GROWING GUIDE

Macadamia grower's handbook

Main authors

Paul O'Hare *Russ Stephenson*
Kevin Quinlan *Noel Vock*

Contributing authors

Henry Drew *Eric Gallagher* *Chris Searle*
Joe Ekman *Pat O'Farrell* *Ian Vimpany*
Daryl Firth *Peter Rigden* *Geoff Waite*

Macadamia industry technical panel

David Bell *Cliff James* *Andrew Pearce*
Lindsay Bryen *Kim Jones* *Jeff Peterson*
John Gillett *Ian McConachie* *Kim Wilson*

Department of Primary Industries and Fisheries

Macadamia Grower's Handbook

First published 2004

Grower guide series: ISSN 0727-6273

QI03052

National Library of Australia Cataloguing-in-Publication

Macadamia grower's handbook

Includes index

ISBN 0 7345 0241 9

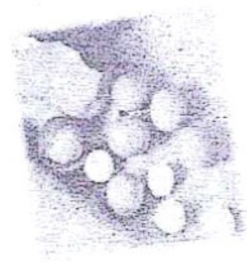
1. Macadamia nut - Australia. I. O'Hare, P. J. (Paul Joseph), 1957- . II. Queensland. Dept. of Primary Industries. III. NSW Agriculture. IV. Australian Macadamia Society. (Series : Growing guide).

634.5

Enquiries should be addressed to:

Department of Primary Industries & Fisheries
Maroochy Research Station
PO Box 5083 SCMC
Nambour 4560 Qld Australia

Ph: (07) 5441 2211 Fax: (07) 5441 2235 Int Code: + 61 7
Web: www.dpi.qld.gov.au/agrilink



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

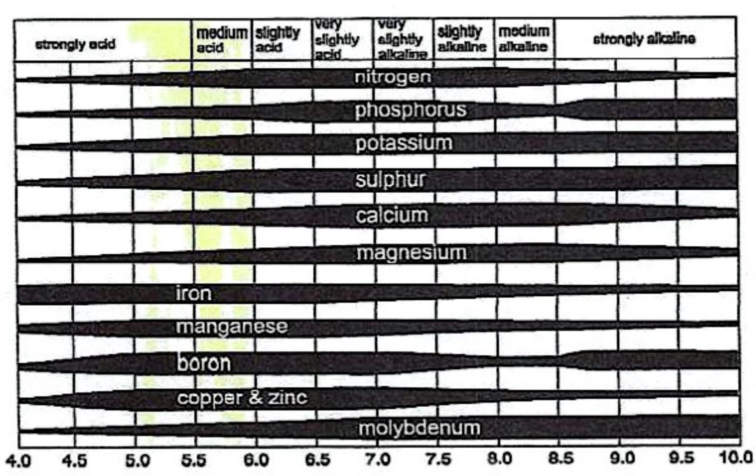
Physical properties of the soil such as soil structure, texture, bulk density, porosity, and plasticity, have a profound effect on soil health and thus on the health of the tree. These properties influence the water infiltration rate, and consequently the effective utilisation of rainfall and irrigation. 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



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).

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?*

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.

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.*

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 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

The most important nutrient for tree growth.

A key component of chlorophyll (the green pigment in leaves), which is why nitrogen deficient trees are light green or yellow.

An essential requirement for the synthesis of plant hormones, which control tree growth.

Behaviour in soil and plant

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.

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.

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.

Fertiliser forms

Urea (46% N)

Sulphate of ammonia (Gran-Am®, 21% N).

Potassium nitrate (13% N and 38% K).

Calcium nitrate (15% N and 18 to 19% Ca)

Calcium ammonium nitrate (CAN, 27% N and 8% Ca)

Management

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.

PHOSPHORUS (P)

Function

Essential for energy metabolism in maintenance and growth.

Particularly important for root growth, flower initiation and nut set.

Behaviour in soil and plant

Only a small proportion of soil phosphorus is generally available for tree uptake.

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.

Relatively immobile in the soil and not readily leached.

Very mobile in the plant, moving readily in both an upward and downward direction.

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).

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.

Fertiliser forms

Superphosphate (9% P, 11% S, 20% Ca).

Triple superphosphate (19% P, 2% S, 18.5% Ca).

Diammonium phosphate (DAP, 18% N, 20% P, 2% S).

Monoammonium phosphate (MAP, 12% N, 22% P, 3% S).

Rock phosphate (phosphorus content varies according to source; check content before calculating rates).

Management

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.

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 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 A2 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 A2 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 ECse*–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 krasnozem 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.

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.

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

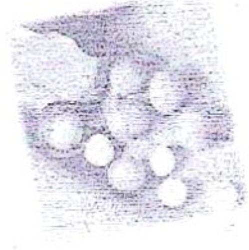
- Venturi suction from a tank with the flow rate controlled by a gate-valve;
- Direct injection into the suction line of the irrigation pump (beware of impeller corrosion);
- Pressure differential (PD) drums, where some mainline flow is bled off through a pressure drum containing a concentrated fertiliser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