenchyma) cells, designed to heal the wound (like a scab). In grafting, the cambium of both stock and scion are placed close together and the callus produced by both ‘knits’ and interlocks. Eventually the unspecialised parenchyma cells develop into specialised wood and bark tissue to form a permanent and strong union.
- Cambium** The cambium is a thin layer of very specialised (meristematic) cells between the bark and wood, capable of dividing and forming new cells. The cambium is responsible for the growth in trunk diameter of woody plants. Matching the cambium of the rootstock and scion is essential for successful grafting.

- Cincture** Cincturing (or girdling) is the process of interrupting the downward flow of sap in the bark (usually by removing a strip of bark right around the base of the stem). This allows carbohydrates, auxins and other growth chemicals to accumulate above the cincture. In macadamia, this buildup of materials enhances the successful ‘take’ of grafts.
- Cuttings** A section of one plant that under the right conditions forms a complete new plant. Stem and leaf cuttings initiate new root systems while root cuttings initiate new shoot systems. When cuttings are taken, specialised meristematic cells that have the ability to divide are stimulated to produce a mass of callus tissue that forms the new roots (for stem and leaf cuttings) or shoots (for root cuttings).
- Clone** A vegetatively produced plant that has the same genetic make up as the parent plant from which it was produced. Note that a cutting is a clone of the parent plant.
- Topworking** Topworking is used to change a tree from one variety to another by grafting wood from a desirable variety onto the stump (or major branch) of a superseded variety, or preferably onto the original rootstock of the tree.
- Budding** Budding or bud grafting uses a small piece of bark with a single bud to form the scion.
- Budwood** Scion wood or bud sticks taken from the mother tree of the desired variety to form the scion of the graft.

Why use rootstocks?

The main reason macadamia trees are grafted or budded onto rootstocks is to obtain varieties that are less variable and more precocious than seedlings. However, it is also possible to get true-to-type, precocious trees directly from cuttings, without the need for rootstocks. Clonal macadamia trees (produced from cuttings) are widely and successfully used in South Africa. There, trees are produced in two ways, either from rooted cuttings (without rootstocks), or by grafting a scion variety onto a rooted cutting. Rooted cuttings give a more uniform orchard because they are genetically identical. Seedlings, on the other hand, are genetically diverse.

In other tree crops, rootstocks are also often important in contributing desirable characteristics such as disease resistance and dwarfing. However, there is little information yet available to indicate such benefits with grafted macadamia trees. This may emerge as current and future research is completed.



See page 181 for more information on cuttings and their production.

Understanding the basics of propagation

While there is some interest in growing trees from cuttings, the majority are grafted to seedling rootstocks. A bud or bud stick from the required variety is grafted onto an established rootstock or, in the case of topworking, an established tree. The most commonly used variety for rootstock production is H2 (Hinde). H2 seedlings are used because they are uniform (most seedlings look and perform like the mother tree), vigorous, and easy to graft. However, it must be emphasised they are not true-to-type. Renown (D4), which was used in the past, was highly variable, producing a very diverse progeny of seedling rootstock trees. Very little is known about rootstocks and their effect on production except that grafted trees are more uniform and come into production much earlier than variable seedling trees.

The scion wood is generally cinctured 5 to 6 weeks before grafting, depending on variety and season, by removing a strip of bark about 15 to 20 mm wide from the base of suitable branches 15 to 20 mm thick. A pair of pliers can be clamped around the branch to squeeze and tear the bark in a twisting motion



Cinctured wood ready for grafting

around the branch. Branches should be mature but not old. They should also be healthy, leafy, long, evenly thick with long internodes, and preferably with no side shoots. Cinctured scion wood is ready for grafting when the cincture forms a good callus, indicating buildup of carbohydrates in the budwood above the cincture. Do not allow the callus to heal over as this will allow the buildup of stored carbohydrates to bypass the cincture. If necessary, trim the cut to remove callous overgrowth.

Bud grafting (budding) is a specialised operation, requiring skill and experience.

It is less wasteful of scion wood and scion wood branches do not have to be cinctured. Budding is usually done in spring when sap flow is expected. The bark must lift readily from the cambium layer on both budwood and scion wood.

Raising seedlings for rootstocks

Potting mixes

The choice of potting mix will depend on availability and cost of ingredients, and the method of watering. It should be well drained, particularly if automatically-timed, overhead sprinkling is used. If watering on demand, heavier mixes can be used. Potting mixes containing soil and madacamia husk tend to settle in the pot, thus reducing air-filled porosity, a requirement for

good seedling root growth. Soil also presents a disease risk unless sterilised. Some examples of potting mixes (by volume) that are used include:

- one part coarse river sand; one part composted macadamia husk;
- one part coarse river sand; one part peat; one part soil;
- One part coarse river sand; one part composted sawdust; one part composted pinebark.

Potting mixes, especially those containing soil, should be sterilised before use, although sterilisation of potting mixes is not universally carried out in macadamia nurseries. Steam pasteurisation at 65°C for 40 minutes is ideal. Methyl bromide is sometimes used for sterilisation but is less popular. After treatment, add fertiliser and mix thoroughly. Two commonly used fertiliser combinations are shown in Table 32.

Table 32. Common fertiliser combinations for macadamia potting mixes

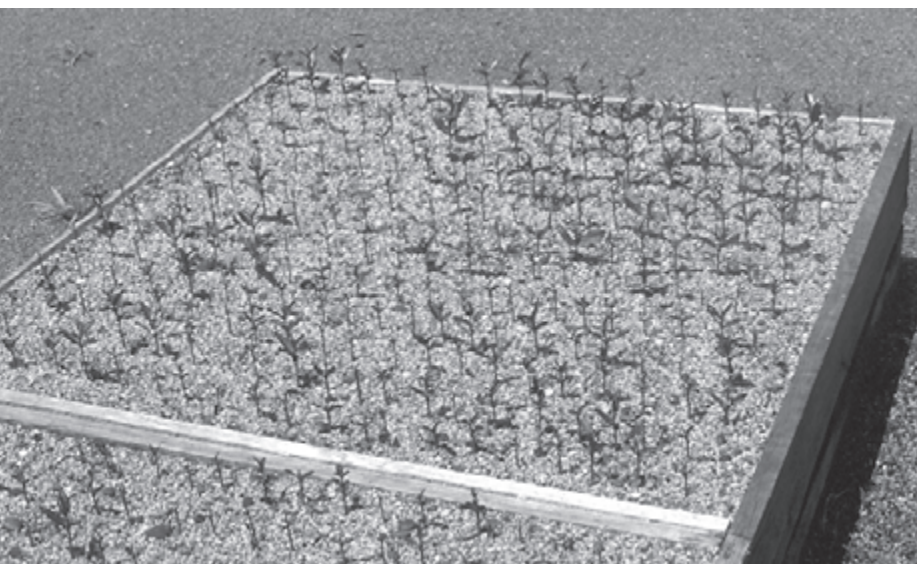
Combination 1 (per cubic metre of mix)	Combination 2 (per cubic metre of mix)
325 g sulphate of ammonia	1 kg fine superphosphate
1 kg fine superphosphate	1 kg fine lime
200 g potassium nitrate	1 kg fine dolomite
3 kg dolomite	3 kg 9-month slow release NPK (18:2.6:10 or similar)
1 kg trace element mixture	1 kg 3-month slow release NPK (16.3:3.5:10 or similar)
	1 kg slow release micronutrients
	0.5 kg coated iron
Note: with this combination, seedlings need additional fertiliser after they have started to grow.	Note: with this combination, the slow-release fertilisers should last for several months.

Many brands of trace element mixtures are commercially available. However, 1 kg of the trace element mixture referred to is approximately equivalent to 50 g iron sulphate, 12 g copper sulphate and 6 g zinc sulphate.

Raising seedlings

Seeds are easy to germinate. They can be planted at any time as long as they are protected from extremes of temperature. To reduce contamination, harvest the green-mature nut-in-husk from the tree and dehusk straight away. Plant the nut-in-shell immediately or store in a perforated plastic bag for up to 12 months in the warmest part of a refrigerator or cold room. Do not store or plant nuts that are damaged or pre-germinated as the resultant seedlings may be distorted and have multiple shoots.

Seeds can also be planted directly into pots or planter bags, but this is wasteful. The most common method is to plant into seedbeds, usually of coarse river sand, and then replant the seedlings into planter bags. To ensure an even batch of seedlings, place the nuts in an unshaded, raised bed lined with black plastic, and water three times a day. When the shells split, plant them out into a seedbed, ensuring that the suture is on the side, parallel to the soil surface to allow unhindered root and shoot growth. When the seedlings are



A macadamia seedbed



A nursery with seedlings. Note that the planter bags are on pallets on gravel to provide good drainage and to prevent contact with the soil

big enough (approximately 10 to 15 cm or when 6 to 8 leaves have formed) and the first flush has hardened, plant them into 9 L planter bags to avoid distortion and twisting of roots. To maintain good drainage and minimise disease, keep the seedbed and planter bags off the ground on pallets or on a bed of gravel.

Growing-on

Seedlings are ready for grafting in 12 to 18 months. They should be well grown with long internodes for ease of grafting. Segregate the young trees for size, and discard unthrifty trees.

Container-grown plants

The main advantages of growing plants in polythene planter bags are the ease of handling, lack of disruption to the root system at planting, and relative freedom from root diseases. Ideally, the planter bags should be at least 300 mm deep (9 L preferred—6 L minimum) to encourage a framework of straight, well-developed roots. Trees may be kept in these bags for up to 24 months.

Be careful not to over-fertilise young trees. It is easy to upset the phosphorus:iron balance, the consequence being yellow, unthrifty leaves. The best approach is little and often. A safe fertilising regime is monthly applications of liquid fertiliser. A common mixture is 2 teaspoons of Aquasol® or Thrive®, one teaspoon of urea and one teaspoon of iron chelate in 10 L water. This supplements the fertiliser incorporated into the potting mix, especially if slow-release mixtures have not been used in the mix. Commercial preparations of foliar fertiliser are equally suitable.



Figure 33. Whip grafting showing the scion wood and rootstock about to be brought together



A small wood-plane is useful for getting flat surfaces for grafting

Water plants regularly. Daily watering may be required, depending on size, time of the year, and density of the potting mix. Check at regular intervals to make sure plants are not under-watered or over-watered. Remove all side shoots to encourage a strong, upright stem for grafting. Insect pests, such as twig-girdler, broad mite, thrips, scales and caterpillars, are a major problem in nurseries and can quickly devastate trees.

Grafting and budding

Macadamia rootstocks are ready for budding or grafting when they are up to 1m high and 10 to 15 mm in diameter. Both rootstock and scion wood need to be in good condition (healthy and free of pests and disease). Grafting in the spring is preferred but it can be done at any time, provided trees are protected from hot, frosty or windy conditions. Remember that for grafting, scion wood needs to be cinctured 6 to 12 weeks beforehand, as outlined earlier in this section. Budding is more difficult but is quicker and less wasteful of (uncinctured) budwood. For budding, rootstock stems, approximately 7 mm in diameter at a point 25 cm from the soil, are ideal. Plant out grafted plants after the second flush from the scion wood has hardened. In the meantime, remove grafting tape and all side shoots and suckers. Contract grafters will graft or bud trees for a unit price per tree. This is often a viable option when propagating a large number of trees.

Whip graft

The whip graft, the most commonly used grafting technique for macadamias, is simple and effective. To whip graft, make matching, sloping cuts about 30 mm long at the base of the scion and on the stock with a sharp grafting knife (Figure 33). A small wood-plane can also be used to ensure perfectly flat surfaces for good contact. The cut needs to be longer if the diameter of the wood is more than 10 mm. Matching the thickness of the rootstock and scion wood, before cutting off the top of the rootstock, will help to get a good match between the cambium layers of the rootstock and scion wood. If the stock and scion are not the same size, match the cambium layers on one side only. The cambium is the slightly darker layer just under the bark. It lifts with the bark. Secure the scion to the stock with budding tape. Clothes pegs can be used to help hold the scion in place. Always apply tape from the bottom upwards to produce an overlapping pattern that sheds water away from the graft. Paint the scion and tape with grafting mastic to prevent it drying out. The graft is successful when the scion wood produces a new shoot. The whip graft is commonly used by nurseries but is difficult for the beginner. Once mastered, it is a relatively quick method of grafting.



Matching the thickness of the scion wood and rootstock before cutting the top of the rootstock



Applying grafting mastic to seal the graft



A completed graft union before taping

A successful whip graft after removal of shoots below the graft



Punch budding

Punch budding allows a perfect match between the scion and stock by using the same tool to remove the bark from the rootstock and the bark with a bud from the scion wood. Punch budding is best carried out in the spring but can be done at any time provided there is sap flow in both rootstock and budwood. Sap flow is detected by seeing how easily the bark is removed from the wood and bending the bark backwards between the thumb and forefinger to detect the presence of sap.



A successful bud take showing the new bud growth

Select an internode position on the rootstock, approximately 25 cm from soil level. From the bud stick, select a bud to suit. Remove a patch of bark from the rootstock with an oval punch. Remove the bud from the bud stick with the same punch and place the bud in position on the stock. Wrap the bud completely with grafting tape. Remove the tape after 6 weeks. At this time, if the bud is green and healthy, cut the rootstock at the node above the bud. Paint the bud and the cut on the rootstock with grafting mastic to seal the wound. Remove any shoot growth from the rootstock as it appears. Cut the remaining stub above the bud after the bud has established.

Note that this is a simplistic description of the operation. In reality, it is very difficult to perform successfully, and expert advice and practice is necessary to achieve good results. For further reading, refer to *Punch budding macadamia in New South Wales, what is the problem?* in the AMS News Bulletin, July 1998 edition.

Cuttings

Growing macadamias from cuttings (clones) is a specialised operation requiring skill. As mentioned earlier in this section, cuttings have been used in South Africa for some time, the variety Beaumont being particularly popular. There are big differences between varieties in successful striking of cuttings. Beaumont cuttings root readily and grow vigorously. Cuttings from other tetraphylla varieties and hybrid varieties (for example the HV A series and H2) also strike readily, but those from Hawaiian varieties (HAES 246, HAES 344) are more difficult.

Although clonal rootstocks such as cuttings have the advantage of being uniform, since there is no genetic variability compared with seedling rootstocks, any defects, weaknesses or desirable characteristics may be magnified in the orchard. When cuttings were first used, resultant trees had a reputation of being prone to wind damage. However, as long as cuttings are planted deeply enough, and root systems are well developed, tree stability is not a serious problem.

Misting house requirements

To produce good, healthy, vigorous trees successfully from cuttings, it is essential to propagate them in a misting house. It is not essential to provide bottom heat, although it may result in a better and more rapid strike in cooler areas. Ideally, root temperature should be maintained between 24 and 26°C. In summer, cuttings take about 3 to 4 months to strike and produce a good root system, after which they can be transferred to a shade house. The misting house should be well ventilated, allowing hot air to escape at the top. Leaf temperatures should not exceed 30°C and some provision should be made for cooling when these temperatures are reached, for example evaporative cooling by sprinklers on the outside of the structure. It is desirable for the misting house to be covered with shade cloth to prevent excessively high temperatures developing inside.

To prevent leaves drying out at high temperatures, electronic leaf sensors can be used to control misting to ensure the leaves remain wet. As the leaf dries, the sensors activate misting jets via a solenoid. The sensor electrodes require regular maintenance every 2 to 3 weeks and should be cleaned with 00 emery paper. Misting jets operate at not less than 90 p.s.i.

Chlorination of misting water is necessary to minimise the risk of disease. Use liquid chlorine injected on the delivery side of the pump. Pass the chlorinated water through a sand filter to remove iron precipitate. Monitor the chlorine level to ensure it does not exceed 10 ppm free chlorine. The chlorinated water is then stored and regulated by the electronic leaf sensors. As an additional precaution against root disease, a phosphorous acid drench may be applied every few weeks. Set misting jets about 2 m above the cutting trays on either raised benches or on well-drained screenings on the ground. Arrange the jets in a triangular grid, 1 m apart.

Cutting material

Healthy, leafy, semi-hardwood tip cuttings with 4 to 5 nodes taken from the last hardened flush in spring/summer give the best results. Collect cutting material early in the day, before it gets too hot. Prepare and plant cuttings the same day. Store cuttings in a plastic bag, wrapped in moist paper to prevent drying out, under shade, in an esky or in a refrigerator. Cut off basal leaves, leaving about two sets of leaves, and trim the bottom cut just below the last node. Hold secateurs or a knife at right angles to the cutting and use the blade to scrape down to the cambium layer on each side of the cutting for a short distance from the base. Dip the base of the cutting in purple Clonex® gel or similar rooting hormone formulation.

Rooting media

Use a sterile, well aerated and well drained potting mix to raise cuttings. A successful mix is 2 parts 2-mm washed sand, 1 part coir and 1 part 4-mm polystyrene prill. Plant the cuttings so that the bottom two nodes are covered. Keep cuttings in the misting house until the roots are well established (generally in 6 to 12 weeks).

Shade house

Once the roots are well established, transplant the cuttings into planter bags of at least 6 L capacity (9 L preferred). These allow the cuttings to be planted more deeply. Use a free draining potting mix. A suitable mix is 35% composted hardwood sawdust, 35% pinebark, and 30% coarse river sand, to which is added 100 g urea, 400 g dolomite, 1 kg gypsum, 2 kg blood and bone, and 700 g single superphosphate per cubic metre. The shade house should provide 60% shade. Sprinkle the cuttings with water frequently, particularly during summer. An automatic irrigation system is ideal. Small amounts of foliar or slow release fertiliser can be applied to struck cuttings in the shade house. When the plants are approximately 45 cm high, move them to a hardening-off area and progressively expose to full sunlight.

Once hardened off, cuttings can be planted in the field. Alternatively, if the cuttings are being used as rootstocks, they can be grafted to the desired variety in the same way as seedling rootstocks.

Topworking

Topworking in the field involves grafting established trees to a new variety. This provides an alternative to completely removing trees of unsuitable varieties and replanting with new nursery stock. Topworking gets the orchard back into production more quickly than replanting. However, the cost effectiveness of topworking has not been thoroughly documented yet for macadamia. Studies indicate that the cost of topworking is similar to the cost of tree removal and replanting. The cost effectiveness will therefore depend on the rate of return of topworked trees to production. This is currently being determined in trial work.

Various methods can be used for topworking. Preparation of the original tree ranges from:

- Stumping (cutting back to the main trunk at about the level of the first whorl of branches);
- Staghorning (cutting back to three to five main branches about 50 cm long); or
- Partial canopy removal (temporary retention of whole limbs left to maintain assimilate production, nutrient translocation and protection from sunburn and wind damage).

Stumping is thought to be risky, as trees may die or lose vigour. Studies have shown that partial canopy removal results in greater tree growth, less sun damage and earlier return to production than complete canopy removal.

Grafting methods include grafting or budding of regrowth or bark grafting which involves inserting scion wood under the lifted bark of a newly cut limb.

Lopped branch showing regrowth shoots ready for topworking

Nurse branch (left unpruned until new variety is well established on other branch)



Topworking using the partial canopy removal method

For the partial canopy removal method, lop off one to three major limbs about 0.75 to 1.5 m above the ground, leaving a 15 cm stub to encourage suckering. For better protection from the sun, it is best to remove branches on the southern side of the tree, preferably in October/November and no later than April, so that vigorous suckers, 8 to 12 mm thick at the base, are ready for grafting next spring. About one third, but no more than half, of the canopy is removed at this time. The remaining branches help to protect the new growth from wind and sunburn, and maintain assimilate supply and translocation of nutrients. For autumn grafting, reverse the process so that vigorous suckers are ready for grafting on the northern side of the tree in autumn. Because of the risk of sunburn, it is best to paint the exposed trunk with white plastic paint. Also avoid, where possible, topworking on very hot, sunny days.

Cincture scion wood at least 6 to 12 weeks before grafting and allow plenty of material of varying sizes. Identify the cinctured branches with flagging tape marked with the variety name and date. Graft when favourable cool weather is forecast. In the case of grafting regrowth, select at least two, well-placed

suckers per limb and remove the remainder. If the area has become shaded, remove overhanging branches. The suckers to be grafted should be near the top of the stub on opposite sides so that they callus across the top of the stub, join up and add strength to the graft union. Paint all exposed limbs and grafts with white plastic paint to protect from sunburn.

Remove all suckers on grafted branches regularly to force the buds to grow. Also remove suckers or small limbs likely to cause physical damage to soft new shoots. De-suckering should be carried out every 2 to 3 weeks. When the scion has grown approximately one metre long, remove another half of the old limbs remaining on the tree. Remove all old limbs within two years of topworking. The cuts must be clean and close to, but not flush with, the main trunk (just outside the branch collar), with no stubs, so that the callus can heal over the surface. If reworking an entire block, it is advisable to do alternate rows or trees. This provides wind protection and minimises crop losses in the change over period.

Field grafting

This involves grafting specified varieties to a seedling rootstock already established in the field. It is generally done 12 to 18 months after planting out, depending on the size of the seedlings and growing conditions. The whip graft is most popular. It is important to protect the graft with Steriprune® or a similar protectant. The main disadvantages are that grafting is slow, maintenance is high, and the trees are subject to the elements of heat, cold, wind, animals and birds. The rootstock may also be stunted or completely fail.