MACADAMIA FERTILIZATION IN KWAZULU-NATAL

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The Fertilizer Advisory Service at Cedara gives fertilizer and lime recommendations based on soil analysis. Recommendations based on soil analysis are essential before establishment, especially for the correction of soil acidity. Maintenance fertilization of established macadamias should be based on both leaf and soil analysis.

Soil acidity

Macadamias are fairly tolerant of soil acidity, and there are reports of lime-induced iron deficiency in this crop (Stephenson, 2002). However, it is recommended that soils are limed before establishment of orchards to reduce the chance of aluminium and manganese (Mn) toxicity. It is very difficult to correct subsurface soil acidity in established orchards; lime applications generally affect only the top few centimetres of the soil, and van Niekerk (2002) indicates that surface applications of lime should be limited to 500 kg/ha/year to minimise the risk of lime-induced disorders. The following guidelines for lime and gypsum use have been adapted from general recommendations for tree crops.

Lime and gypsum at establishment

Lime requirement

It is recommended that the tilled layer of soil should have an acid saturation of 1% or less before macadamia trees are established.

The recommended amount of lime (to reduce acid saturation to 1%) is calculated as follows:

LR = ["Acidity(Al+H)" - ("Total cations" x 0.01)] x 4.96

where LR is the lime recommendation in t/ha and "Acidity(Al+H)" and "Total cations" are given in the soil analysis. Lime recommendations are rounded to the nearest 0.5 t/ha.

In determining the lime requirement, it is assumed that the lime will be incorporated to a depth of 200 mm. If subsoils are acid, deeper incorporation of lime (if possible) is advisable. For deep liming, soil samples should be taken to the relevant depth, and recommendations should be increased proportionately:

Lime required (t/ha) = Recommended rate (t/ha) x actual depth of mixing (mm) ÷ *200* (mm).

Lime should be applied 6-8 weeks before establishment, to allow time for reaction with the soil. Note that some soil moisture is required for lime to react; if liming is done in the dry season, a longer period of time before planting may be necessary. Thorough incorporation is essential; discing followed by ploughing is recommended for incorporation to 200 mm depth, but for deep incorporation of lime, double trench-ploughing is recommended (Du Preez, 1988).

If tillage of the area to be established is not possible, lime should be broadcast at half the recommended rate, with the proviso that not more than 5 t/ha is applied in a single year (as recommended for maintenance, below).

Magnesium

If soil magnesium (Mg) levels are low (<100 mg/L), dolomitic lime (usually the cheapest source of Mg) or some other source of Mg should be applied. Apply sufficient Mg to raise the Mg level of the top 200 mm of soil to 150 mg/L:

Mg recommendation (kg/ha) = (150 - Soil Mg) x 2.5

Sandy, low CEC soils probably don't require as much as 100 Mg/L; it is sufficient to raise the Mg to 15% of *Total cations*:

If *Total cations* is less than 5 $cmol_c$/L, then

Mg recommendation (kg/ha) = (*Total cations* x 18.2 - Soil Mg) x 2.5

If the pH (KCl) is greater than 6, avoid the use of alkaline sources of Mg like dolomitic lime, magnesite ($MgCO_3$) and magnesium oxide (MgO). Magnesium sulphate and magnesium nitrate are alternatives.

For macadamias, the Ca/Mg ratio (both expressed in mg/L) in the soil should be within the range 2.5-5.4 (ITSC, 1994; Johnston, 1986).

Gypsum

Gypsum recommendations are not given routinely for soil samples submitted, but gypsum is a cost-effective source of Ca and S. Lime is the preferred source of Ca and Mg, and should be used to correct soil acidity over the whole land to as deep a depth as possible. If, however topsoil and/or subsoil incorporation of lime is not possible, gypsum may be used as a supplementary source of Ca, applied as a topdressing over the whole area. If the topsoil does not require lime, or the recommended lime is to be incorporated into the topsoil, the recommendations in Table 1 apply. If, on the other hand, lime is recommended but can only be topdressed (at half the recommended rate as indicated above), the recommendations in Table 2 may be used.

Table 1. Gypsum recommendations for establishment where the topsoil acid saturation will be less than 1% (i.e. If no lime was recommended for the topsoil, or the recommended lime is to be mixed into the top 200 mm of soil over the whole land)

Subsoil acid saturation	Gypsum recommendation
<10%	250 kg gypsum/ha (to supply S; the extra sulphate may also enhance the uptake of Ca supplied in the form of lime.)
10-20%	1 t gypsum/ha
>20%	2 t gypsum/ha

Table 2. Gypsum recommendations at establishment where the topsoil acid saturation is not corrected (i.e. If half the lime recommended at establishment is to be topdressed)

Subsoil acid saturation	Gypsum recommendation
<10%	Apply gypsum at half the recommended lime rate, with the proviso that not more than 3 t/ha be applied (to supply Ca).
10-20%	Apply gypsum at a rate of 1 t/ha plus half the recommended lime rate, with the proviso that not more than 3 t/ha be applied (to supply Ca).
>20%	Apply gypsum at a rate of 2 t/ha plus half the recommended lime rate, with the proviso that not more than 3 t/ha be applied (to supply Ca).

Maintenance lime and gypsum applications

Lime

It is assumed that maintenance lime dressings will be broadcast over the entire area, and not incorporated by any form of tillage. The recommended amount of lime is calculated as follows:

LR = ["Acidity(Al+H)" - ("Total cations" x 0.01)] x 2.0

where LR is the lime recommendation in t/ha and "Acidity(Al+H)" and "Total cations" are given in the soil analysis. Lime recommendations are rounded to the nearest 0.5 t/ha. Not more than 3 t lime/ha should be applied in a single year. Use a foliar spray containing iron, zinc and copper if chlorosis develops in young leaves.

Gypsum

Gypsum recommendations are not given routinely for soil samples submitted, but gypsum is a cost-effective source of Ca and S. The following guidelines are suggested:

If the top 20 cm of soil has an acid saturation of less than 1% (ie no lime is recommended), if the subsoil acid saturation is less than 10%, and if the Ca/Mg ratio is greater than 2.5, then calcium supplementation is probably not necessary; 250 kg gypsum/ha may be topdressed to supply S.

If lime was recommended it should be topdressed rather than incorporated (to avoid disturbance of the root system), and topdressed gypsum can be used to supplement Ca; topdressed gypsum can also be used to supplement subsoil Ca. Recommended rates are given in Table 3.

Table 3. Maintenance gypsum recommendations to supply Ca in acid soils (assuming the recommended lime is to be topdressed)

Subsoil acid saturation	Gypsum recommendation
<10%	Apply gypsum at the recommended lime rate, with the proviso that not more than 3 t/ha be applied.
10-20%	Apply gypsum at the recommended lime rate plus 1 t/ha, with the proviso that not more than 3 t/ha be applied.
>20%	Apply gypsum at the recommended lime rate plus 2 t/ha, with the proviso that not more than 3 t/ha be applied.

Phosphorus

Establishment

The P requirements are determined as follows:

P Recommendation (kg/ha) = (Target P value - soil P) x PRF

Target P depends on the crop and on the sample density (an indication of texture) of the soil (Table 4). PRF = Phosphorus requirement factor. This represents the amount of applied phosphorus (kg/ha) required to raise the soil test value by 1 mg/L. The PRF's used for both establishment (when the P applied is incorporated into the soil), and for maintenance (when P is topdressed) are also given in Table 4.

Table 4. Values of "Target P" (in mg/L) and "PRF" for soils of different sample density for macadamia.

Soil sample density (g/mL)	Target P (mg/L)	PRF for establishment (P incorporated)	PRF for maintenance (P topdressed)
1.00	14	10.78	5.00
1.05	16	9.29	5.00
110	18	7.95	5.00
1.15	20	6.78	5.00
1.20	23	5.76	5.00
1.25	25	4.89	4.89
1.30	27	4.19	4.19
1.35	30	3.64	3.64
1.40	32	3.24	3.24
1.45	34	3.00	3.00

These target P levels are similar to those found necessary for optimum production in Queensland

(Stephenson, Gallagher & Pepper, 2002). They suggest a tentative norm of 84-88 mg P/kg using the Collwell test. This is equivalent to about 25 mg/kg using the Olsen test, which is similar to the Ambic-2 extraction used at Cedara.

A minimum "starter" dressing of 20 kg P/ha is recommended for fruit and nut crops unless the soil P test is high (more than double the target soil test).

Where the soil P test of a sample is high (more than double the target soil test), and the sample is truly representative of the whole field, no fertilizer P should be applied until test levels indicate a P requirement.

All the P recommended should be broadcast and incorporated into the soil before establishment. To minimise the risk of P toxicity, do not apply P fertilizer in the planting holes. No N or K fertilizer should be applied in the planting hole either; this reduces the risk of salt burn.

Maintenance

Heavy applications of P fertilizer to established macadamias can induce iron deficiency and depress yield (Stephenson *et al*., 2002). Avoid building soil P levels to more than twice the Target P (given in table 4 for different soil sample densities).

Maintenance P fertilizer recommendations are calculated using the formula given above: However, a maximum P requirement factor of 5.00 is used for maintenance (See Table 4). Also, recommended P is adjusted as follows:

Calculated P (kg/ha)	**Recommended P(kg/ha)**
<1	0
1-20	20
20-50	as calculated
>50	50

Potassium

Establishment

The K fertilizer recommendation is calculated to raise the soil K test to the "target K" level of the crop to be fertilized. Where the applied K is incorporated into the soil (prior to establishment), it is assumed that 2.5 kg K is required to raise the soil K test by 1 mg/L, and the following equation is used.

Recommended K (kg/ha) = ("Target K" - soil K) x 2.5

Target K for macadamia is 120 mg/L. This is reduced for soils with a low effective cation exchange capacity (generally sandy soils); if “Total Cations” (given on the soil analysis printout as an estimate of the soil’s cation exchange capacity) is 3.0-4.0 $cmol_c$/L, Target K is 96 mg/L, and if “Total Cations” is less than 3.0 $cmol_c$/L, Target K is 72 mg/L.

K applied at establishment should not be applied in the planting hole. Potassium recommended on the basis of a soil test should be broadcast before planting and incorporated into the soil, to increase the soil test of the topsoil to the target K level.

Maintenance

Maintenance K fertilization can commence once the trees are growing vigorously (after 1 year), and standard maintenance K recommendations are given in Table 5. The annual dressing should be applied in October.

Table 5. Recommended maintenance K

Tree age (years)	Recommended K (g/tree/year)	Fertilizer equivalent KCl (g/tree/year)
1	50	100
2	150	300
3-5	220	440
6-8	280	560
Mature trees	375	750

Leaf and soil analyses should be used as a guide to fertilization once the trees start bearing. If leaves are sampled correctly, K concentrations of greater than 0.8% indicate that K applications can be reduced, whereas leaf K concentrations of less than 0.5% indicate that K applications should be increased (ITSC, 1994).

Maintenance K dressings (Table 5) may be applied if the soil K is less than 240 mg/L; above that level, no maintenance K is necessary.

If the soil K is lower than the target K, a K recommendation is given to correct the soil K; this extra K can be supplied in addition to the maintenance K. However, leaf tests may show that extra K is not necessary, as the trees may get a large proportion of their K from the subsoil.

For the calculation of maintenance dressings (top-dressings) of K, it is assumed that 1.5 kg K/ha (and not 2.5) is required to raise the soil K value by 1 mg/L. The formula therefore becomes:

$$\text{Recommended K(kg/ha)} = (\text{"Target K"} - \text{soil K}) \times 1.5$$

The target K for maintenance is the same as for establishment.

Nitrogen

For macadamias, N recommendations are given in the guideline messages and expressed in kg N/tree. The rates recommended are given in Table 6. No N fertilizer should be applied at planting.

Table 6. Nitrogen recommendations for macadamias (Koen 1992).

Tree age (years)	N (g/tree/year)	Fertilizer equivalent LAN (g/tree/year)	Fertilizer equivalent Urea (g/tree/year)
1	50	180	110
2	80	290	170
3-5	130	460	280
6-8	210	750	460
Mature trees	360	1290	780

Maintenance N fertilization can commence once the trees are growing vigorously (after 1 year). The recommended N for young trees (1-3 years) should be split into five dressings, applied in February, April, July, October and December. Nut-bearing trees should receive a third of their N in March, a third in August, and a third in October/November.

Leaf analyses should be used as a guide to fertilization once the trees start bearing. If leaves are sampled correctly, N concentrations of greater than 1.5% indicate that N applications can be reduced, whereas leaf N concentrations of less than 1.2% indicate that N applications should be increased (ITSC, 1994).

These nitrogen recommendations are lower than those used previously, and are in line with the findings of Stephenson *et al*. (2002a), Kuperus, Abercrombie and Swanepoel (2000), and Kruger, which all indicate that high rates of nitrogen can have negative impacts on nut yield and quality.

Sulphur and micronutrients

This crop requires 20 - 30 kg S/ha/annum. This can usually be supplied from the atmosphere and by the mineralization of organic S in soils, but supplementary S fertilizers may be necessary on sandy soils, where sulphate is lost by leaching.

Zinc deficiency is common in macadamia orchards. Soil zinc is often low, and deficiency can be induced by lime and P applications. If leaf Zn is low, spray leaves with 100 g zinc sulphate heptahydrate/100L (Weir, Cresswell and Loebel, 1995). Response to soil-applied zinc sulphate (10 g/m^2) is slow, but lasts 2-5 years (Weir, Cresswell and Loebel, 1995).

Copper deficiency does occur on the South Coast. Leaf Cu is not always a good indicator of deficiency; responses to copper oxychloride have been observed in orchards where leaf tests have indicated sufficient Cu (Abercrombie, 2000). If leaf Cu is low (less than 5 mg/kg), soil Cu is low (less than 2 mg/L), or tree die-back is observed, apply foliar sprays. Use additional soil applications of copper sulphate if soil Cu is low. For soil applications use copper sulphate at 30 kg/ha and for foliar application use copper oxychloride at 400 g/100L (Weir, Cresswell and Loebel, 1995).

Low leaf boron is widespread in KZN, and B deficiency is probably common. Foliar sprays have increased yield, kernel recovery, and kernel quality (van Niekerk, 2002). Where B is low, use up to four foliar sprays of Solubor (1 g/L) between Sept and December and a soil application of 3 g borax/m^2 in the drip area around the trees (van Niekerk, 2002). There is a narrow range between B deficiency and B toxicity, and special care must be taken with application rates of B, especially on sandy soils.

Leaf iron levels for macadamias in KZN are generally in the normal range (25-200 mg/kg). Iron chlorosis can occur if soil pH is high (lime-induced) or if P is high (phosphorus toxicity). Leaf P concentrations of greater than 0.15% are regarded as excessive and can induce iron chlorosis, and P-induced iron chlorosis is indicated by an Fe/P ratio of less than 0.07 (Hue and Bittenbender, 1997). A low Fe/Mn ratio (<1.2) is also an indicator of iron chlorosis risk.

Organic matter and mulching

Several authors draw attention to the importance of organic matter, mulching and erosion control (O'Hare and Vock, 1990; Wilkie, 1995; van Niekerk, 2002; Paton Fertilizers, 2003). Wilkie (1995) advocates the use of an inter-row cover crop which can be cut to supply material for mulching. Maintenance of an organic mulch (rather than the use of manures or fertilizers) may deliver the following advantages for crop nutrition:

- Erosion control and consequent maintenance of a healthier root system;
- Better maintenance of moisture at the soil surface (where the bulk of nutrients are taken up);
- Slow release of plant nutrients with no risk of salt burn or salinity builup;
- Improved micronutrient availability through the creation of a layer without strong micronutrient-fixing properties, the possible promotion of proteoid roots and the production of natural chelates.

Soil and leaf sampling

Soil and leaf analysis is the most accurate way to determine the nutritional status of an orchard and can be of tremendous value in diagnosing the cause(s) of nutrient deficiencies (Aylward, 2003). Leaf analysis should be done over a number of years, so trends in the nutrient status of the orchard can be monitored, and can warn of a possible deficiency or toxicity before the plant shows any visible symptoms. Factors such as rootstock, crop load, soil type and weather conditions influence nutrient uptake.

Soil analysis, alone, is not as accurate in determining the nutritional status of an orchard. It does, however, play an important role in fertility programs when used in conjunction with a leaf analysis. In established orchards, the main value of a soil test is to monitor soil pH and monitor nutrient trends. A soil test should also always be taken before an orchard is planted, since it is much easier to adjust nutrient levels before the trees are established. Amelioration of nutrient deficiencies should be through the soil but where chronic deficiencies are noted through visual leaf symptoms, a foliar spray may be used to alleviate the problem temporarily.

Collecting soil samples

- Collect at least 30 sub-samples from each orchard or block
- Take the sub-sample from under the dripline of the tree on both the N- and S-facing sides of the tree at a distance of 300-500mm from the tree stem.
- Sample the topsoil (0-150mm), and subsoil (300-600mm) if required.
- Avoid patches with visible fertilizer residues, distinctly different soil types. Sample these separately
- Mix sub-samples together and submit sample to the Fertilizer Advisory Services at Cedara along with "Soil Fertility Analysis" form.

Collecting leaf samples (Aylward, 2003)

- Sampling should be done during October and November from the 4th pair of leaves from the first fully open leaf at the tip of the branch (Fig. 1). Leaves must be young, fully developed and hardened-off.
- Divide the orchards into blocks not exceeding 3 hectares based on: Cultivar, tree age, rootstock and soil type
- Collect 20-30 healthy leaves distributed evenly throughout the block (These can be marked & used as index trees for annual leaf sampling). Sample 1-2 leaves per tree between waist and

eye level from both sides of the tree.

- Place leaves in a paper bag and submit to the Plant Analysis Laboratory at Cedara along with the completed "Plant Sample Analysis" form.

Figure 1. Correct leaf to sample from the tip of a primary branch (Koen, 1993)

Table 7. Leaf nutrient norms for macadamia (Weir, Cresswell and Loebel, 1995).

Nutrient	Deficient	Low	Normal	High	Excess
Nitrogen (%)	0.3-0.8	0.9-1.2	1.3-1.5	1.6-1.8	>2.0
Phosphorous (%)	<0.05	0.05-0.07	0.08-0.10	0.11-0.15	>0.15
Potassium (%)	<0.35	0.36-0.49	0.50-0.79	0.80-1.20	>1.20
Calcium (%)	<0.3	0.3-0.4	0.5-0.8	0.9-1.1	>1.1
Magnesium (%)	<0.05	0.05-0.07	0.08-0.12	0.13-0.20	>0.20
Sulphur (%)	<0.10	0.11-0.17	0.18-0.25	>0.25	
Sodium (%)			0.01-0.10	0.2-0.3	>0.4
Chloride (%)			0.01-0.20	0.3-0.6	0.7-1.5
Copper (mg/kg)	<3	3-4	5-12	15-70	
Zinc (mg/kg)	<9	9-14	15-50	>50	
Manganese (mg/kg)	<20	20-90	100-1500	1600-3000	3600-5500
Iron (mg/kg)			25-200		
Boron (mg/kg)	8-12	13-19	20-50	60-80	

Note: mg/kg is equivalent to ppm

Table 8. Soil nutrient norms for macadamia.

Nutrient	Extraction method	Optimum range
pH	1 *M* KCl	4.5-5.5
Acid saturation (%)		0-1
Organic Carbon (%)	Walkley-Black	2-6
Nitrogen (mg/kg)	1:5 water extraction	25
Potassium (mg/L)	Ambic-2	120-250
Phosphorous (mg/L)	Ambic-2	14-34[#]
Calcium (mg/L)	1 *M* KCl	600-1500
Magnesium (mg/L)	1 *M* KCl	150-400
Exchangeable Sodium Percentage, ESP (%)		<5
Zinc (mg/L)	Ambic-2	3
Ca/Mg ratio		2.5-5.4

[#] See Table 4

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