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Nitrogen and environmental factors influencing macadamia quality

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Abstract. Applications of nitrogen fertiliser in macadamia orchards remain high, despite indications that optimum yields and quality are obtained at a lower rate. This 6-year study examined the effect on quality of 230, 690 and 1150 g nitrogen/tree . year, applied in April (floral initiation), in April and June (inflorescence development), in April, June and November (rapid nut growth and premature nut drop), in April, June, November and January (nut maturation/oil accumulation) or monthly. Higher rates of nitrogen increased kernel recovery by 1% in 5 years out of 6. In 1 year only, 4 or more split applications of the medium and high rates of nitrogen increased kernel recovery by up to 1.6%. These increases were insufficient to compensate for depressed yields (17% lower) at high nitrogen. In good years, when yields were above average, kernel recovery tended to be high and in years with poor yields, kernel recovery tended to be low except when nuts were small. Moderate summer–early autumn rainfall of about 100 mm/month was associated with high kernel recovery whereas very heavy rainfall (>200 mm/month) during this period was detrimental.

The percentage of first grade kernels was influenced most by season but was negatively correlated with the rate of nitrogen. Impurities, including immature, deformed, mouldy and insect-damaged kernels, were lowest at low rates of nitrogen and highest during wet harvest seasons.

Time of nitrogen application had no significant effect on yield, kernel recovery, the percentage of first-grade kernels or impurities. For sustained high yield and quality, 355 g nitrogen, or 0.8 kg urea/tree.year, applied in April–June is indicated. Agronomic and economic advantages of reducing rates of nitrogen applied to macadamia orchards are enhanced by increasingly important environmental considerations.

Multiple regression analyses indicated that the rate, strategy and timing of nitrogen application, rainfall, temperature, flushing and litterfall were correlated with kernel recovery and first-grade kernels but more work is needed to elucidate the significance of these factors.

Introduction

Indications are that the standards for optimum leaf nitrogen (N) concentration in Hawaiian macadamia orchards (Hirae 1976) require some downward adjustment under Queensland conditions (Stephenson and Cull 1986; Stephenson and Gallagher 1989*a*). Stephenson *et al.* (1997) proposed that 1.3% leaf N (as percentage dry matter) was optimum for yield of 'Keaau' (HAES 660) trees in a deep, well-drained red clay-loam soil in southern Queensland whereas, in many orchards, concentrations are currently as high as 1.8%.

In macadamia, the way in which cultural treatments and environment affect nut quality is poorly understood. Stephenson and Gallagher (1989*b*) identified a trend for kernel recovery (KR) to be higher at low N but timing was also important. Applications of 690 g N/tree in June, before anthesis, increased KR slightly in 2 of 4 years compared with similar rates applied in April and January. The effect of N applications on the percentage of grade 1 kernels (G1K) was less consistent but was not adversely affected by low N status. Profitability in the macadamia industry depends on producing consistently high quality kernels, as well as high yield. There is a need, therefore, to gain a better understanding of factors that limit quality under different N regimes so that optimal, comprehensive management strategies can be developed to maximise productivity of macadamias. This study identifies some of the environmental,

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phenological and cultural factors that limit quality and discusses implications for fertiliser management.

Materials and methods

Experimental details were described previously (Stephenson *et al.* 1997). Mature Keaau (HAES 660) macadamia trees at 200 trees/ha (about 10 by 5 m spacing) in a deep, well-drained red clay-loam soil near Mt Bauple, Queensland (lat. 26^{o}S, 75 m) were used for this study over a 6-year period from 1987 to 1993. Supplementary irrigation was provided and nutrients other than N, and possibly magnesium, were within the adequate range (Stephenson *et al.* 1997). Concentrations of nutrients in leaf dry matter (data not shown) were adequate (Robinson *et al.* 1997). Orchard operations, including pest, disease and weed control, were carried out as required.

Experimental design

A split-plot, randomised block design, consisting of 5 application strategies combined with 3 rates of N in 4 replicate rows was used. Main plots contained 9 trees each, with subplots of 3 trees. Main treatments (application strategies, N_{time}) were the following: 1 application of N in April (floral initiation); 2 applications of N, 1 in April and 1 in June (inflorescence development); 3 applications of N, in April, June and November (rapid nut growth and premature drop); 4 applications of N, in April, June, November and January (nut maturation/oil accumulation); and monthly applications of N. Subtreatments consisted of 230, 690 and 1150 g N/tree.year as urea, the 230 g N/tree.year treatment being the standard, based on a previous study (Stephenson and Gallagher 1989*b*). Fertiliser was spread evenly on the soil surface under the tree canopy. Irrigation was then provided. Concern for tree health precluded a zero N control.

Data collected

Yield. Whole plot yield was expressed as nut-in-shell (NIS) at 10% moisture. Nuts were then sorted into <17 mm in diameter (of no commercial value), 17–19 mm (marginally acceptable) and >19 mm in diameter (commercially acceptable nuts).

Quality. Commercially acceptable nuts (>19 mm diameter) were oven dried to about 1.5% moisture, cracked and KR determined [wt kernel/wt nut-in-shell (NIS)]. The percentage of G1K with an oil content ≥72% was calculated, based on percentage by weight of kernels which floated on water (Ripperton *et al.* 1938; Mason and Wills 1983). The occurrence of impurities, such as immature, deformed, mouldy, or insect damaged kernels, was determined as the percentage by weight.

Flushing. Previous studies showed that the pattern and timing of vegetative flushing influenced both KR and G1K (Stephenson and Gallagher 1989*b*). A visual estimate of the percentage of terminal branches on the canopy, which had new or continuing vegetative growth each month, was made (Stephenson *et al*. 1986*a*).

Litterfall. Four buckets to collect tree litter were suspended in the canopy, just below the skirt and about one third of the radius from the outer canopy edge (north, south, east and west). Litter was collected monthly and divided into leaves, twigs, floral parts and nuts that were then separated into a range of 6 categories.

Weather data. Temperature and rainfall were recorded at a standard weather station in the orchard. Temperature records were incomplete.

Statistical analyses

Split-plot analysis of variance was used to identify the effects of N fertiliser, both rate and application strategy, and year on KR and the percentage of G1K. Forward, step-wise general linear model analysis (as a mixture of factors and covariates) was used to identify those factors likely to influence quality and to assess the relative importance of some environmental components of seasons and phenological factors and that of N status. Quadratics were also screened to test for nonlinear effects. These factors influenced macadamia yields in previous studies (Stephenson *et al.* 1986*b*). Data for dependent variables were the means across replicates from the analysis of variance (90 datum points, being 6 years × 5 times of application × 3 application rates). Explanatory variables were the following: percentage flushing (F) in each of 12 months before April in each year [i.e. F (8) refers to percentage flushing in August of the previous year]; N status either as leaf %N (L_{N}) in October in the years 1987–92, or the rate (N_{rate}) or times of application (N_{time}) of fertiliser N; rainfall (R) — monthly totals in each of 12 months before April in each year; litter — leaf litter (L_{lit}) both number and weight of leaves; and nut drop (N_{d}) — 3, 3–20 and >20 mm diameter (complete data sets were available from 1988 to 1992); average maximum temperature (°C) of each month, (T_{max}) (complete data sets were available from 1990 to 1993).

Results

Yield

Yield of commercial sized (>19 mm) NIS was highest in 1989, high in 1991 and 1990, and lowest in 1993 (Table 1). The low and medium rates of N produced higher yields of commercial-sized nuts than the high rate (33.8, 29.6 and 28.8 kg NIS/tree, respectively, $P<0.05$). Time of N application had no significant effect on total (all nut sizes) or commercial (>19 mm) nut yield over all years (data not shown). In 1992, however, a single

Table 1. Yield of nut-in-shell >19 mm (kg/tree) and the effect of rate of nitrogen fertiliser applications on kernel recovery of macadamia nuts, cultivar Keaau from 1988 to 1993

Means followed by the same letter between years for yield and mean kernel recovery for each year, and between rate of nitrogen for kernel recovery within each year and the mean kernel recovery across years for each rate of nitrogen, are not significantly different at $P = 0.05$
NIS, nut-in-shell; KR kernel recovery

Year	Yield NIS (>19 mm, kg/tree)	Kernel recovery (%) Rate of N applied (g N/tree.year)			
		230	690	1150	Mean KR
1988	8.4d	36.0a	35.6a	36.5a	36.1c
1989	14.0a	36.2b	36.9a	37.0a	36.7b
1990	11.8c	35.1b	35.6a	36.2a	35.7d
1991	13.2b	36.9b	37.9a	38.3a	37.7a
1992	8.2d	32.8b	33.8a	33.9a	33.5e
1993	5.9e	35.4b	36.6a	36.5a	36.2c
Mean	10.2	35.4b	36.1a	36.4a	36.0c

Table 2. Yield of nut-in-shell (NIS) >19 mm (kg/tree) and the effect of rate application of nitrogen fertiliser on kernel recovery of macadamia nuts, cultivar Keaau, averaged over April and June harvests in the poor 1992 season

Values followed by the same letter between application strategies (vertical comparisons) for yield, kernel recovery within each rate of N and mean kernel recovery for each application strategy, are not significantly different at $P = 0.05$

Values preceded by the same letter between rates of N within each application strategy and means for rates on N (horizontal comparisons) are not significantly different at $P = 0.05$

NIS, nut-in-shell; KR kernel recovery

Time (and number) of applications	Yield NIS (>19 mm, kg/tree)	Kernel recovery (%) Rate of N applied (g N/tree.year)			
		230	690	1150	Mean KR
April (1)	8.9a	a32.7a	a34.1ab	a33.9ab	33.5a
April, June (2)	8.5a	a33.2a	a34.4ab	a33.9ab	33.8a
April, June, November (3)	7.9a	a32.8a	a33.1b	a33.1b	33.0a
April, June, November, January (4)	7.6a	b32.4a	a34.6a	a34.1ab	33.7a
Monthly (12)	8.2b	b33.0a	b33.1b	a34.7a	33.6a
Mean	8.2	b32.8	a33.8	a33.9	33.5

application in April was as effective as any treatment in eliciting high yield under the conditions of this experiment (Table 2).

Kernel recovery

Kernel recovery increased at the higher rates of N applied ($P<0.05$) (Table 1), being highest overall in 1991, high in 1989 and 1993, and lowest in 1992. Timing of N applications did not significantly affect KR, except in 1992 (Table 2), a single application in April being as good as any other treatment. In 1992, low N applied in summer (January or monthly), intermediate N applied monthly, and all rates of N applied in late spring (November) resulted in a significant reduction in KR of up to 1.7% compared with 4 applications at the intermediate and high rates and monthly at the high rate of N. When 172.5 g of N or more was again applied in January (intermediate and high rates of N applied in 4 split applications), however, KR increased by 1.0–1.5% to normal levels for that season. Monthly applications of 95.8 g N (high rate) had a similar response.

A large percentage of the variation in KR was accounted for ($R^2 = 0.87$–0.93) by the factors in general linear models 1–3 (Table 3). The 3 models were based on different data sets due to differences in data

Table 3. General linear models identifying environmental, phenological and cultural factors significantly associated with kernel recovery

The number of the month in which the factor was related to kernel recovery is shown in parentheses after the description of the factor

Ranges for independent variables are: R (1), 31–126 mm; R (3), 29–349 mm; R (6), 4–125 mm; F (1), 0.2–32%; F (3), 3.6–70%; F (5) 1.7–43.3%; F (9), 0.3–20.8%; L_N, 1.11–1.44%; $N_{d(3\text{–}20\ \text{mm})}$ (12), 4–68 nuts; $N_{d(<3\ \text{mm})}$ (12), 0.6–12.3 g; T_{max} (3), 27–29.7°C; L_{litwt} (6), 2–12.6 g leaves

Model	Constant	Nitrogen[A]	Rainfall (R, mm)	Temperature (T, °C)	Flushing (F, %)	Litterfall[B] (g)	Variance accounted for (%)
1	34.197	$+ kN_{rate}$	$+ 0.02R$ (6) $– 0.01R$ (3) $+ 0.01R$ (1)	—	$+ 0.03F$ (5) $+ 0.06F$ (9)	—	87
2	32.27	—	—	—	$+ 0.05F$ (1) $+ 0.05F$ (5) $+ 0.02F$ (3)	$+ 0.07N_{dno(3\text{–}20\ \text{mm})}$ (12) $+ 0.16N_{dwt(<3\ \text{mm})}$ (12)	89
3	–15.69	$+ 4.544L_N$	—	$+ 1.579T_{max}$ (3)	—	$+ 0.12L_{litwt}$ (6)	93

[A] Nitrogen is represented by leaf N concentration (L_N, %) or by the rate of fertiliser N (N_{rate}, N/tree.year, g), where k is N_{rate} constant i.e. $0_{rate\ 1}$, $+ 0.53N_{rate\ 2} + 0.78N_{rate\ 3}$.

[B] Litterfall includes nut drop (N_{dno}, number; N_{dwt}, weight of dropped nuts) subscript numbers in brackets show the size of dropped nuts, and leaf litterfall, L_{litwt} (g).

Table 4. General linear models identifying environmental, phenological and cultural factors significantly associated with the percentage of first grade kernel

The number of the month in which the factor was related to first gade kernel is shown in brackets after the description of the factor
Ranges for independent variables are: R (3), 29–349 mm; R (5), 31–151 mm; R (12), 32–256 mm); F (4), 0.4–28%; F (11), 0–46%; L_{N}, 1.1– 1.7%; $N_{\mathrm{dwt(>20\ mm)}}$ (11), 0–3 g; L_{litno} (7), 0–26 leaves

Model	Constant	Nitrogen$^{\mathrm{A}}$	Rainfall (R, mm)	Flushing (F, %)	Litterfall$^{\mathrm{B}}$	Variance accounted for (%)
4	87.65	$-4.34L_{\mathrm{N}}$	$+ 0.5R\ (5) - 0.003[R\ (5)]^2$ $-0.05R\ (12)$	$-0.08F\ (4) + 0.15F\ (11)$	—	80
5	96.19	$+ k^{\mathrm{C}}N_{\mathrm{time}}$	$-0.02R\ (3)$	—	$+ 0.08L_{\mathrm{litno}}\ (7)$	82
6	98.10	$+ k^{\mathrm{D}}N_{\mathrm{time}}$	$-0.02R\ (3)$	—	$-0.62N_{\mathrm{dwt(>20mm)}}\ (11)$	86

[A] Nitrogen is represented by leaf N concentration (L_{N},%) or by the application strategy for fertiliser N (N_{time}), where $N_{\mathrm{time\ 1}}$ is 1 application in April; $N_{\mathrm{time\ 2}}$ is 2 applications, 1 in April and 1 in June; $N_{\mathrm{time\ 3}}$ 3 applications, 1 in April, 1 in June and 1 in November; $N_{\mathrm{time\ 4}}$ is 4 applications, 1 in April, 1 in June, 1 in November and 1 in January; and $N_{\mathrm{time\ 5}}$ is 12 monthly applications.

[B] Litterfall includes: nut drop in collection buckets, N_{dwt} (g), subscript numbers in parentheses show the size of dropped nuts, and leaf litter fall, L_{litno} (the number of leaves dropped).

[C] k = constant for N_{time}: 0 $N_{\mathrm{time\ 1}}$, $-0.102N_{\mathrm{time\ 2}}$, $+ 0.187N_{\mathrm{time\ 3}}$, $+0.506N_{\mathrm{time\ 4}}$, $+1.353N_{\mathrm{time\ 5}}$.

[D] k = constant for N_{time}: 0 $N_{\mathrm{time\ 1}}$, $-0.481N_{\mathrm{time\ 2}}$, $-0.271N_{\mathrm{time\ 3}}$, $+0.303N_{\mathrm{time\ 4}}$, $+1.242N_{\mathrm{time\ 5}}$.

availability across years. Although high N status (L_{N} or N_{rate}) consistently elicited higher KR (Tables 1 and 3), rainfall was associated with about ± 3% KR in model 1: high rainfall in June (max. 125 mm) and January (max. 126 mm) collectively enhanced KR by up to 3.1% whereas high rainfall in March (max. 349 mm) depressed it by up to 2.1%. When litter data were added to the data set (complete for the years 1989–1993, model 2), flushing in January (max. 32%), March (max. 70%) and May (max. 43%) was associated with enhanced KR by 1.5–2.0% each. Flushing in September (max. 39%) (model 1) was also associated with enhanced KR by up to 2.1%. Premature drop of developing nuts (up to 20 mm diameter) was also associated with high KR. The addition of temperature and litter data to the analysis (available for 1991–1993 only, model 3) also exerted an influence on KR. High day temperature in March (28–30°C) was associated with high KR, as was a large amount of leaf litter in June (and again, high leaf N).

First grade kernel

First grade kernel was highest in 1991 and 1993 (97.1 and 96.6%, respectively, $P<0.01$) and lowest in 1988, 1989 and 1992 (89.7–90.3%). Analysis of variance failed to show any effects of N treatments on G1K (data not shown), although high N was associated with low G1K (Table 4, model 4). There was a trend for G1K to increase with the frequency of split applications of N fertiliser (N_{time}, models 5 and 6), monthly applications being most beneficial. Rainfall was associated with low G1K, particularly rainfall in March, May and December (Table 4). In contrast, flushing in November was associated with high G1K but in April had an adverse effect. Leaf litter in July, when inflorescence elongation commences, however, was positively associated with G1K. The weight of nuts >20 mm that dropped in November was also negatively associated with G1K (model 6).

Impurities

In this study, impurities, including immature, deformed, mouldy and insect-damaged kernels, tended to be higher than the acceptable industry limit of 3.5%, and increased from 4.2% at low N to >5.2% for intermediate or high N ($P<0.001$). They were highest during the first 3 years of this work (>5.7%) compared with the final 3 years (<4.4%).

Discussion

Kernel recovery

High KR in 1989 and 1991 coincided with higher commercial yields (14 and 13.2 kg/tree, respectively) but in 1993 when KR was also high, yields were very low (5.9 kg/tree), the percentage of smaller nuts being high (8.7% compared with 1.4 and 2.3% in 1989 and 1991, respectively). In 1992, when KR was relatively low, commercial yield was also relatively low (24.6 kg/tree). Hence, there is no consistent trend between KR and yield, seasonal and other factors being important.

The slight increase in KR with the rate of N applied (Tables 1–3) suggests the use of some supplementary N to alleviate low KR in certain situations. Stephenson and Gallagher (1989*b*), however, reported inconsistent responses of KR to applied N. Kernel recovery was highest at low N (230 g N/tree.year) applied in small monthly doses, but was similarly high when the intermediate level of N (690 g N/tree.year) was applied in a single dose in June, before inflorescence growth and anthesis. Further work is needed to clarify KR responses to N.

In the present study, timing of N applications did not affect KR except in 1992 (Table 2), the year in which yields were relatively low. The tendency for KR to be slightly lower after November split applications of intermediate to high rates of N in 1992 is worthy of further investigation. In the meantime, applications of N in spring should be avoided.

Factors influencing kernel recovery

The models in Table 3 provide an insight into some of the important factors possibly affecting KR. The trend for higher rates of N fertiliser (or higher L_N) to increase KR by 1–2% (Tables 1–3, model 1) is confirmed, but other factors are also involved.

Rain appeared to be beneficial in June and January, but detrimental in March. In 1992, KR was lowest and monthly rainfall in both February and March was at least double the monthly average (Stephenson *et al.* 1997). The adverse effect of high March rainfall was less pronounced when rainfall was average or below in January and February. Above-average rainfall in 1988 and 1990 (Stephenson *et al.* 1997) was associated with high KR in subsequent seasons, 1989 and 1991 (Table 1). Further work is needed to elucidate these responses. Enhanced KR was associated with flushing in May, September, January and March, and with warm days (27–30°C) in March. In a previous study, flushing was also associated with rainfall (Stephenson *et al.* 1986*a*) so it is not surprising that it can also account for part of the variation in KR. Identification of the correlations with KR in the general linear models requires further work to elucidate the apparent effects.

First-grade kernels

As with KR, there was no consistent relationship between G1K and yield. Both KR and the percentage of G1K were high in 1991 and 1993 but the former was also high in 1989 when the percentage of G1K was low. Factors influencing quality are obviously complex.

Factors influencing the percentage of first-grade kernels

The percentage of G1K seemed higher at low leaf N and appeared to improve as the number of split applications of N increased. Statistically, however, N fertiliser treatments, both rate and timing, had no significant influence on G1K under the conditions of this experiment. Hence, these effects are obviously small and confounded by other factors.

Above-average rainfall (>120 mm) in May (model 4), which was also associated with above-average rainfall in March and April (Stephenson *et al.* 1997), resulted in a 4–7% reduction in G1K compared with below-average (<40 mm) rainfall in May. In 1988, when May rainfall was only slightly below the monthly average of 80 mm, G1K was also low (90.3%) but the rainfall in April was very high (>300 mm, compared with the April average of <100 mm). Thus, high rainfall in the latter stages of oil accumulation appears to have adversely affected the process, resulting in lower G1K. Further work is needed to investigate the factors correlated with G1K in Table 4.

Impurities

Since impurities include a range of defects such as immature kernels and insect damage, trends were inconsistent. It is interesting, however, that low N_{rate}, which produced the highest yield of commercially acceptable nuts also resulted in lower levels of impurities.

Fertiliser strategies

Commercial yield was highest at low rates of N but was not generally affected by the timing of N applications. Although KR was increased by up to 1.5% at higher rates of N under certain conditions, this was insufficient to compensate for the higher yields (about 17% higher) at low N. It is therefore unlikely that N fertiliser strategies should be developed on the basis of KR alone. Moreover, there was no consistent trend between KR and yield.

Total yield of 14.2 kg NIS/tree (all nut sizes) obtained at the low rate of N (230 g N/tree) would remove about 149 g N from the orchard (Bryen and Vimpany 1997). Hence the low rate of N, applied in April–June, should be adequate to sustain this level of cropping under these experimental conditions. If excessive leaching of N is likely, the application can be split between April and June to achieve a similar response. There is an urgent need for soil and leaf tests calibrated for yield across the range of soil types represented in the macadamia industry to confirm the appropriateness of this suggested strategy for the Australian macadamia industry.

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References

Bryen L, Vimpany I (1997) ‘Managing macadamia fertiliser program. 2. Nutrient removal in the crop.’ Australian Macadamia News Bulletin, September 1997. p. 55.

Hirae HH (1976) Leaf and soil analysis in macadamia In ‘16th Annual proceedings of the Hawaii Macadamia Producers Association’. May 1976. pp. 65–70.

Mason RL, Wills RBH (1983) Evaluation of the use of specific gravity as an objective index of the quality of Australian macadamia nuts. *Food Technology in Australia* **35**, 245–248.

Robinson JB, Treeby MT, Stephenson RA (1997) Fruits, vines and nuts. In ‘Plant analysis: an interpretation manual (2nd edn)’. (Eds DJ Reuter, JB Robinson) pp. 347–382. (CSIRO Publishing: Melbourne, Australia)

Ripperton JC, Moltzau RH, Edwards DW (1938) ‘Methods of evaluating the macadamia nut for commercial use.’ Hawaiian Agricultural Experiment Station Bulletin No. 79. 26 pp.

Stephenson RA, Cull BW (1986) Standard leaf nutrient levels for bearing macadamia trees in southeast Queensland. *Scientia Horticulturae* **30**, 73–82.

Stephenson RA, Gallagher EC (1989*a*) Timing of nitrogen application to macadamias. 1. Tree nitrogen status and vegetative growth. *Australian Journal of Experimental Agriculture* **29**, 569–574.

Stephenson RA, Gallagher EC (1989*b*) Timing of nitrogen application to macadamias. 3. Reproductive growth, yield and quality. *Australian Journal of Experimental Agriculture* **29**, 581–585.

Stephenson RA, Cull BW, Stock J (1986*a*) Vegetative flushing patterns of macadamia trees in southeast Queensland. *Scientia Horticulturae* **30**, 53–62.

Stephenson RA, Cull BW, Mayer DG (1986*b*) Effects of site, climate, cultivar, flushing, and soil and leaf nutrient status on yields of macadamia in southeast Queensland. *Scientia Horticulturae* **30**, 227–235.

Stephenson RA, Gallagher EC, Doogan VJ (1997) Leaf nitrogen as a guide for fertilising macadamia. *Australian Journal of Experimental Agriculture* **37**, 599–604.

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