Time of nitrogen application and yield of Bengal lychee on a sandy loam soil in subtropical Queensland

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Summary. Nitrogen (N) was applied over 4 years to 6-year-old lychee trees (*Litchi chinensis* Sonn. cv. Bengal) growing in subtropical Queensland (lat. 27°S.) on a sandy loam soil (0–15 cm) with 2.8 mg nitrate-N/kg, to determine the effect of time of N application on leaf N concentration, vegetative growth, flowering, and yield. Applications of N (equivalent to 750 kg N/ha in year 4) were made after panicle emergence in July, after harvest in January, or split between the 2 periods. Control trees received no N. Leaf N concentrations in April–June were, on average, about 0.1% lower after a single N application in winter than application in summer or split applications. Leaf N concentrations in November–February were about 0.1% higher after winter or split N applications than after summer applications.

Timing of fertiliser application had no affect on yield. It took 4 years without N fertiliser to show significant reductions in yield compared with fertilised trees. In year 4, yield increased from 20 to 60 kg/tree on individual pairs of trees as leaf N in August increased from 0.95 to 1.56%. Lower yields in control trees in year 4 were associated with poor leaf growth in the previous 2 years, and with lower concentrations of N in the panicles, leaves, twigs, and small branches, as well as lower chlorophyll concentrations and net CO_2 assimilation after fruit set, compared with trees receiving N.

Introduction

Yields from lychee orchards in Australia are often low and variable due to poor flowering or failure of fruit set (Menzel *et al.* 1988; Menzel and Simpson 1992*a*, 1992*b*). Provided insect pests are controlled, the success of flowering and fruiting is primarily dependent on weather conditions during different phases of the crop cycle (Menzel 1983, 1984).

The role of nutrition, especially of nitrogen (N), on the growth and yield of lychee is poorly understood, and there is also no consensus on the optimum time to apply fertilisers (Menzel and Simpson 1987). The importance of N fertiliser on the yield of lychee was shown by Ghosh *et al.* (1986, cited in Mitra 1988), who indicated the highest yields of cv. Bombai over 3 years in India were obtained with the highest rate of N used (600 g/tree for 6-year-old trees). They suggested an optimum leaf N concentration over a narrow range of 1.46–1.48%, with leaves collected 10 days before flowering. Data collected by Koen *et al.* (1981) indicated maximum yield of Tai So lychees in South Africa with a leaf N concentration of 1.47%, with significantly ($P<0.05$) lower yields at 1.42 or 1.52%. Leaf samples were taken after fruit set. Menzel *et al.* (1988) studied the effects of N fertiliser on Tai So lychee in subtropical Australia and found it took a rate of 2600 kg N/ha or more after 3 years to depress flowering. Lower, but excessive, rates of N had no effect on flowering.

There have been few reports indicating the benefits of a particular timing of N application on the yield and fruit quality of fruit trees. Hill-Cottingham (1963) studied the effects of N applied in June, July, August, September, or March and April on the productivity of apple trees in England. Potential yield as indicated by the number of fruit set was significantly ($P<0.05$) greater when N was applied in September than in August. None of the other treatments was significantly better than the September application. Yields of Imperial mandarin in subtropical Queensland were similar in 3 of 4 years but significantly ($P<0.05$) higher in 1 year with the application of N in winter, compared with applications split in spring and summer (Chapman 1982). Accumulated yield over 4 years was 9% higher with the winter N treatment than with spring–summer treatment. Fruit quality, as indicated by the Brix to acid ratio, was also better when N was applied in winter. In more recent work, commercial yields from control macadamia trees receiving frequent low N applications were similar to those from strategic high N

treatments in 3 of 4 years and better in 1 out of 4 years (Stephenson and Gallagher 1989).

This paper reports the effect of N application on the seasonal pattern of leaf N concentration and whether this has any influence on vegetative flushing, flowering, and yield of lychee trees in subtropical Queensland (lat. 27°S.). Nitrogen was applied in winter or summer, or was split between the 2 periods. The effects of N fertiliser on the distribution of N in the soil and tree, and on CO_2 assimilation, were also investigated.

Materials and methods

Site description

The experiment began in July 1987 on 6-year-old Bengal lychee trees growing in a commercial orchard at Beerwah near Nambour in subtropical Queensland (lat. 27°S.). The soil was a sandy loam (0–15 cm) overlying a sandy clay loam (15–30 cm), with the following characteristics (0–15 cm): pH 4.7; electrical conductivity, 0.03 dS/m; organic carbon, 0.8%; chloride, 20 mg/kg; nitrate-N, 2.8 mg/kg; bicarbonate-extractable P, >99 mg/kg; [cmol(+)/kg] Ca 0.66, Mg 0.33, K 0.25, Na 0.03; (mg/kg) Cu 1.3, Zn 15.5, Mn 2.0, Fe 107, B 0.1. Analysis methods were as described in Menzel *et al.* (1992*a*). Rainfall and temperature data were collected for Nambour, which is about 40 km from Beerwah (Menzel *et al.* 1988). Total rainfall was 12% lower than average in 1987, 12% higher in 1988, and 28% higher in 1989. Average daily maximum temperature in October 1988 was 5°C higher than the long-term average; maximum temperatures in October 1989 and minimum temperatures in August 1987, April and August 1988, April and May 1989, and April 1990 were 2–3°C higher than the long-term average.

Experimental design and plant culture

There were 4 treatments in 8 randomised blocks: nil N (control); N application after panicle emergence in July (winter N); N application after harvest in January (summer N); N application split between the 2 periods (split N). Each tree received 0.5 kg N in 1987–88, 1.0 kg N in 1988–89, and 1.5 kg in 1989–90 and 1990–91. All trees including controls received the following nutrients (g/tree) each year: P 180, K 800, Mg 150, Zn 100, B 6. Major nutrients were applied after panicle emergence and after harvest, and trace elements only after panicle emergence. The orchard was irrigated with mini-sprinklers to supplement rainfall. This ranged from 250 L/week in winter to 600 L/week in summer without rainfall. Since no record was kept of soil or plant water status, it is not known whether irrigation met crop water demand. However, the trees set satisfactory crops, and so it is assumed that they did not suffer significant water deficits. Trees were spaced at 8 m in rows 10 m apart, equivalent to 125 trees/ha. At the end of the experiment, the diameter of the trees was about 5 m and the canopy cover (surface of the ground covered by the tree's foliage) was about 20 m^2. The inter-rows of the orchard were under grass.

Phenology and leaf sampling

A monthly record was kept of the proportion of the terminal shoots with vegetative flushing and flowering (panicle formation) by a visual assessment of each tree. Yield was determined at harvest. At 2–3 weeks after last flower opening, measurements were also made of panicle length and stalk dry weight (1988–90) and number of fruit per panicle (1989–90). At harvest, average fruit fresh weight (1989–91) on 4 randomly selected panicles/tree was measured. At the end of the experiment, there was at least 1.5 m between adjacent trees within the rows.

Leaves were sampled monthly for total N concentration, and annually after fruit set in October for concentrations of P, K, Ca, Mg, Fe, Mn, Zn, Cu, B, and Cl. Each sample was washed in mild detergent (1 mL/L) and acetic acid (0.6 mL/L), rinsed in distilled water, dried at 52°C for 3 days, milled, and re-dried at 100°C for 18 h. Samples were dried at 65°C for 24 h, ground to <1 μm in a pulverising mill, pelletised in a hydraulic press at 2 t/m^2, and analysed in an ARL 8480 simultaneous/sequential X-ray fluorescence spectrometer for K, Ca, Mg, Cl, Mn, Fe, Zn, and Cu. Separate samples of finely ground material were used for the analysis of N and P using a semi-micro Kjeldahl digestion procedure following the method of Searle (1974) for N and Murphy and Riley (1962) for P. Boron was analysed by a dry ashing procedure followed by acid dissolution and determination by inductively coupled plasma spectrometry (Lyons *et al.* 1984). A single mature leaf behind the flowering or fruiting panicle or leaf flush was sampled from 8 randomly selected terminal branches/tree and pooled. Samples were collected from branches about 1.5–2.0 m above the ground. Samples from adjacent blocks were pooled giving 4 replicates/treatment.

Distribution of nitrogen in the soil and tree

In November 1990, soil samples (0–15, 15–30, 30–45, 45–60 cm deep) were taken between the trunk and drip-line. Since there was no significant difference in the performance of trees receiving N, it was decided to limit sampling to the control and winter N trees. Samples were bulked from each of 8 trees/treatment (depths kept separate) and analysed for total N concentration by Kjeldahl digestion with sodium sulfate and selenium as catalysts (Bremner 1965). Following dilution with water, ammonium-N was determined by automated colorimetric procedure based principally on the indophenol reaction between salicylate and sodium dichloroisocyanurate (Crooke and Simpson 1971). Samples were taken in November 1990 from fruit, panicles, leaves, twigs (<1 cm diameter), small branches (1–3 cm diameter), medium branches (3–5 cm diameter),

large branches (5–10 cm diameter), trunk (>10 cm diameter), large roots (>1 cm diameter), and small roots (<1 cm diameter) for total N determination. Two branches (1 north-facing, 1 south-facing) were taken from each tree for the fruit, panicle, twigs, and small branches and pooled. Four core samples (0.7 cm diameter) excluding the bark were taken from medium and large branches, trunk, and large roots and pooled. Four samples were taken midway between the trunk and drip line (north, south, east, west) for the small roots and pooled. Samples from adjacent blocks were pooled giving 4 replicates/treatment.

Net carbon dioxide assimilation and chlorophyll concentration

In November 1990, measurements were made of net CO_2 assimilation rate (A) of the control and winter N treatments on the most recently matured leaf behind the fruiting cluster between 0900 and 1230 hours on a single, cloud-free day, using a Li-Cor 6200 portable photosynthesis meter with a 250 mL leaf chamber. During the measurements, photosynthetic photon flux density was 1708–2165 μmol quanta/m^2.s, air temperature was 30–37°C, and vapour pressure deficit was 2.2–3.2 kPa. Despite the high temperatures, stomata would not be expected to be closed under these conditions (Batten *et al.* 1992). Data are the means of a single leaf per tree with 8 trees/treatment. At the same time, leaf discs were collected for total chlorophyll concentration according to the method of Marini and Marini (1983). Data are the means of 3 leaves/tree with 8 trees/treatment.

Statistical analyses

Leaf flushing was analysed separately for each year (1988–90) by split-plot analysis of variance (N as main plots, split for months). In each year, only data for the months in which flushing occurred were included in the analyses. Data were analysed after transformation by arcsine. Leaf N was analysed by split-plot analysis of variance (N as main plots, split for years and months). Leaf nutrient concentrations (excluding N), flowering, panicle length and stalk weight, number of fruit per panicle, yield, and average fruit weight were analysed by split-plot analysis of variance (N as main plots, split for years). Nitrogen concentrations in the various plant parts were analysed by split-plot analysis of variance (N as main plots, split for plant part), A was analysed by split-plot analysis of variance (N as main plots, split for time of day), and chlorophyll concentration was analysed by 1-way analysis of variance (N effect only).

Results

Yield

There was no significant ($P>0.05$) effect of N treatment on yield in 1988–90 (Table 1). In 1991, however, control trees yielded significantly ($P<0.05$) less than trees receiving N. The relative order of increasing average yield was 1988 < 1989 < 1990, 1991. Average fruit fresh weight was not significantly ($P>0.05$) affected by N treatment and only varied from 17 to 18 g between years.

Table 1. Effect of timing of nitrogen treatment on the yield (kg/tree) of lychee trees from 1988 to 1991

Means followed by the same letter are not significantly different at $P = 0.05$
Data are the means of eight trees

Treatment	1988	1989	1990	1991
Control	0.9a	38.4cd	48.2def	27.2b
Winter N	1.4a	32.5bc	47.2def	47.5def
Summer N	0.8a	38.8cde	52.5f	51.7ef
Split N	1.4a	35.0bc	46.7def	55.8f

Flowering

Flowering was not significantly ($P>0.05$) affected by N treatment, but was significantly lower in 1987 (8%) than in 1988, 1989, and 1990 (90–99%).

Panicle stalk length and weight, and number of fruit per panicle after flowering

There was no significant ($P>0.05$) effect of N treatment on panicle size or on number of fruit per panicle counted 2–3 weeks after last flower opening. In contrast, panicles were significantly ($P<0.05$) shorter in 1989 and 1990 than in 1988 (18.7, 19.3 *v.* 27.8 cm). Panicles weighed significantly less in 1989 than in 1988 and 1990 (5.6 *v.* 7.0–7.3 g). Fruit set was significantly ($P<0.05$) higher in 1989 than in 1990 (30 *v.* 17 fruit/panicle).

Vegetative flushing

Time of N application had a significant ($P>0.05$) effect on leaf flushing in 1989 only. In 1988, there was no significant ($P>0.05$) difference among treatments. Consequently, the data have been presented as means of the 4 treatments across months; >40% of terminal branches flushed in January, April, and May (Fig. 1). In 1989, there was a significant ($P<0.05$) difference between the control and summer N, and the winter and split N treatments, with flushing limited to the winter N and split N treatments in March and April. In 1990, flushing was significantly ($P<0.05$) greater in trees receiving N than in the controls in March and April.

Leaf nitrogen concentration

The leaf N concentration (mean ± s.e.) at the start of the experiment was 1.84 ± 0.02, 1.84 ± 0.05, 1.89 ± 0.08, and 1.88 ± 0.03% in the control, winter N, summer N, and split N treatment, respectively. By December 1987, leaf N had declined to 1.42 ± 0.04, 1.51 ± 0.05, 1.33 ± 0.01, and 1.53 ± 0.02%, respectively.

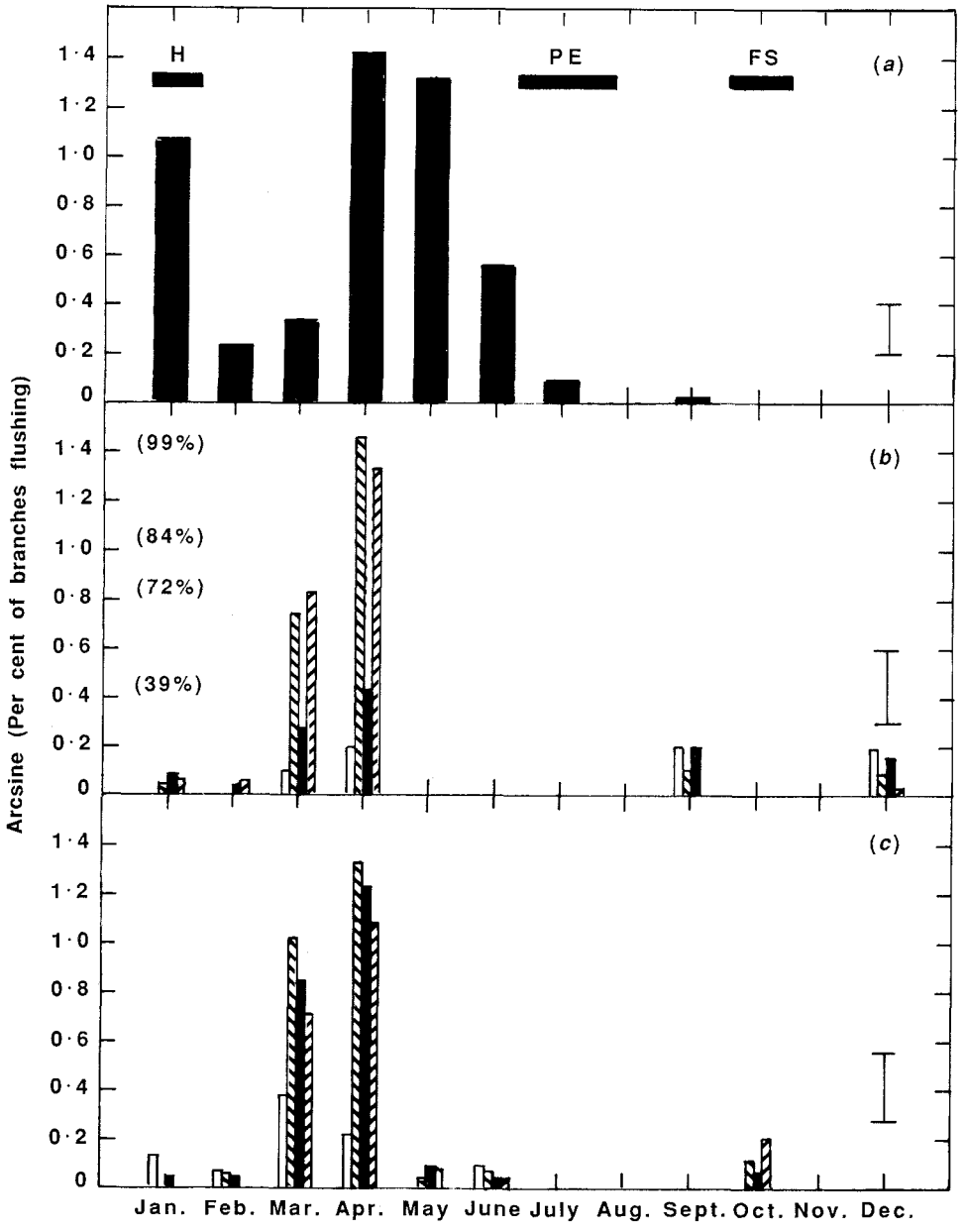

Figure 1. Proportion of terminal branches flushing in the lychee orchard in (*a*) 1988, (*b*) 1989, and (*c*) 1990. Data for 1988 have been pooled for the 4 nitrogen treatments. Equivalent flushing percentages shown on the inside of the *y*-axis. Control (□), winter N (▨); summer N (■), and split N (▨). Data are the means of eight trees. Vertical bars indicate l.s.d. (P = 0.05). Histograms show periods of harvest (H), panicle emergence (PE), and fruit set (FS).

In the control, mean leaf N decreased from 1.40% in 1988, to 1.28% in 1989, and to 1.18% in 1990 (Table 2). In the other treatments, mean leaf N ranged from 1.39 to 1.53%, and was generally higher in 1988 than in 1989 and 1990. In these treatments, the range in leaf N concentration was about 0.2–0.3% during the year. The difference in concentration between control and N treatments was higher in August–December than in January–July. This difference increased over time and was pronounced by 1990.

Nitrogen applied in summer (single or split) increased leaf N concentrations within 1–2 months, whereas

Table 2. Effect of timing of nitrogen treatment on leaf N concentration (%) of lychee trees from 1988 to 1990

Optimum leaf N concentration range for healthy, high-yielding lychees in subtropical Queensland is 1.5–1.8% (Menzel *et al.* 1992*b*)
Data are means of eight trees

Treatment	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year mean
						1988							
Control	1.48	1.52	1.60	1.48	1.42	1.50	1.45	1.33	1.29	1.21	1.32	1.19	1.40
Winter N	1.53	1.63	1.71	1.53	1.43	1.53	1.48	1.42	1.42	1.38	1.41	1.41	1.49
Summer N	1.47	1.66	1.76	1.57	1.58	1.71	1.40	1.40	1.36	1.23	1.31	1.28	1.48
Split N	1.56	1.69	1.83	1.62	1.58	1.59	1.42	1.50	1.40	1.32	1.52	1.34	1.53
						1989							
Control	1.25	1.23	1.29	1.33	1.32	1.34	1.25	1.33	1.22	1.36	1.22	1.21	1.28
Winter N	1.49	1.45	1.46	1.42	1.36	1.49	1.43	1.43	1.43	1.54	1.34	1.39	1.43
Summer N	1.27	1.33	1.47	1.43	1.44	1.44	1.41	1.52	1.34	1.49	1.30	1.27	1.39
Split N	1.49	1.50	1.62	1.50	1.45	1.51	1.41	1.48	1.38	1.51	1.37	1.36	1.46
						1990							
Control	1.24	1.19	1.27	1.28	1.34	1.22	1.17	1.10	1.04	1.05	1.19	1.05	1.18
Winter N	1.43	1.45	1.49	1.41	1.57	1.41	1.48	1.44	1.40	1.41	1.44	1.43	1.45
Summer N	1.29	1.39	1.48	1.58	1.63	1.55	1.51	1.36	1.32	1.32	1.25	1.33	1.42
Split N	1.46	1.48	1.53	1.52	1.61	1.57	1.52	1.49	1.41	1.38	1.40	1.39	1.48
l.s.d. ($P = 0.05$)						0.13[A]							0.06[B]

[A] For month means, except when comparing means with the same levels of N treatment, N treatment x year or N treatment x month, where l.s.d. ($P = 0.05$) is 0.12.
[B] For year means, except when comparing means with the same levels of N treatment or N treatment x year, where l.s.d. ($P = 0.05$) is 0.03.

N applied in winter did not increase leaf N concentration until after harvest (Table 2). Leaf N concentrations were, on average, about 0.1% lower in April–June and about 0.1% higher in September–February in the winter N than the summer N treatment. Similarly, leaf N concentrations were about 0.1% lower in March–June in the winter N than the split N treatment. Average leaf N concentrations were about 0.1% lower in November–March in the summer N than the split N treatment.

Concentration of other nutrients in the leaves

It can be difficult to compare changes in leaf nutrient concentrations over time in different treatments because of the effect of leaf age on the concentrations of all nutrients. When N promotes vegetative growth, the youngest mature leaf on this treatment will be younger than on a treatment where there has been no flushing as in the case of the control trees in 1989–1990 and the summer N treatment in 1989. Leaf Ca concentration can sometimes be used as an indicator of leaf age and, typically, increases with the age of the leaf; however, leaf Ca did not appear to be higher in the controls in 1989–90 or in the summer N treatment in 1990 compared with sampling at other times (data not presented).

The concentrations of Ca and Mg were significantly ($P<0.05$) lower for trees receiving N than control trees (Table 3). There was also a significant ($P<0.05$) difference in leaf Fe and B, with control trees having higher concentrations than winter N and split N trees. There were no significant ($P>0.05$) differences between control trees and those receiving N with respect to concentrations of other nutrients. Consequently, the data have been pooled across N treatments (Table 4). There were changes in the concentrations of most nutrients across years, but only the changes in leaf P, K, and Ca appear significant. No nutrient concentration increased over time. Direct comparisons of the concentrations of the nutrients with standards for lychee based on samples collected before flowering (Menzel *et al.* 1992*b*) are not possible. The composition of the leaves for mobile nutrients (N, P, K) would be expected to be lower, and the less mobile nutrients (Ca, Mg, Mn, Fe, B) higher,

Table 3. Effect of timing of nitrogen treatment on the mean concentration (% or μg/g DW) of leaf calcium (Ca), magnesium (Mg), iron (Fe), and boron (B) in lychees

Data are the means of four blocks collected in October pooled over four years (1987–90)

Nutrient	Control	Winter N	Summer N	Split N	l.s.d. ($P = 0.05$)
Ca (%)	0.57	0.47	0.47	0.41	0.09
Mg (%)	0.45	0.37	0.37	0.32	0.04
Fe (μg/g)	84	67	70	58	15
B (μg/g)	82	68	76	62	11

Table 4. Leaf nutrient concentrations (% or μg/g DW) in the lychee orchard from 1987 to 1990

Data are averaged over N treatments with samples collected in October Leaf nutrient standards for lychee (Menzel *et al.* 1992*b*) are also presented

Nutrient	Leaf standard	1987	1988	1989	1990	l.s.d. ($P = 0.05$)
		Macronutrients (%)				
P	0.14–0.22	0.14	0.11	0.15	0.15	0.02
K	0.70–1.10	1.00	0.61	0.75	0.99	0.07
Ca	0.60–1.00	0.50	0.58	0.48	0.35	0.06
Mg	0.30–0.50	0.31	0.43	0.38	0.39	0.04
Cl	<0.25	0.15	0.16	0.16	0.16	n.s.
		Micronutrients (μg/g)				
Mn	100–250	123	148	133	85	18
Fe	50–100	90	72	64	54	12
Zn	15–30	36	85	52	35	12
Cu	10–25	53	136	64	15	16
B	25–60	81	78	63	67	8

with the later sampling. Leaf P and K appeared to be low in 1988 and leaf Ca low in 1987, 1989, and 1990.

Distribution of nitrogen in the soil and tree in 1990

There was no difference in the mean concentration of total soil N in the control and winter N plots. Total soil N decreased slightly with soil depth from 0.03 to 0.04% at 0–15 cm, to 0.02% at 45–60 cm. Nitrogen concentrations in the fruit, panicle, leaves, twigs, and small branches were significantly ($P<0.05$) lower in the control than the winter N treatment (Table 5). In the control, the highest concentrations of N were found in the fruit and leaves, while in the winter N treatment the highest concentrations of N were found in the fruit, panicle, leaves, and twigs. In both treatments, the lowest concentrations were found in the medium branches, large branches, trunk, and large roots.

Table 5. Effect of winter nitrogen treatment on the concentration (%) of N in different plant parts of lychee

Data are the means of eight trees sampled in November 1990

Plant part	Control	Winter N
Fruit	0.92	1.11
Panicle	0.59	0.97
Leaves	0.93	1.18
Twigs (<1 cm diam.)	0.43	0.90
Small branches (1–3 cm diam.)	0.26	0.54
Medium branches (3–5 cm diam.)	0.14	0.29
Large branches (5–10 cm diam.)	0.19	0.23
Trunk (>10 cm diam.)	0.21	0.24
Large roots (>1 cm diam.)	0.23	0.24
Small roots (<1 cm diam.)	0.65	0.80
l.s.d. ($P = 0.05$)	0.17[A]	

[A] Except when comparing means within the same N treatment, where l.s.d. ($P = 0.05$) is 0.16.

Net carbon dioxide assimilation and chlorophyll concentration in 1990

The A value of the control trees was significantly ($P<0.05$) lower than that of the winter N treatment (2.1 *v.* 5.0 μmol $CO_2/m^2.s$). Mean A was 3.8, 4.2, 2.9, and 3.3 μmol $CO_2/m^2.s$ at 0900, 1030, 1130, and 1230 hours, respectively (l.s.d. at $P = 0.05$ was 0.6). Total leaf chlorophyll concentration after fruit set was significantly ($P<0.05$) lower in the control than in the winter N treatment (341 *v.* 622 mg/m^2).

Relationship between yield and leaf nitrogen

We studied the relationship between yield and leaf N concentration in August across individual pairs of trees in the same N treatment from 1988 to 1991. Yield in 1988 was low, reflecting poor flowering in 1987. In 1989 and 1990, yield ranged from 22 to 50 and from 35 to 65 kg/tree, respectively, but was not correlated ($P>0.05$) with leaf N (1.27–1.62% and 1.22–1.57%, respectively). However, in 1991 yield increased from 20 to 60 kg/tree as leaf N increased from 0.95 to 1.56% (Fig. 2). Yield

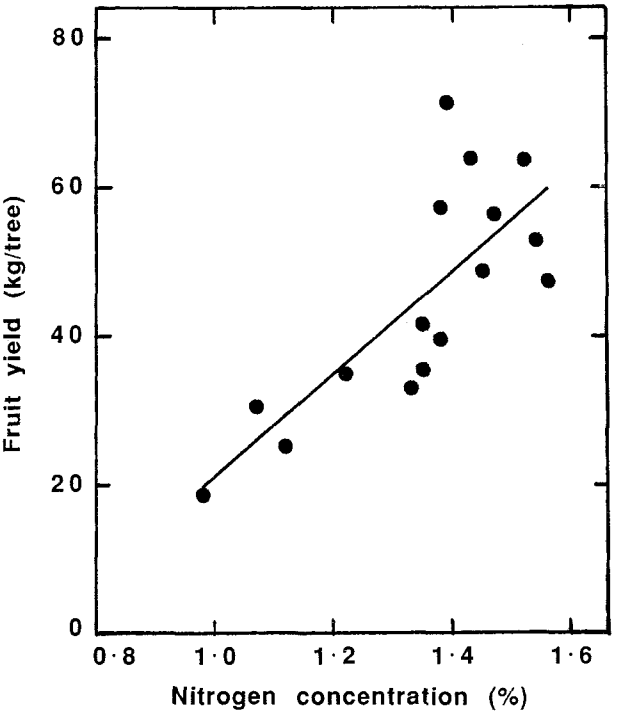

Figure 2. Relationship between yield in 1991 and leaf nitrogen concentration in August 1990. Data are means of pairs of trees for each N treatment. Regression for yield (y) and leaf N:

$y = 69.06\ (\pm\ 15.24)N - 48.03$ ($R^2 = 59\%$, $P<0.001$).

Table 6. Correlation (r^2, %) for the relationship between yield in 1991 and leaf nitrogen concentration during months of 1990

Regressions from means of pairs of tree for each N treatment

Month	r^2	Month	r^2
Jan.	17	July	0
Feb.	30*	Aug.	59**
Mar.	32*	Sept.	47**
Apr.	38*	Oct.	30*
May	45**	Nov.	10
June	2	Dec.	29*

*P<0.05; **P<0.01.

and leaf N were not as strongly correlated in the other months (Table 6). High yielding trees (>50 kg/tree) came from all 3 treatments receiving N.

Discussion

Lychee trees responded to N applications only after 4 years and there was no effect of time of N application. Pot studies with citrus in Florida showed that N absorption occurred throughout the year but was at a maximum in the warmer months (Roy and Gardner 1946). In our experiment, winter applications were as good as summer applications. We would have expected leaf N to increase more rapidly when N was applied in summer, with greater metabolic activity at higher temperatures, and greater root growth.

Concentrations of N were higher in metabolically active tissues such as fruit, leaves, twigs, and small branches. Menzel *et al.* (1992*c*) indicated that leaf tissue was preferred for estimating tree N status. Leaves accounted for about 28% of the vegetative dry matter of a 6-year-old lychee tree, contained about 57% of the tree's N, and reflected the concentration of N in other important tissues such as twigs (7%) and small branches (17%). Leaf N concentration declined over 4 years in the control trees, indicating that N reserves in the soil were inadequate to replace N in the leaves used for growth and cropping. Reserves have been shown to be important in the growth and cropping of evergreen, as well as deciduous, fruit trees. Old shoots, stems, and roots supplied most of the N used by flowers, fruitlets, and new flushes in calamondin trees (*Citrus mitis*) (Legaz *et al.* 1982). Over 20 days from the start of flowering, about 80% of the ^{15}N absorbed by the tree from the nutrient solution went to the spring flush leaves and roots and <2% to the flowers. In blueberry, 90% of N used in reproductive growth up until anthesis came from N stored in the shoots and roots, whereas new vegetative shoots in spring received 65–90% of their N from reserves (Birkhold and Darnell 1993). These results highlight the importance of N reserves to the overall productivity of fruit trees. In the present experiment, differences in the concentration of N in the leaves between the control trees and those receiving N were greater between July and December during reproductive development when the demand for plant N was relatively high.

Excessive rates of N application equal to 2600 kg/ha reduced the proportion of terminal branches flowering in 1 year out of 3 (Menzel *et al.* 1988). Lower rates that were also excessive had no effect on flowering. We used a rate of N equivalent to 750 kg/ha in year 4 in our experiment. Flowering was very poor in 1987 compared with the other years. Rainfall and temperatures in May–July before flowering were not higher in 1987 than in 1988 to 1990. Total rainfall ranged from 380 to 480 mm, and average maxima and minima ranged from 21.4 to 22.6°C and 9.9 to 11.2°C, respectively. Leaf N was similar in both periods when adjusted for the movement of N to younger leaves (Menzel *et al.* 1987). The difference in the flowering in 1987 and 1988–1990 cannot be readily explained but does not appear to be related to temperature, rainfall, or leaf N concentrations.

The 12-year-old trees used by Koen *et al.* (1981) would have had a diameter of about 6 m and a canopy cover of about 28 m^2. Their maximum yields were achieved with application of 0.84 kg N/tree or about 30 g N/m^2 canopy cover. In contrast, our trees growing on a sandy loam soil received about 3 times this rate of N on an area basis.

The main period of leaf flushing was from January to April and was not consistently altered by applying N at different times of the year. Application of N just after panicle emergence did not promote vegetative growth from August to December. These results agree with earlier studies where leaf growth was generally confined to the period between harvest and panicle emergence (Menzel and Simpson 1992*a*). In contrast, high leaf N concentrations in spring were correlated with lower yields in avocado, possibly because N promoted leaf growth at the expense of fruit set (Embleton *et al.* 1959).

Yield in 1991 increased over the range of leaf N concentration in August from 1.0 to 1.6% (Fig. 2). Lack of a response to applied N until year 4 is not unexpected, since fruit and nut trees may take several years to respond to applied fertilisers (e.g. it took 3 years before there were substantial differences in the yield of quality macadamia nuts among trees fertilised at different times of the year; Stephenson and Gallagher 1989). In pecan, it took 6 years for the leaves to respond to N applications (Worley 1974), possibly due to the accumulation of nutrients in storage tissues or recycling from leaf fall (Adams and Attiwill 1986). The control trees flushed poorly in 1989 and 1990 and it is likely that 2 consecutive years of poor flushing led to low yields in year 4 as a result of a decline in nutrient and carbohydrate reserves. The control trees also had lower chlorophyll concentrations and A values after fruit set in

1990 and fewer (but not smaller) fruit at harvest than the trees receiving N. Nitrogen has been shown to increase the yields of lychee but to have a variable effect on average fruit weight (e.g. Yamdagani *et al.* 1980; Sharma and Azad 1989). Our data agree with the results in several crops showing lower *A* values under lower leaf N concentrations (Sinclair and Horie 1989). Fruit growth in lychee has been shown to be dependent on current photosynthesis (Yuan and Huang 1988), and it is not surprising that control trees with lower leaf N and *A* values in 1990 had lower yields in 1991.

Leaves collected just after panicle emergence in August are preferred for leaf analysis in lychee, since leaf composition is more stable then (Menzel *et al.* 1992*b*). In 1991, yield was correlated with leaf N in August 1990; with earlier or later sampling it was less well correlated. The concentration of N in August also remained fairly constant in the different treatments, with average yields of 40–50 kg/tree from 1989 to 1991: i.e. 1.42–1.44% for winter N, 1.36–1.52% for summer N, and 1.48–1.50% for split N.

Conclusion

It took 4 years without N fertiliser before trees growing on a sandy loam soil showed significant reductions in yield compared with fertilised trees. High yields were achieved with August leaf N concentrations in the range 1.33–1.52%. Lower concentrations were associated with lower yields.

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