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The effect of nitrogen on cashew in north Queensland 1995-99

A report for the Rural Industries Research and Development Corporation

by Patrick O'Farrell, John Armour and David Reid

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Foreword

The level of imports of cashew kernel into Australia and the current shortfall in world production of raw cashew nut indicate that cashew production in Australia has good potential. Extensive land areas with climate suitable for cashew production exist in northern Australia. Countries with processing facilities are willing to either purchase or shell Australian nut-in-shell (NIS) production, providing Australian producers with a range of marketing options: NIS, kernel or valued added sales.

Economic NIS yields for cashew have been defined and these will be achieved by a combination of high-yielding varieties and efficient and sustainable crop management practices that support the realisation of genetic potential.

This project investigated the effect of nitrogen (N) on cashew growth and nut production with the practical aims of defining an annual crop management program coordinating the range of management practices used in commercial cashew nut production and defining sustainable nitrogen nutrition practices.

This report describes work undertaken in 1998 and 1999 to confirm treatment responses observed during 1995–1997 under RIRDC Project DAQ 145A. The 1998 and 1999 results are compared with the 1995–1997 results and recommendations previously made concerning a crop management program, N rate and timing and tree N assessment are reviewed. Data previously presented for N concentration in leachate are quantified.

This project was jointly funded by Queensland Department of Primary Industries and from RIRDC Core Funds that are provided by the Federal Government.

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Executive Summary

Introduction

Cashew (*Anacardium occidentale* L.) is a tropical evergreen tree generally considered to be native to the northern part of South America. The tree is valued for its nutritious kernel and, in terms of world production of edible nuts, it ranks third at about 700 000 t.

The potential for commercial cashew production in Australia and the need for research to define efficient and sustainable crop management programs were discussed by the authors under RIRDC Project DAQ 145A '*Cashew nutrition management strategies*'. Under this project, the authors studied the effect of nitrogen (N) rate and timing on cashew growth and nut yield from 1995 to 1997 at Dimbulah, north Queensland. The aim of this work was to gain information for the development of crop management programs. It was found that in some years N applied during the vegetative growth phase (December–April) improved commercial nut-in-shell (NIS) and kernel yield and the timing of nut drop compared with N applications during the reproductive growth phase (June–October). When reporting these results, the authors recommended continuation of the work for a further two growth seasons to confirm treatment responses.

This report describes work undertaken in 1998 and 1999 to confirm treatment responses observed during 1995–1997. The 1998 and 1999 results are compared with the 1995–1997 results and recommendations made previously concerning a crop management program, N rate and timing and the assessment of tree N requirement are reviewed. Data previously presented for N concentration in leachate during the wet season are quantified.

Objectives

The objective of this Project, which began under RIRDC Project DAQ 145A, was to develop techniques, using N, to regulate growth and achieve a phenological growth cycle (the 'ideal' cycle) best correlated with high nut yield.

The practical outcomes of this work, which would be achieved by 2001, were to develop:
1. An annual crop management program based on the 'ideal' phenological cycle for the Dimbulah region;
2. Nitrogen application recommendations that promote the 'ideal' phenological cycle; and
3. Procedures to assess tree N requirement (an index leaf, leaf sampling time and leaf N standards) to guide N practices to achieve the 'ideal' phenological cycle.

Methodology

The project objectives were achieved through a trial in which N was applied at two rates and at three times during the phenological cycle. The times were 100% of the annual rate applied during the vegetative growth phase (December–April), 100% during the reproductive growth phase (June–October) and 50% during each phase. Nitrogen treatments were designed to modify vegetative and reproductive growth to provide understandings of the relationship between these growth phases and nut production.

Results and outcomes

Effects of N on vegetative and reproductive growth

The results of this work over the five crop cycles show that it is important to apply N during the vegetative growth phase of the tree in the Dimbulah area. The application of N confined to this period produced a seasonal pattern of growth most consistent with the 'ideal' phenological cycle. The results also caution against N applications outside this period because of the risk of nut drop occurring during the wet season.

The main features of the 'ideal' cycle at Dimbulah were vegetative growth between December and April, floral growth between July and September and nut drop between October and December. A crop management program was scheduled on a generalised phenological cycle for the Dimbulah area as was done for cashews growing at Wildman River in the Northern Territory. These program bear sufficient similarities to indicate that they could be adapted to other areas of northern Australia defined as suitable for cashew.

Canopy surface area (CSA) was primarily responsible for commercial NIS and kernel yield through its influence on nut number. While CSA was promoted when N was applied during the vegetative growth phase, this treatment required the heaviest pruning. The results of this work show that both CSA and N timing will be important considerations of canopy management in commercial practice.

While this study clearly defined the most appropriate time to apply N for high NIS and kernel yield, the most appropriate rates were not well defined because of limited N rates. The mean N rate (g/m^2 of CSA) for the best performing treatment applied over the term of the study was 17.9, producing consistent yield of about 210 g NIS/m^2 of CSA. This rate is adequate to produce high NIS and kernel yields for the tree sizes and planting density (208 trees/ha) of this study.

Assessment of tree N requirement

Two leaves, one from a vegetative shoot (*ME*) and one from a floral shoot (*LMFF*) showed potential for indicating tree N status. Both leaf types were easily recognisable and predicably available but their value for diagnosing tree N status could not be determined. In all years of the study, N concentration of *ME* and *LMFF* leaves varied between sampling dates within their respective sampling periods. There was therefore no time of nutrient stability on which to base a sampling time. To overcome this leaf samples should be taken twice during the phenological cycle, a pre-vegetative assessment in November–December and a pre-floral assessment in April–May.

The number of N rates of the study was insufficient to develop a response curve relating growth or yield to N concentration and therefore to define critical N concentrations. When N was applied during December–April at the high rate, leaf N concentration was usually above 2.0% in the *ME* leaf and above 1.5% in the *LMFF* leaf over the years 1996–1998. This treatment produced the greatest NIS and kernel yield and suggests that these concentrations are at least sufficient to achieve high yields.

Soil pH and N management

High concentrations of nitrate-N measured in leachate at a depth of 1 m indicate that the method of N fertiliser management used in this experiment is not sustainable in terms of potential N loss from the production system and degradation of soil and water quality. The results of the current study also have implications for perennial and semi-perennial crops, such as mango, lychee, longan and bananas, grown on well-drained soils of northern Australia where summer rainfall dominates and N fertilisers are applied.

Nitrogen treatments were applied in monthly applications to maximise N uptake by the tree. Despite this, up to 39% of the N applied was calculated to have leached to a depth of 1 m. Over the five years of the study there was a serious decline in mean soil profile pH (6.3 to 4.8) and in the capacity of the soil to retain cations such as potassium, calcium and magnesium. It is not known if the N leached to 1 m was

lost from the production system. In the soil at Dimbulah root activity can extend to at least 1.2 m. Little control can be exercised over drainage depth during rainfall, but irrigation management should control drainage to this region of root activity.

Improvement on the N fertiliser management used in this study can be achieved by matching tree demand for N more closely. Fertigation is the only practical and economical method of achieving this. In addition, N sources that do not cause soil acidification should be used. These include calcium nitrate, potassium nitrate, and to a lesser extent, calcium ammonium nitrate. Slow release N fertilisers that are currently very expensive may also reduce leaching losses.

Phosphorus (P) accumulated in the soil between 1995 and 1997 showing that the application rate of 100 kg/ha during this time greatly exceeded that removed by the crop and leaching. In contrast, the 5 kg P/ha applied between 1997 and 2000 was insufficient to prevent P concentrations from halving. Application rates of 16 to 25 kg P/ha for 4 to 6 year old trees, respectively, have been recommended from other research at this site and are consistent with the soil P trends measured.

The dramatic changes in soil pH and phosphorus concentrations demonstrate the importance of regular soil testing as a tool for long term monitoring of fertiliser programs. Because of the depth of roots of cashews, sampling to at least 1 m is recommended each year.

Implications

The impact of the N management practices defined from this work on cashew production at Cashews Australia, Dimbulah, north Queensland, was described in the final report for RIRDC Project DAQ 145A. The total planted area of commercial cashew in Australia has been stable at 300 ha since about 1995. Large increases in the area under cashew at Wildman River in the Northern Territory are currently being planned. Information from this study has been incorporated with other nutrition information in the *Cashew information kit* (Queensland Department of Primary Industries: Agrilink Horticulture Series) and serves as a complete guide for cashew nutrition programs in Australia in the future.

Recommendations

Further work is still required to define optimal and sustainable rates of N, an N diagnostic procedure and to develop fertigation practices. While the work showed that N should be applied during the vegetative growth phase, it also showed that large quantities of N are potentially leached when N is applied at this time because of wet season rainfall.

Research should also be undertaken to define canopy management practices for cashew in Australia. Canopy surface area was shown to be primarily responsible for NIS and kernel yield and this is important information for such research. Large cashew plantations of 500 ha are envisaged as necessary for Australia production, and it is likely that the cost of pruning will dictate that trees be maintained in hedgerows. At this time nothing is known about the response of cashew to pruning in this manner.

1. Introduction

Cashew (*Anacardium occidentale* L.) is a tropical evergreen tree generally considered to be native to the northern part of South America (Ohler 1979). The tree is valued for its nutritious kernel and, in terms of world production of edible nuts, it ranks third at about 700 000 t (Chacko *et al.* 1998).

The potential for commercial cashew production in Australia and the need for research to define efficient and sustainable crop management programs were discussed by the authors under RIRDC Project DAQ 145A '*Cashew nutrition management strategies*' (O'Farrell *et al*. 2000). Under this project, the authors studied the effect of nitrogen (N) rate and timing on cashew growth and nut yield from 1995 to 1997 at Dimbulah, north Queensland. The aim of this work was to gain information for the development of crop management programs. It was found that in some years N applied during the vegetative growth phase (December–April) improved commercial nut-in-shell (NIS) and kernel yield and the timing of nut drop compared with N applications during the reproductive growth phase (June–October). The authors recommended continuation of the work for a further two growth seasons to confirm treatment responses (O'Farrell *et al.* 2000).

The current report describes work undertaken in 1998 and 1999 to confirm treatment responses observed during 1995–1997. The 1998 and 1999 results are compared with the 1995–1997 results and recommendations made previously (O'Farrell *et al.* 2000) concerning a crop management program, N rate and timing and the assessment of tree N requirement are reviewed. Data previously presented for N concentration in leachate during the wet season are quantified.

2. Objectives

The objective of this Project, which began under RIRDC Project DAQ 145A, was to develop techniques, using N, to regulate growth and achieve a phenological growth cycle (the 'ideal' cycle) best correlated with high nut yield.

The practical outcomes of this work, which would be achieved by 2001, were to develop:

1. An annual crop management program based on the 'ideal' phenological cycle for the Dimbulah region;
2. Nitrogen application recommendations that promote the 'ideal' phenological cycle; and
3. Procedures to assess tree N requirement (an index leaf, leaf sampling time and leaf N standards) to guide N practices to achieve the 'ideal' phenological cycle.

3. Methodology

3.1 Site description and trial design

This study was undertaken as a continuation of the same experiment used for Project DAQ 145A (O'Farrell *et al.* 2000). It was conducted at a cashew plantation known as 'Cashews Australia' located at Dimbulah, north Queensland (17° 10'S, 145° 05'E, elevation 460 m). Dimbulah has an average annual rainfall of 780 mm, 81% falling in the months December to March (Bureau of Meteorology). Mean maximum and minimum temperatures during the study (1995–1999) ranged from 26.1°C in June to 33.2°C in November and from 11.5°C in July to 20.8°C in February, respectively.

The experimental site was situated on a gently inclined 3–5% slope facing south-east. The 24 experimental trees were *cv* 9/14 and were seven years old in December 1997 at the start of treatment applications. Tree and row spacings were 6 m and 8 m (208 trees/ha), respectively, and tree rows were orientated north-east/south-west. The soil is a haplic, mesotrophic, red, chromosol with a Principal Profile Form of Dr4.62 (Northcote 1971; Neil Enderlin, pers. comm.). Clay content increases from 6% in the surface 200 mm to 14% at 450–1000 mm.

Nitrogen rates-by-timing trial

The trial design was a two N rates by three N timing factorial in a randomised complete block design. Treatments were replicated four times as single tree plots.

Nitrogen was applied as ammonium nitrate (34% N) in five equal monthly dressings during the vegetative and reproductive growth phases in 1998 and 1999 (Table 3.1). Nitrogen rate and timing was designed to modify vegetative and reproductive growth to gain understandings of the relationship between vegetative, floral and nut development. Nitrogen treatments were applied within the irrigation zone under the trees over an area extending out to a 1.5 m radius from the tree. Treatments were watered into the soil in the absence of following rain. Nitrogen rates were increased from 1997 to 1998 but kept the same from 1998 to 1999 because canopy size at the start of the 1999 treatments in December 1998 (Tables 4.3 and 4.4) was considered to be the maximum for the tree spacing of the experiment.

Table 3.1 Nitrogen treatments of the N rates-by-timing trial.

Treatment	N rate in 1998 and 1999 (kg N/ha/yr)	Proportion (%) of the annual N applied during:	
		Vegetative growth (December–April)	Reproductive growth (June–October)
Med 100% Veg.	180 (Medium)	100	0
Med Veg./Rep.	180 (Medium)	50	50
Med 100% Rep.	180 (Medium)	0	100
High 100% Veg.	240 (High)	100	0
High Veg./Rep.	240 (High)	50	50
High 100% Rep.	240 (High)	0	100

3.2 Tree management

Maintenance fertiliser was applied in May 1998 (phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg)) and 1999 (K, Ca and Mg) as surface dressings to the same area under the trees as N treatments. Rates were guided by soil and leaf analyses and by experience with other crops on similar low fertility soils.

Soil moisture was monitored with a neutron moisture meter (CNP 503 DR Hydroprobe) (NMM) to a depth of 1.2 m in two replicates each of the Med. 100% Veg. and Med. Veg./Rep. treatments. In the absence of rainfall, irrigation was applied at weekly intervals at rates to achieve drainage to 0.7–1.0 m depth. Insects were controlled by insecticide sprays, and weeds were controlled by chemical sprays under the tree canopy and slashing of inter-rows. Infection by Cercospora Blotch (*Pseudocercospora anacardii*) (Teixeira 1988), the first reporting of the disease in Australia, caused heavy defoliation in the months following June 1999.

Trees were pruned immediately following the completion of nut drop. Trees of the 100% Veg. and Veg./Rep. treatments were pruned in December 1998 and 1999 while trees of the 100% Rep. treatment were pruned in March 1999 and December 1999. Foliage outside an area defined by a 45° angle from the base of the tree and a perpendicular 2.5 m from the trunk was removed.

3.3 Growth and yield measurements

Canopy dimensions (height, diameter, and skirt height) were recorded in December 1998 and 1999 and pruning fresh weight was recorded at the time of pruning (see Section 3.2). Shoot length, panicle number and NIS weight were recorded monthly and panicle density was recorded in December 1998 and November 1999. Canopy surface area (CSA), pruning dry weight removed, monthly percent shoot and panicle growth and nut drop, vegetative and floral indices, number of panicles per m^2 of CSA and total number of panicles per tree were derived from these data as described previously (O'Farrell *et al*. 2000).

Nut-in-shell yield was calculated from monthly harvests of nuts that matured from May to March the following year. Commercial NIS and kernel yield in 1998 and 1999, and all derived variables were determined by the methods described previously (O'Farrell *et al*. 2000). The NIS variables were total NIS weight, and variables based on commercial NIS: commercial NIS weight, number of nuts, mean nut weight, percent nut drop in August, November and January, number of nuts per panicle and canopy productivity. The kernel variables were percent defective nuts, total kernel weight and percent kernel recovery. Nut-in-shell and kernel weight were expressed at 9 and 5% water content (WC), respectively. Kernel recovery was the ratio of kernel weight (5% WC) to commercial NIS weight (9% WC). Defective nuts included nuts that were void (lacking a kernel), had a kernel size less the 25% of the internal shell cavity and had rotted or insect infested kernels.

3.4 Sampling and analyses of soil and leaves

Soil samples were collected annually (June 1998 and 1999) at the end of vegetative N treatments and prior to the start of the reproductive N treatments, and in February 2000 at the end of the experiment. Sampling procedures were as described by O'Farrell *et al.* (2000).

Two leaf types were sampled at monthly intervals. These leaves were a mature terminal leaf from a quiescent vegetative shoot on the periphery of the canopy *(ME)* and the largest pre-floral vegetative flush leaf *(LMFF)* (O'Farrell *et al*. 2000). The *ME* leaves were generally available during the summer–autumn months (corresponding to the vegetative N treatment applications) and the *LMFF* leaves over the winter–spring months (corresponding to reproductive N treatment applications).

Analytical procedures for soil and leaf samples were unchanged from O'Farrell *et al.* (2000).

3.5 Modelling of soil drainage with PERFECT

Soil water was sampled with ceramic cups, installed in December 1996, to compare N movement in fertilised and unfertilised zones. Three cups were located at a depth of 1 m under the fertilised area of two trees receiving the medium N rate, one the 100% Veg. timing and the other the Veg./Rep. timing. A single cup was installed at a similar depth in the middle of the unfertilised inter-row adjacent to each

of the two treatment trees. Water samples were collected at weekly intervals during various periods from January 1997 to May 2000. Laboratory analytical procedures were as described by O'Farrell *et al.* (2000).

The ceramic cups were unconfined and could not directly measure soil drainage. The water balance model PERFECT (Littleboy *et al*. 1999) was used to estimate drainage so that N leaching to 1m could be quantified. It is a biophysical model that simulates plant-soil-water-management dynamics in an agricultural system and its design includes the prediction of soil drainage.

Daily weather records and soil and crop parameters were used to simulate the water balance (runoff, soil evaporation, transpiration and soil water storage, redistribution and deep drainage). Rainfall, maximum and minimum temperatures and solar radiation were recorded on site, while evaporation data were derived from Southedge Research Station, approximately 40 kms from the site. The soil parameters (Table 3.2), with the exception of air-dry moisture content and upper limit moisture content which were calculated (Ian Webb, pers. comm.), were recorded on site. Crop factors were derived from those used for mango (Y Diczbalis pers. comm.) and the considerations of Dagg and Tapley (1967) for cashew, and ranged from 0.60–0.75 in 1997 and 0.62–0.77 in 1998 and 1999.

Simulations of soil drainage were run from January 1997 to June 2000. The model's prediction of drainage was confirmed by comparing the model's prediction of volumetric soil moisture (VSM) with measurements taken with a NMM. The NMM was calibrated over the period June–August 2001 to VSM at 125, 300, 400, 500, 600, 700 and 900 mm depths for the soil under study. The regressions explained 87–93% of the variation.

The total drainage (mm) for each sampling period was determined by summing the daily drainage computed by the model. This drainage was used with the mean concentration of ammonium- (NH_4-N) and nitrate-N (NO_3-N) of the three cups to calculate the N leached to 1 m for each sampling period and converted to kg N/ha of plantation by multiplying the result by 0.14 (fertiliser application area of 1.5 m radius and 208 trees/ha).

Table 3.2 Soil parameters used for model simulations with PERFECT.

Depth (mm)	Air dry moisture content (volumetric %)	Lower limit moisture content (volumetric %)	Upper limit moisture content (volumetric %)	Saturation moisture content (volumetric %)	Saturated hydraulic conductivity (mm/hour)
100	0.3	2.5	13.1	39	100
300	0.3	2.5	14.2	39	100
600	0.4	3.4	14.0	35	100
1000	0.6	4.1	12.5	35	100

3.6 Measurement of root activity

The root activity of cashew at Dimbulah was extrapolated from measurements of water extraction by cashew roots subsequent to irrigation. The water extraction measurements were made under a separate study during July–August 1993 and were recorded from four-year-old seedling trees of *cv* K160. These trees had been transplanted into the field from poly-pots at tree and row spacings of 6 m and 8 m, respectively, as had the trees of this experiment.

Three trees were irrigated to drainage below 1.2 m. Access tubes of the NMM used to measure soil moisture were installed prior to irrigation. Similar studies in a Cununurra Clay soil at Kununurra, Western Australia, showed that the water extraction pattern of four-year-old cashews in the intra-row

was similar to the inter-row area (J. Sherrard pers. comm). The access tubes were therefore only installed in the intra-row area at distances of 1, 1.5, 2 and 3 m from the tree and aligned in the same plane as the tree row. Immediately following irrigation the irrigated area was covered with plastic to prevent water loss from the soil by evaporation.

The NMM was calibrated to VSM content at 200, 300, 400, 500, 600, 700, 900 and 1200 mm depths for the soil under study. The regressions explained 73–92% of the variation. Soil moisture was recorded 7, 14, 21, 28 and 42 days after irrigation.

3.7 Statistical procedures

Data were analysed by standard analysis of variance to determine the effects of N rate and timing on vegetative and reproductive growth. Normality and variance assumptions were checked and transformations were applied where necessary. Shoot length data were square-root transformed ($\sqrt{(x+1)}$) prior to analysis in order to stabilise the variance. Means were tested using a protected least significant difference (lsd) test at the 5% level.

4. Results

4.1 Soil fertility

Soil mineral N concentrations were very low (mean profile NH_4-N and NO_3-N <1 mg/kg) in 1997 and 2000 (Table 4.1). In the 1998 and 1999 samples, mean profile N concentrations reflected the N rate and timing treatments. In both years, NH_4-N and NO_3-N concentrations in the 100% Veg. treatments were approximately 8 mg/kg for the medium N rate and 24 mg/kg for the high N rate. Nitrogen concentrations were always low (<1 mg/kg) for the 100% Rep. treatments regardless of rate of application and reflect the period (October–June) between the last N application and the time of sampling. Concentrations in the Veg./Rep. treatments were intermediate between the 100% Veg. and 100% Rep. treatments.

Table 4.1 Mean soil profile (0–90 cm) NH_4-N and NO_3-N concentrations.

Sampling date	Treatment	NH_4-N (mg/kg)	NO_3-N (mg/kg)
18/06/1997	All	<1	<1
03/06/1998	Med 100% Veg.	7.5	7.6
	High 100% Veg	25.0	24.0
	Med 100% Rep.	<1	<1
	High 100% Rep.	<1	<1
	Med Veg./Rep.	1.5	1.6
	High Veg./Rep.	5.7	3.7
10/06/1999	Med 100% Veg.	9.8	8.2
	High 100% Veg	20.0	24.0
	Med 100% Rep.	1.5	<1
	High 100% Rep.	<1	<1
	Med Veg./Rep.	2.3	3.1
	High Veg./Rep.	12.0	11.0
01/02/2000	All	<1	<1

Profile soil pH under the trees decreased from a mean of 6.3 at the commencement of the trial to 5.2 in 1997 and to 4.8 in 2000 but fluctuated around a mean of 6.3 in the unfertilised inter-row (Figure 4.1). This decline was associated with the leaching of NO_3-N from ammonium nitrate fertiliser as presented in the leachate data (Table 4.13). Differences in pH due to the timing of N application and the rate of applied N were limited and inconsistent. The decline in pH was associated with a decline in the effective cation exchange capacity (ECEC) of the soil. Between 1995 and 2000, the mean profile ECEC decreased from 1.73 to 1.45 m.e./100g.

Phosphorus concentrations decreased between 1997 and 2000 during which only 5 kg P/ha was applied. This is in contrast with trends between 1995 and 1997 (Table 4.2). Concentrations in 1998 and 1999 were intermediate between the 1997 and 2000 values (data not presented).

Calcium and Mg concentrations generally decreased throughout the profile between 1997 and 2000 despite applications in total of 183 and 44 kg/ha, respectively (Table 4.2). Potassium and sodium (Na) concentrations remained very low (80 kg K/ha applied). Electrical conductivity readings were always very low (mean 0.04 dS/m).

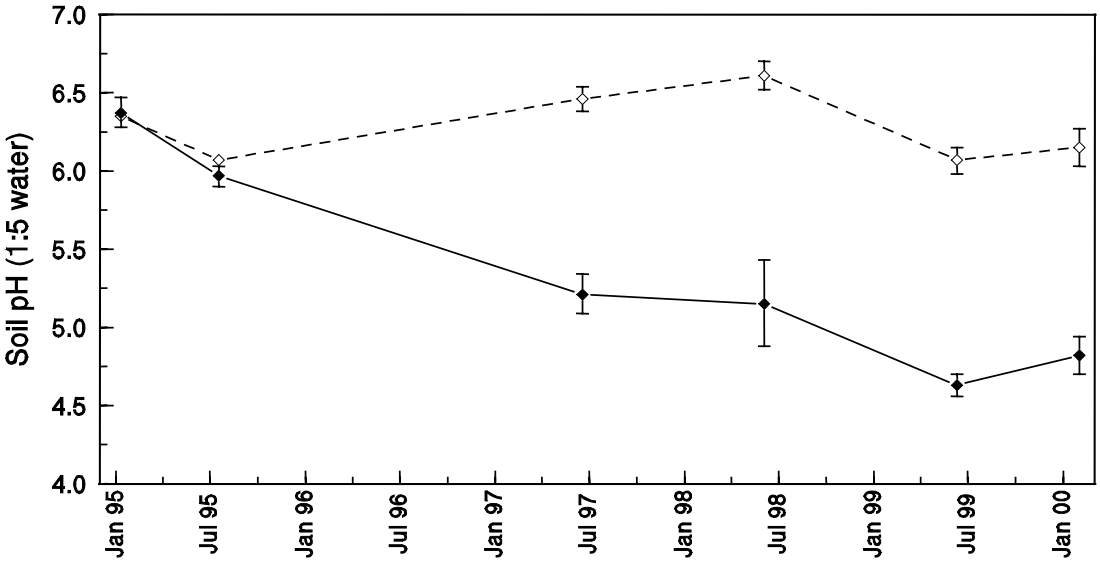

Figure 4.1 **Mean soil pH (0–90 cm) for N treatments (◆) and inter-row (◇). The vertical bars indicate the standard error of the mean.**

Table 4.2 **Selected soil chemical properties prior to the commencement of treatments (10.1.95), after the start of reproductive N applications in 1997 and at the end of the experiment. Data for individual depths are means for all treatments.**

Depth (cm)	Bicarb P[1] (mg/kg)	Exchangeable. cations (m.e./100g[2])			
		Na	K	Ca	Mg
		10.1.1995			
0–10	27	0.09	0.45	1.17	0.35
10–20	13	0.09	0.36	0.95	0.22
20–30		0.09	0.31	0.73	0.20
30–45		0.10	0.24	0.76	0.45
45–60		0.10	0.22	0.77	0.45
60–90		0.10	0.21	0.90	0.74
		18.6.1997			
0–10	101	0.04	0.05	1.04	0.17
10–20	83	0.05	0.05	0.52	0.08
20–30		0.04	0.07	0.43	0.08
30–45		0.03	0.12	0.37	0.13
45–60		0.04	0.21	0.63	0.24
		1.2.2000			
0–10	47	0.05	0.07	0.42	0.23
10–20	43	0.05	0.05	0.14	0.06
20–30		0.04	0.05	0.12	0.04
30–45		0.03	0.07	0.18	0.04
45–60		0.04	0.07	0.43	0.04
60–90		0.06	0.13	0.85	0.12

[1] Bicarb P = bicarbonate extractable P

[2] m.e./100g = milliequivalents/100 g

4.2 Canopy growth and pruning

Canopy growth

Differences in CSA among N timing treatments in December 1997 persisted during 1998 with the 100% Veg. and Veg./Rep. timings having greater (P<0.01) CSA than the 100% Rep. timing in December 1998 (Table 4.3). However, the proportional magnitude of this difference decreased from December 1997 to December 1998 due to greater (P<0.01) growth in CSA during 1998 in the Veg./Rep. and 100% Rep. timings compared with the 100% Veg. timing. Of the two determinants of CSA, canopy height and diameter, canopy diameter contributed mostly to the increase in CSA among N timings from 1997 to 1998 as the increase in canopy height from 1997 to 1998 was similar (P>0.10) for all timings (Table 4.4). There was an interaction (P<0.05) between N rate and N timing for CSA in December 1998. At the medium N rate CSA was similar (P>0.10) among N timings, but at the high rate the 100% Veg. and Veg./Rep. timings had greater CSA than the 100% Rep. timing.

By December 1999, the interaction effect observed for CSA in December 1998 was stronger (P<0.01), and while treatment differences were similar to December 1998, CSA for the High 100% Rep. treatment was smaller than all the other treatments (Table 4.3). This was primarily due to smaller (P<0.01) canopy diameter for the High 100% Rep. treatment compared with the other treatments in December 1999 (Table 4.4). The increase in canopy diameter of the High 100% Rep. treatment from 1998 to 1999 tended (P=0.052) to be less than the other treatments. This was responsible for the smaller (P<0.01) increase in CSA from 1998 to 1999 of the High 100% Rep. treatment compared with the other treatments. All treatments were pruned in December 1998 with the exception of the High 100% Rep. treatment, which was pruned three months later in March 1999. All treatments, including the High 100% Rep. treatment, were again pruned in December 1999. As a result, the High 100% Rep. treatment had three months less growth than the other treatments between successive prunings.

Table 4.3 Nitrogen treatment effects on canopy surface area (m^2) from 1997 to 1999. Means not followed by a common letter differ significantly (P<0.05).

	December 1997	December 1998	Increase 1997-98	December 1999	Increase 1998-99
N rate	n.s.	*	n.s.	n.s.	**
Medium	48.48	59.51 b	11.03	71.18	11.68 a
High	51.78	63.32 a	11.55	72.02	8.70 b
5% lsd	4.37	3.79	3.00	4.88	1.87
N Timing	***	**	**	***	***
100% Veg.	56.42 a	64.24 a	7.82 b	77.83 a	13.59 a
Veg./Rep.	52.09 a	63.59 a	11.51 a	73.57 a	9.98 b
100% Rep.	41.87 b	56.41 b	14.54 a	63.40 b	6.99 c
5% lsd	5.35	4.64	3.67	5.97	2.29
Rate x Timing	n.s.	*	n.s.	**	**
Med. 100% Veg.	53.59	59.63 c	6.04	73.61 b	13.98 a
Med. Veg./Rep.	49.26	60.92 bc	11.66	71.13 b	10.21 bc
Med. 100% Rep.	42.59	57.97 c	15.38	68.81 b	10.84 abc
High 100% Veg.	59.25	68.85 a	9.60	82.06 a	13.21 ab
High Veg./Rep.	54.91	66.27 ab	11.35	76.01 ab	9.75 c
High 100% Rep.	41.16	54.85 c	13.69	57.99 c	3.14 d
5% lsd	7.57	6.57	5.19	8.45	3.23

n.s. = not significant (P>0.10); * P<0.05; ** P<0.01; *** P<0.001

Table 4.4 Nitrogen treatment effects on canopy height and diameter (m) from 1997 to 1999. Means not followed by a common letter differ significantly (P<0.05).

	December 1997	December 1998	Increase 1997-98	December 1999	Increase 1998-99
			Canopy height		
N rate	*	*	n.s.	n.s.	P=0.064
Medium	4.57 b	5.06 b	0.49	5.64	0.58
High	4.73 a	5.28 a	0.55	5.78	0.49
5% lsd	0.15	0.18	0.13	0.22	0.10
N Timing	***	**	n.s.	***	***
100% Veg.	4.84 a	5.31 a	0.47	5.99 a	0.68 a
Veg./Rep.	4.70 a	5.26 a	0.56	5.78 a	0.52 b
100% Rep.	4.41 b	4.94 b	0.54	5.36 b	0.42 b
5% lsd	0.18	0.22	0.16	0.28	0.12
Rate x Timing	n.s.	*	n.s.	P=0.070	n.s.
Med. 100% Veg.	4.68	5.04 bc	0.36	5.75	0.71
Med. Veg./Rep.	4.60	5.19 bc	0.59	5.73	0.54
Med. 100% Rep.	4.43	4.95 c	0.53	5.45	0.50
High 100% Veg.	5.01	5.59 a	0.58	6.23	0.64
High Veg./Rep.	4.80	5.33 ab	0.53	5.83	0.50
High 100% Rep.	4.39	4.94 c	0.55	5.28	0.34
5% lsd	0.26	0.31	0.22	0.39	0.17
			Canopy diameter		
N rate	n.s.	n.s.	n.s.	n.s.	*
Medium	5.19	5.56	0.37	5.83	0.28 a
High	5.34	5.63	0.28	5.80	0.17 b
5% lsd	0.22	0.16	0.16	0.18	0.10
N Timing	***	P=0.092	***	*	n.s.
100% Veg.	5.58 a	5.66	0.08 c	5.93 a	0.27
Veg./Rep.	5.38 a	5.66	0.28 b	5.88 a	0.23
100% Rep.	4.85 b	5.46	0.61 a	5.64 b	0.18
5% lsd	0.27	0.20	0.19	0.22	0.12
Rate x Timing	n.s.	*	n.s.	**	P=0.052
Med. 100% Veg.	5.48	5.59 abc	0.11	5.85 a	0.26
Med. Veg./Rep.	5.24	5.51 bc	0.28	5.76 a	0.25
Med. 100% Rep.	4.86	5.58 abc	0.71	5.89 a	0.31
High 100% Veg.	5.68	5.73 ab	0.05	6.00 a	0.28
High Veg./Rep.	5.51	5.80 a	0.29	6.00 a	0.20
High 100% Rep.	4.84	5.35 c	0.51	5.39 b	0.04
5% lsd	0.38	0.28	0.27	0.31	0.17

n.s. = not significant (P>0.10); * P<0.05; ** P<0.01; *** P<0.001

Dry weight of pruning removal

In 1998 and 1999 there were interactions between N rate and N timing for pruning removal (Table 4.5). In 1998, the High 100% Rep. treatment had greater (P<0.05) pruning removal than most of the other treatments while in 1999 this treatment had the least (P<0.001) of all treatments. These responses were associated with the different time periods between successive prunings of the High 100% Rep. treatment compared with the other treatments, three months longer in 1998 and three months shorter in 1999.

Cumulative pruning removal from 1995 to 1999 of the 100% Veg. timing was greater (P<0.01) than the Veg./Rep. and 100% Rep. timings.

Table 4.5 Nitrogen treatment effects on dry weight (kg) of pruning removal. Means not followed by a common letter differ significantly (P<0.05).

	1998	1999	Cumulative 1995-99
N rate	P=0.066	***	n.s.
Medium	7.92	3.26 a	33.50
High	9.37	2.23 b	36.14
5% lsd	1.57	0.39	3.44
N Timing	n.s.	***	**
100% Veg.	8.40	3.18 a	38.94 a
Veg./Rep.	8.48	2.96 a	33.91 b
100% Rep.	9.06	2.11 b	31.61 b
5% lsd	1.92	0.48	4.22
Rate x Timing	*	***	P=0.060
Med. 100% Veg.	7.70 b	3.21 a	34.78
Med. Veg./Rep.	9.27 ab	3.17 a	34.79
Med. 100% Rep.	6.78 b	3.41 a	30.92
High 100% Veg.	9.11 ab	3.14 a	43.11
High Veg./Rep.	7.68 b	2.75 a	33.02
High 100% Rep.	11.33 a	0.81 b	32.30
5% lsd	2.71	0.68	5.97

n.s. = not significant (P>0.10); * P<0.05; ** P<0.01; *** P<0.001

4.3 Shoot and panicle growth

Shoot growth

There was no difference (P>0.10) between N rates or among N timings in pre-July shoot growth in 1998 and 1999 (Table 4.6). This contrasts with 1995 and 1996 when the 100% Veg. timing had greater pre-July shoot growth than the 100% Rep. timing (O'Farrell *et al.* 2000). There was no difference (P>0.10) in shoot growth by December in either 1998 or 1999 between N rates or among N timings, a consistent response in all years (1995–1999) of the study (Table 4.6).

Table 4.6 Nitrogen treatment effects on shoot length (mm) of 10 branches. Means are square root transformed with backtransformed means in parentheses. Means not followed by a common letter differ significantly (P<0.05).

	June	December	Increase June–December
		1998	
N rate	n.s.	n.s.	n.s.
Medium	32.89 (1081)	34.44 (1185)	10.08 (101)
High	30.48 (928)	32.04 (1025)	9.80 (95)
5% lsd	3.79	3.80	1.44
N Timing	n.s.	n.s.	*
100% Veg.	30.22 (912)	32.01 (1024)	10.48 a (109)
Veg./Rep.	31.39 (985)	32.56 (1059)	8.54 b (72)
100% Rep.	33.44 (1117)	35.15 (1235)	10.81 a (116)
5% lsd	4.64	4.65	1.76
Rate x Timing	n.s.	n.s.	n.s.
Med. 100% Veg.	31.16 (970)	32.74 (1071)	9.93 (98)
Med. Veg./Rep.	34.11 (1163)	35.23 (1240)	8.76 (76)
Med. 100% Rep.	33.41 (1115)	35.36 (1249)	11.55 (133)
High 100% Veg.	29.28 (856)	31.29 (978)	11.03 (121)
High Veg./Rep.	28.68 (821)	29.88 (892)	8.32 (68)
High 100% Rep.	33.48 (1120)	34.95 (1220)	10.07 (100)
5% lsd	6.56	6.58	2.50
		1999	
N rate	n.s.	n.s.	P=0.053
Medium	33.14 (1097)	35.16 (1235)	11.57 (133)
High	29.99 (899)	31.62 (999)	9.80 (95)
5% lsd	4.44	4.42	1.80
N Timing	n.s.	n.s.	n.s.
100% Veg.	29.86 (891)	31.57 (995)	10.08 (101)
Veg./Rep.	34.41 (1183)	36.18 (1308)	10.98 (120)
100% Rep.	30.43 (925)	32.42 (1050)	10.99 (120)
5% lsd	5.44	5.41	2.21
Rate x Timing	n.s.	n.s.	n.s.
Med. 100% Veg.	28.79 (828)	30.75 (945)	10.71 (114)
Med. Veg./Rep.	37.56 (1410)	39.15 (1532)	11.00 (120)
Med. 100% Rep.	33.08 (1093)	35.56 (1264)	13.01 (168)
High 100% Veg.	30.93 (956)	32.38 (1047)	9.46 (88)
High Veg./Rep.	31.26 (976)	33.21 (1102)	10.97 (119)
High 100% Rep.	27.78 (771)	29.27 (856)	8.97 (79)
5% lsd	7.69	7.65	3.12

n.s. = not significant (P>0.10); * P<0.05; ** P<0.01; *** P<0.001

Panicle growth

An interaction (P<0.05) between N rate and N timing occurred for pre-July panicle number in 1998 (Table 4.7). The Med. 100% Veg. treatment produced a greater number of panicles than the Med. 100% Rep. treatment and all timings at the high N rate. By December 1998, this interaction was no longer evident but there was an overall effect of N timing with more panicles in the 100% Veg. compared with the 100% Rep. timing. Differences among N timings, the 100% Veg. timing having greater pre-July panicle number than the 100% Rep. timing, were observed in 1995 and 1996 (O'Farrell *et al.* 2000). In contrast with 1998 however, higher levels of pre-July panicle growth in 1995 and 1996 were associated with greater pre-July shoot growth.

Nitrogen rate and timing did not affect (P>0.10) panicle number in 1999, a response observed in 1997 (O'Farrell *et al.* 2000).

Table 4.7 Nitrogen treatment effects on panicle number of 10 branches. Means not followed by a common letter differ significantly (P<0.05).

	1998			1999		
	June	December	Increase June–Dec	June	December	Increase June–Dec
N rate	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Medium	3.2	11.6	8.4	16.1	40.4	24.3
High	2.4	12.1	9.7	14.1	36.2	22.1
5% lsd	1.3	2.9	3.3	6.3	8.5	7.9
N Timing	*	*	n.s.	n.s.	n.s.	n.s.
100% Veg.	3.9 a	14.9 a	11.0	13.0	34.3	21.3
Veg./Rep.	2.6 ab	11.5 ab	8.9	17.8	42.5	24.8
100% Rep.	1.9 b	9.1 b	7.3	14.5	38.1	23.6
5% lsd	1.6	3.5	4.0	7.7	10.4	9.7
Rate x Timing	*	n.s.	n.s.	n.s.	n.s.	n.s.
Med. 100% Veg.	5.0 a	16.0	11.0	13.0	34.3	21.3
Med. Veg./Rep.	3.5 ab	12.0	8.5	21.3	45.0	23.8
Med. 100% Rep.	1.0 c	6.8	5.8	14.0	42.0	28.0
High 100% Veg.	2.8 bc	13.8	11.0	13.0	34.3	21.3
High Veg./Rep.	1.8 bc	11.0	9.3	14.3	40.0	25.8
High 100% Rep.	2.8 bc	11.5	8.8	15.0	34.3	19.3
5% lsd	2.2	5.0	5.7	10.9	14.7	13.8

n.s. = not significant (P>0.10); * P<0.05; ** P<0.01; *** P<0.001

4.4 Nut-In-Shell (NIS) yield at 9% WC, and kernel yield at 5% WC

NIS yield

In 1998, commercial NIS weight was approximately 98% of the total NIS weight (commercial and non-commercial nut weight) (Table 4.8). Total NIS and commercial NIS weight did not differ (P>0.10) among N timings but did differ between rates with greater (P<0.05) NIS weight at the high N rate compared with the medium rate. A similar rate response was observed in 1996 and 1997 (O'Farrell *et al.* 2000). Of the two nut characteristics likely to influence NIS weight (nut number and mean nut weight), nut number was responsible for the N rate effect in 1998 as there was no difference (P>0.10) in mean nut weight between rates. Panicle density (panicles/m^2 of CSA) was similar (P>0.10) among N timings but the 100% Veg. and Veg./Rep. timings had fewer (P<0.05)

nuts per panicle compared with the 100% Rep. timing (Table 4.9). The N timing effect observed for CSA (Table 4.3) was however the reverse of the number of nuts per panicle resulting in no difference in NIS weight among timings.

In 1999, commercial NIS weight was approximately 93% of the total NIS weight (Table 4.8). There was some evidence of an N rate by timing interaction for total NIS weight (P=0.098) and commercial NIS weight (P=0.059) due primarily to low NIS weight of the High 100% Rep. treatment. These interactions however, were dominated by the N timing main effect with greater (P<0.01) NIS weight for the 100% Veg. and Veg./Rep. timings compared with the 100% Rep. timing. A similar timing effect was observed in 1996 and 1997 (O'Farrell *et al.* 2000). Nut number was mainly responsible for these differences in NIS weight in 1999 as nut number displayed a strong (P<0.01) interaction following the same trend as NIS weight. There was only weak (P=0.070) evidence of an N rate by timing interaction and no rate or timing main effects for mean nut weight. There was weak evidence of N timing differences in panicle density (P=0.078) and number of nuts per panicle (P=0.068) (Table 4.9). The effect of these variables on nut number was negated however, as there were less panicles per m^2 of CSA and more nuts per panicle for the Veg./Rep. treatment compared with the 100% Veg. and 100% Rep. treatments. As a result, CSA was primarily responsible for treatment differences in nut number, and hence NIS weight, with similar treatment differences observed in CSA in December 1999 as for nut number (Tables 4.3 and 4.8). In 1996 and 1997 CSA was also influential in determining NIS weight (O'Farrell *et al.* 2000). In both years, CSA determined nut number, as treatments did not affect either panicle density or number of nuts per panicle. Unlike 1996 however, NIS weight in 1997 was due to average nut weight as well as nut number.

Canopy productivity was unaffected (P>0.10) by treatments in 1998 and 1999 as was the case in 1996 and 1997 (O'Farrell *et al.* 2000). In 1995, canopy productivity was greater in the 100% Rep. timing compared with the 100% Veg. timing, however treatment responses were confounded by differential N rate.

Table 4.8 Nitrogen treatment effects on NIS production. Means not followed by a common letter differ significantly (P<0.05).

	Total NIS weight (kg)	Commercial NIS weight (kg)	Number of nuts	Mean nut weight (g)
		1998		
N rate	*	*	*	n.s.
Medium	12684 b	12442 b	2468 b	5.04
High	14404 a	14055 a	2775 a	5.06
5% lsd	1555	1558	263	0.23
N Timing	n.s.	n.s.	n.s.	n.s.
100% Veg.	13598	13199	2647	4.99
Veg./Rep.	13363	13120	2593	5.05
100% Rep.	13670	13426	2624	5.11
5% lsd	1904	1908	322	0.29
Rate x Timing	n.s.	n.s.	n.s.	n.s.
Med. 100% Veg.	13028	12727	2515	5.07
Med. Veg./Rep.	12324	12104	2379	5.07
Med. 100% Rep.	12699	12494	2511	4.99
High 100% Veg.	14167	13671	2780	4.91
High Veg./Rep.	14403	14136	2808	5.03
High 100% Rep.	14641	14358	2737	5.23
5% lsd	2693	2698	455	0.41
		1999		
N rate	ns	n.s.	n.s.	n.s.
Medium	15726	14455	3437	4.20
High	15913	14916	3593	4.17
5% lsd	1749	1697	315	0.19
N Timing	**	**	***	n.s.
100% Veg.	17436 a	15984 a	3823 a	4.18
Veg./Rep.	16407 a	15493 a	3710 a	4.19
100% Rep.	13615 b	12579 b	3012 b	4.18
5% lsd	2142	2079	386	0.23
Rate x Timing	P=0.098	P=0.059	**	P=0.070
Med. 100% Veg.	16281	14639	3434 b	4.26
Med. Veg./Rep.	16117	14986	3492 b	4.30
Med. 100% Rep.	14780	13742	3385 b	4.04
High 100% Veg.	18590	17330	4212 a	4.10
High Veg./Rep.	16697	16001	3927 ab	4.09
High 100% Rep.	12450	11416	2640 c	4.32
5% lsd	3030	2940	546	0.33

n.s. = not significant (P>0.10); * P<0.05; ** P<0.01; *** P<0.001

Table 4.9 Nitrogen treatment effects on panicle growth and canopy productivity (g NIS/m^2 of CSA). Means not followed by a common letter differ significantly (P<0.05).

	1998			1999		
	Number of panicles per m^2 of CSA	Number of nuts per panicle	Canopy productivity	Number of panicles per m^2 of CSA	Number of nuts per panicle	Canopy productivity
N rate	n.s.	P=0.095	n.s.	*	P=0.091	n.s.
Medium	6.4	8.00	210.5	26.6 b	1.92	203.1
High	8.9	5.82	225.7	32.0 a	1.61	205.8
5% lsd	3.1	2.61	31.0	5.4	0.38	15.6
N Timing	n.s.	*	n.s.	P=0.078	P=0.068	n.s.
100% Veg.	8.6	5.17 b	206.6	30.6	1.62	205.3
Veg./Rep.	8.6	5.78 b	207.4	25.0	2.08	210.5
100% Rep.	5.8	9.77 a	240.3	32.3	1.59	197.5
5% lsd	3.9	3.20	38.0	6.6	0.46	19.0
Rate x Timing	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Med. 100% Veg.	7.3	6.18	213.9	28.8	1.65	200.2
Med. Veg./Rep.	7.8	5.74	199.4	22.0	2.28	210.7
Med. 100% Rep.	4.3	12.08	218.2	29.0	1.84	198.5
High 100% Veg.	10.0	4.17	199.4	32.5	1.60	210.5
High Veg./Rep.	9.5	5.83	215.4	28.0	1.88	210.4
High 100% Rep.	7.3	7.46	262.4	35.5	1.34	196.5
5% lsd	5.5	4.52	53.7	9.3	0.65	26.9

n.s. = not significant (P>0.10); * P<0.05; ** P<0.01; *** P<0.001

The proportion of NIS harvested by the end of August, November and January in 1998 was greater (P<0.01) in the 100% Veg. timing compared with the 100% Rep. timing (Table 4.10). A similar response was observed in 1996 (O'Farrell *et al.* 2000). In 1995 treatment differences were confounded by differential N rate, nevertheless 47% of the nut drop of the 100% Rep. timing occurred post-November. In contrast with 1998, N treatments did not affect (P>0.10) nut drop in 1999 and nut drop was completed in all treatments by the end of November (Table 4.10). In 1997, while all treatments had similar levels of nut drop (mean 94%) by the end of November, nut drop was not completed by that time (O'Farrell *et al.* 2000).

Table 4.10 Distribution (%) of NIS weight across time in the 1998 and 1999 harvest seasons. Means not followed by a common letter differ significantly (P<0.05).

	1998 season			1999 season	
	August 1998	November 1998	January 1999	August 1999	November 1999
N rate	n.s.	n.s.	n.s.	n.s.	-
Medium	19.7	81.6	87.9	27.0	100.0
High	20.5	75.4	86.9	28.6	100.0
5% lsd	4.5	9.4	5.0	4.0	
N Timing	***	**	***	n.s.	-
100% Veg.	27.4 a	86.0 a	94.0 a	28.4	100.0
Veg./Rep.	21.2 b	81.8 a	87.9 a	28.7	100.0
100% Rep.	11.7 c	67.7 b	80.3 b	26.4	100.0
5% lsd	5.6	11.5	6.1	4.8	
Rate x Timing	n.s.	n.s.	n.s.	n.s.	-
Med. 100% Veg.	29.3	89.3	95.6	27.9	100.0
Med. Veg./Rep.	20.6	83.2	88.3	26.7	100.0
Med. 100% Rep.	9.2	72.4	79.8	26.4	100.0
High 100% Veg.	25.4	82.6	92.4	28.9	100.0
High Veg./Rep.	21.8	80.5	87.5	30.7	100.0
High 100% Rep.	14.1	63.1	80.8	26.3	100.0
5% lsd	7.9	16.3	8.7	6.8	

n.s. = not significant (P>0.10); * P<0.05; ** P<0.01; *** P<0.001

Kernel yield

In 1998, kernel weight was greater (P<0.05) at the high N rate compared with the medium rate (Table 4.11). This was due to greater NIS weight (Table 4.8) as the other determinants of kernel weight (kernel recovery and proportion of defective nuts) were unaffected (P>0.10) by N rate. A similar response occurred in 1996 and 1997 (O'Farrell *et al.* 2000). In 1999, the 100% Veg. and Veg./Rep. timings gave greater (P<0.05) kernel weight compared with the 100% Rep. treatment (Table 4.11) due to greater NIS yield of these N timing treatments (Table 4.8). The other determinants of kernel weight, kernel recovery and the proportion of defective nuts, were similar (P>0.10) for all N timings. In 1996 and 1997, the 100% Veg treatment also gave greater kernel weight than the 100% Rep. treatment because of greater NIS weight (O'Farrell *et al.* 2000).

The proportion of defective nuts was greater in 1999 (21.6%) compared with 1998 (8.0%) and the previous three years (15.1, 9.8 and 6.6% for 1995, 1996 and 1997, respectively; O'Farrell *et al.* 2000).

Table 4.11 Nitrogen treatment effects on kernel weight and quality. Means not followed by a common letter differ significantly (P<0.05).

	1998			1999		
	Kernel weight (g)	**Kernel recovery (%)**	**Defective nuts (%)**	**Kernel weight (g)**	**Kernel recovery (%)**	**Defective nuts (%)**
N rate	*	n.s.	n.s.	n.s.	n.s.	n.s.
Medium	3987 b	32.1	8.5	4156	28.7	21.8
High	4549 a	32.4	7.5	4340	29.1	21.3
5% lsd	491	0.5	2.6	623	1.1	2.4
N Timing	n.s.	n.s.	P=0.080	*	n.s.	n.s.
100% Veg.	4243	32.2	6.4	4555 a	28.4	23.7
Veg./Rep.	4257	32.4	7.6	4515 a	29.1	21.2
100% Rep.	4305	32.1	10.0	3674 b	29.1	19.8
5% lsd	601	0.6	3.2	763	1.4	2.9
Rate x Timing	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Med. 100% Veg.	4062	31.9	6.8	4119	28.1	24.1
Med. Veg./Rep.	3931	32.5	7.8	4385	29.2	19.8
Med. 100% Rep.	3969	31.8	10.8	3964	28.7	21.5
High 100% Veg.	4424	32.4	5.9	4990	28.6	23.4
High Veg./Rep.	4582	32.4	7.5	4645	29.0	22.5
High 100% Rep.	4641	32.4	9.2	3385	29.6	18.1
5% lsd	851	0.8	4.5	1079	1.9	4.1

n.s. = not significant (P>0.10); * P<0.05; ** P<0.01; *** P<0.001

4.5 Leaf nutrient concentration

Leaf N generally reflected N timing treatments in *ME* and in *LMFF* leaves from 1995 to 1999 (Figure 4.2). During the vegetative N applications, leaf N in *ME* leaves was frequently greater (P<0.05) in the 100% Veg. timing compared with the 100% Rep. timing. Large fluctuations in leaf N of *ME* leaves occurred throughout the *ME* sampling period in each year. This period coincides with vegetative and floral growth flushes (Figure 4.3b and c) suggesting remobilisation of N to points of active growth. Leaf N in *LMFF* leaves was greater (P<0.05) in the latter part of the reproductive N applications (after September) in the 100% Rep. timing compared with the 100% Veg. timing in all years except 1998 (Figure 4.2). Leaf N in *LMFF* leaves declined for all N timings after October or November. The decline coincided with the latter stage of nut development (Figure 4.3a) again suggesting remobilisation of leaf N. Nitrogen applications however maintained greater leaf N in the 100% Rep. timing compared with the 100% Veg. timing during that time of nut development. Leaf N in *ME* and *LMFF* leaves in the Veg./Rep. N timing was generally intermediate between the 100% Veg. and the 100% Rep. timings throughout the year in each year of the study (Figure 4.2).

Leaf N in *ME* and *LMFF* leaves was usually greater (P<0.05) at the high N rate compared with the medium rate throughout the study (Figure 4.4).

Leaf N was generally less in *LMFF* leaves in 1995 (100% Veg. and Veg./Rep. N timings) and greater in 1999 (all N timings) compared with the other years. The 1995 concentrations possibly reflect the low pre-trial nutritional status of the trees and the low N rate applied in 1995, while the 1999 concentrations reflect the effect of defoliation by Cercospora Blotch. Excluding the

concentrations for these years, the range in leaf N concentrations from 1996 to 1998 for the High 100% Veg. treatment, the treatment that produced the greatest commercial NIS weight and proportion of nut drop by the end of November over that period, are shown in Table 4.12.

Concentrations of P, K, Ca, Mg, copper, zinc, manganese and iron were monitored in *ME* and *LMFF* leaves and were generally within the range reported in O'Farrell *et al*. 2000, in Table 4.15.

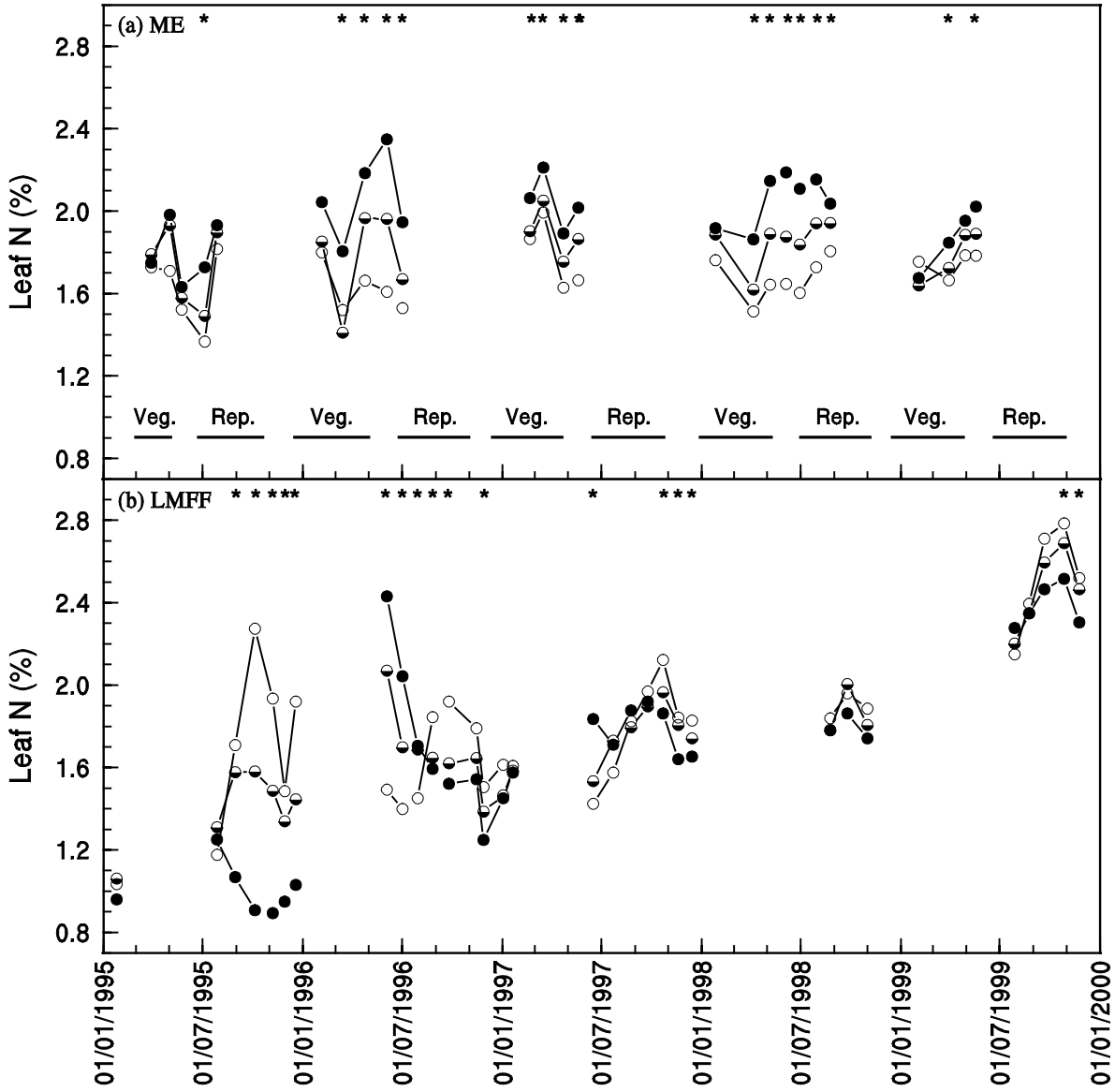

Figure 4.2 **Nitrogen concentration in (a) *ME* and (b) *LMFF* leaves for the three N timing treatments (● 100% Veg.; ◒ Veg./Rep.; ○100% Rep.). The horizontal bars in (a) indicate the period of N application. The asterisk (*) denotes treatments differences at P<0.05.**

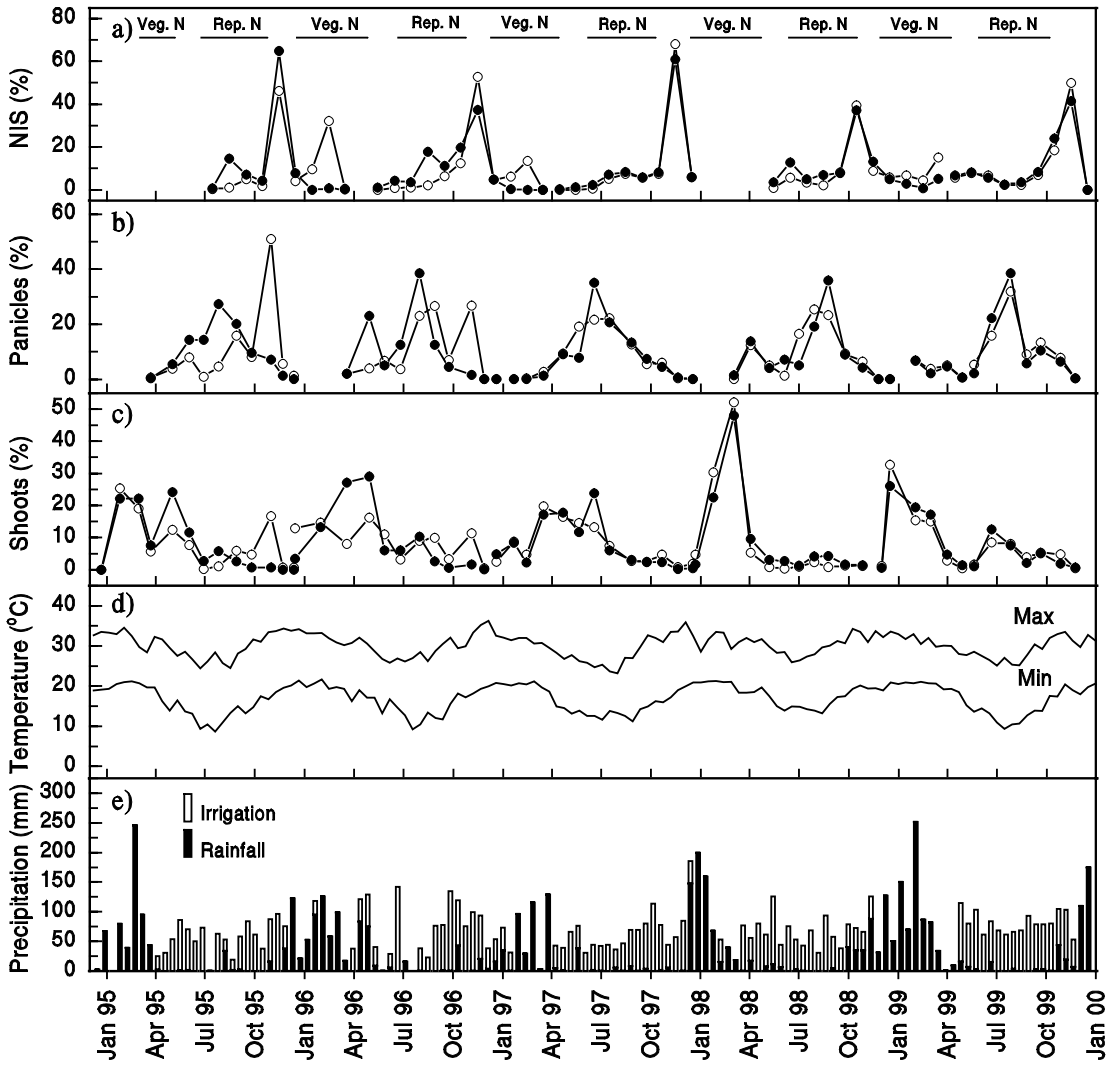

Figure 4.3 **Phenological development of 100% Veg. (●) and 100% Rep. (○) N timings from 1995 to 1999 and their relationship with temperature and precipitation. The horizontal bars in (a) indicating the period of N applications.**

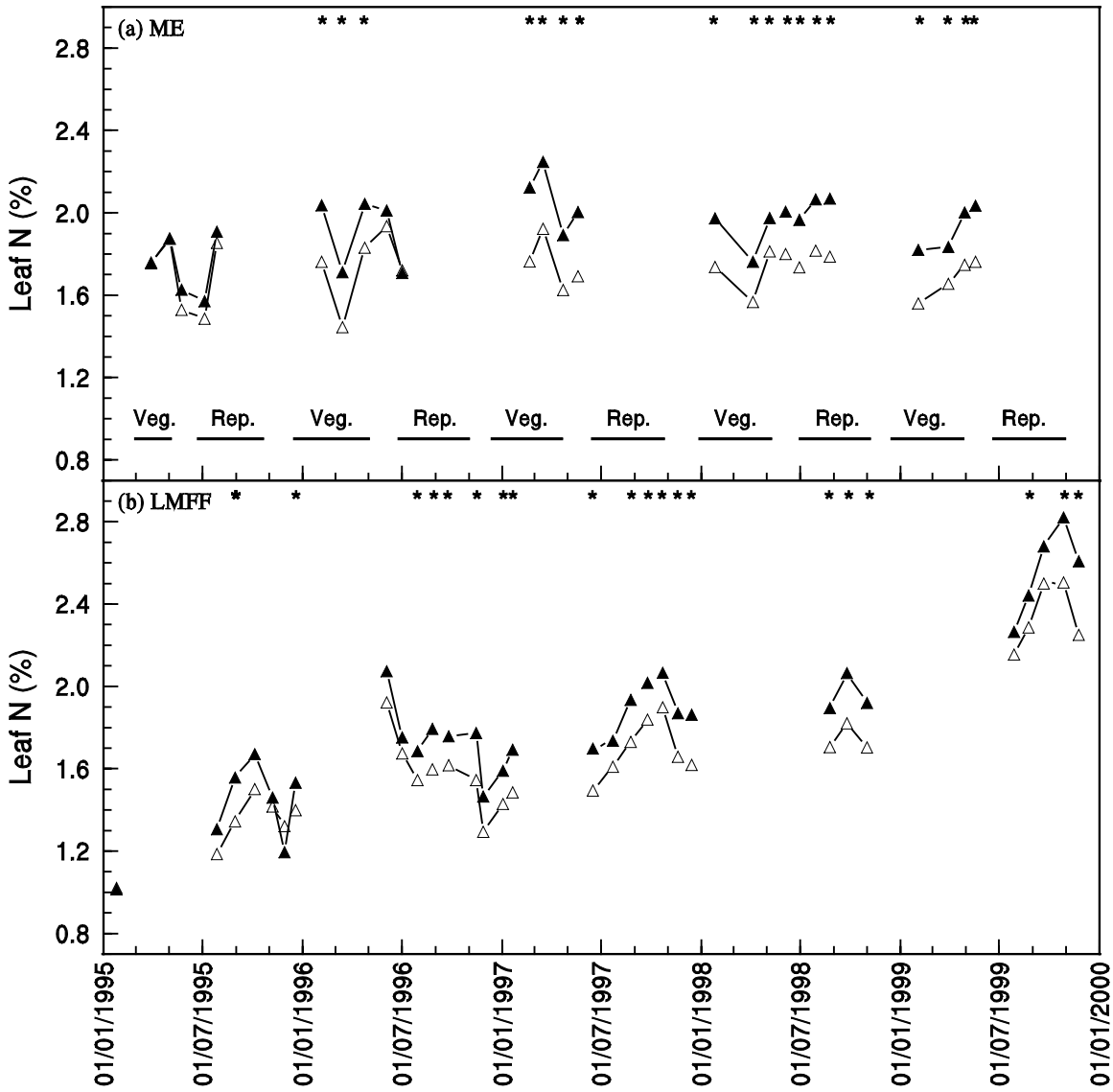

Figure 4.4 **Nitrogen concentration in (a) *ME* and (b) *LMFF* leaves for the two rates of N (Δ Medium; ▲ High). The horizontal bars in (a) indicate the period of N application. The asterisk (*) denotes treatments differences at P<0.05.**

Table 4.12 **Range in N concentrations in *ME* and *LMFF* leaves of the High 100% Veg. treatment from 1996 to 1998. The 1996 and 1997 data are from O'Farrell *et al.* (2000).**

Year	Leaf N concentration (%)	
	***ME* leaves**	***LMFF* leaves**
1996	1.97–2.34	1.35–2.59
1997	2.08–2.40	1.50–2.10
1998	1.99–2.36	1.80–1.94

4.6 Movement of N in drainage

Predicted drainage was simulated from January 1997 to June 2000. Agreement between the predicted and measured mean profile VSM was poor (R^2 < 30%) due mainly to periods of the year when irrigation was applied and when the sample trees had suffered severe defoliation by Cercospora Blotch (subsequent to June 1999). Improved correlation (R^2 = 59%, Figure 4.5) between the two was found during the wet season sampling periods of 1997 and 1999 (NMM data were not available for the 1998 sample period). Measurement of N movement to a depth of 1 m was therefore confined to sampling periods during the wet seasons of 1997, 1998 and 1999 (Table 4.13).

Rainfall for the three sampling periods varied between 129 and 207 mm, of which 48 to 56% was calculated by the model as drainage (Table 4.13). Concentrations of NH_4-N were generally low with only 7% of the total N loss as ammonium (mean of three sampling periods and two N treatments). Nitrate-N concentrations were as high as 126 mg/L. Variability of NO_3-N concentrations between cups was high and at times data for individual cups were lost due to system malfunction. The movement of N by leaching to 1 m varied between 2 and 12 kg/ha of plantation and was between 6 and 39% of the N applied (mean 25%). Movement was not well related to rainfall or rate of applied fertiliser. Other evidence for leaching of applied N is provided by soil analysis. Low concentrations of NO_3-N were measured in the vegetative N treatments (100% Veg and Veg./Rep.) in 1997 (4 months after the last N application) and also in the 100% Rep. treatment in all years from 1997 to 2000 (8 months after the last N application) (Table 4.1).

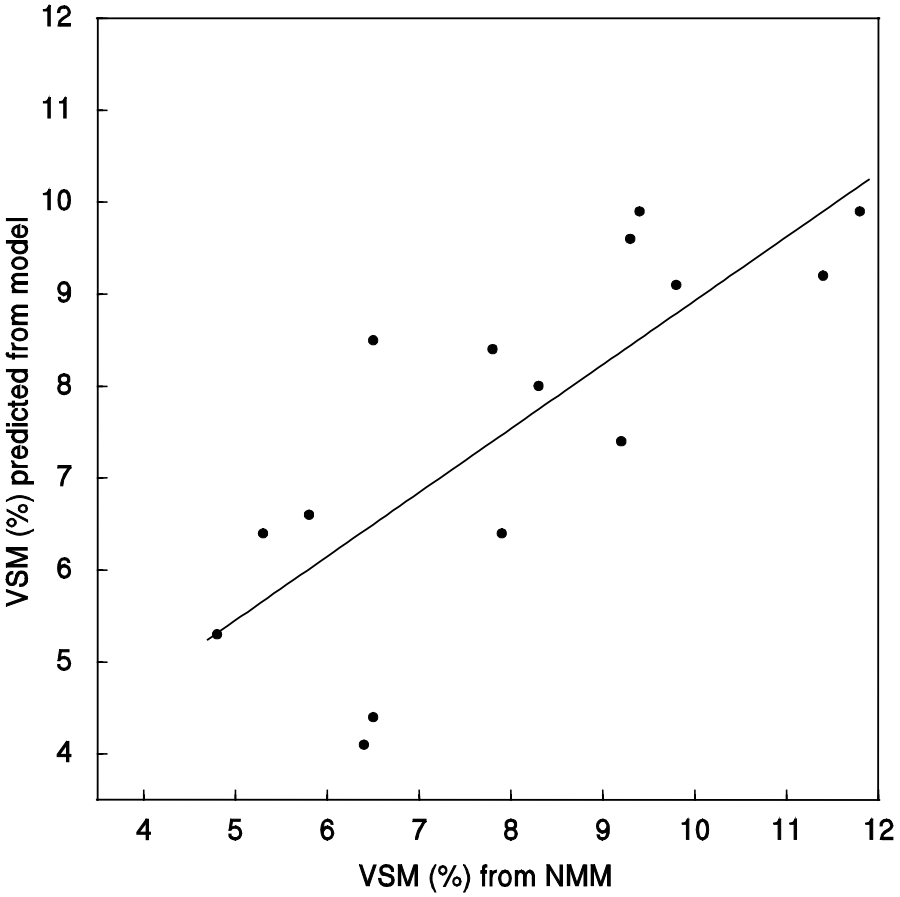

Figure 4.5 Relationship between mean profile (0–90 cm) VSM from NMM readings in 1997 and 1999 and mean profile (0–90 cm) VSM predicted from the soil water model (R^2 = 59%).

Table 4.13 Rainfall, predicted drainage, N applications, concentrations of NH_4-N and NO_3-N and total N in drainage during sampling periods in 1997, 1998 and 1999 of the Med. 100% Veg. and Med. Veg./Rep. treatments.

Sampling periods	Rainfall (mm)	Predicted drainage to 1 m (mm)	N applied (kg/ha)	Range in concentration sampled at 1 m (mg/L)		Total N in drainage at 1 m (kg/ha)
				NH_4-N	NO_3-N	
			Med. 100% Veg.			
21/3–11/4/97	130	70	24	0.4–6.5	71–126	7
14/1–12/2/98	129	73	36	0.3–1.2	11–20	2
15/2–30/3/99	207	100	36	0.1–1	78–95	12
			Med. Veg./Rep.			
21/3–11/4/97	130	70	12	2.3–5.9	35–57	4
14/1–12/2/98	129	73	18	0.1–0.6	32–92	7
15/2–30/3/99	207	100	18	1.1	34	2

4.7 Root activity patterns

Measurements of water extraction by roots showed that the roots were active to 1.2 m, the depth of measurement (Figure 4.6). Higher proportions of activity however, were observed at shallower depths, particularly in the top 500 mm of the soil profile.

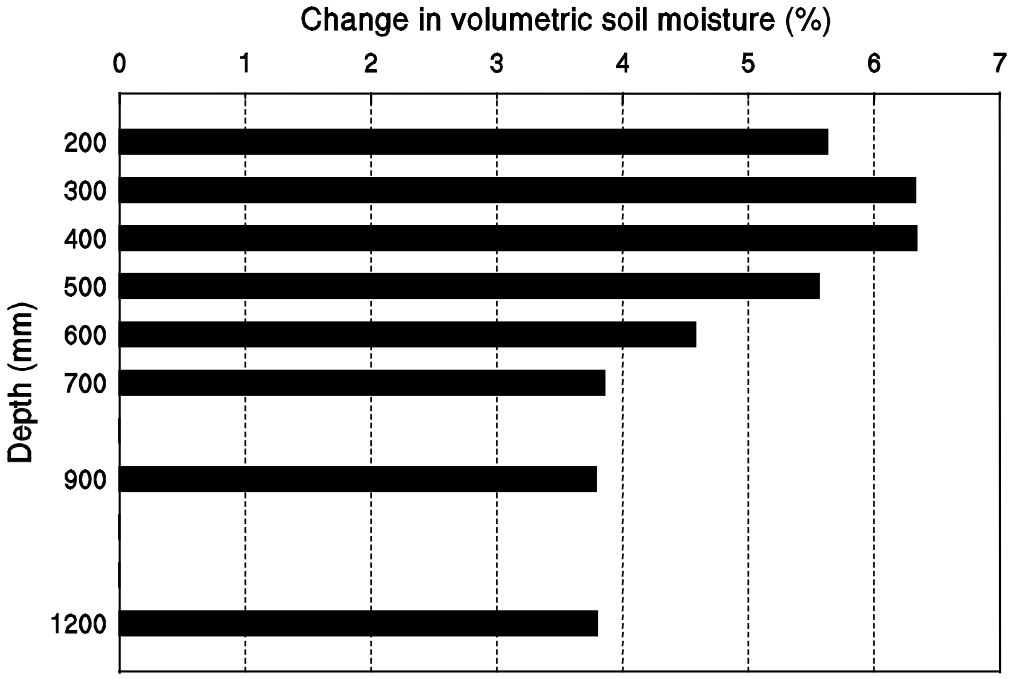

Figure 4.6 Total soil water extracted by roots from 7 to 42 days after irrigating to below 1.2 m.

5. Discussion

Research on the effect of N applied during the vegetative (December–April) and reproductive (June–October) growth phases at two rates was extended to 1998 and 1999 to confirm treatment responses previously observed during 1995–1997.

5.1 Effects of nitrogen on vegetative and reproductive growth

Nut yield was assessed both in terms of yield per tree and the proportion of yield harvested before the end of November, the time defined by which nut drop should be completed to avoid crop loss from monsoon rain and to avoid conflict between harvesting and other farm operations (O'Farrell *et al.* 2000). The results of this work over the five crop cycles show that it is important to apply N during the vegetative growth phase of the tree in the Dimbulah area. The application of N confined to this period produced a seasonal pattern of growth most consistent with the 'ideal' phenological cycle, that is, the cycle that correlates best with highest productivity (B. Cull pers. comm). The results of this work also caution against the application of N outside this period because of the high risk of post-November nut drop.

The main features of the 'ideal' cycle at Dimbulah were vegetative growth between December and April, floral growth between July and September, and nut drop between October and December. While the timing of the various pheno-phases is different, cashews growing at Wildman River in the Northern Territory have a similar pattern of growth (Richards 1993b). This is not surprising since both areas have a wet-dry climate and growth, according to Ohler 1979, is influenced by seasonal periodicity of the climate. According to Haarer (1954), the optimum climate for cashew production is one with a well-defined wet season alternating with an equally well-defined dry one. Richards (1993b) scheduled a crop management program on a generalised phenological cycle as we have done for the Dimbulah area (O'Farrell *et al.* 2000, Figure 5.1). These programs bear sufficient similarities to indicate that they could be adapted to other areas of northern Australia defined (Gunn and Cocks 1971) as having a wet-dry climate and suitable for cashew.

Canopy surface area was primarily responsible for commercial NIS and kernel yield through its influence on nut number. Richards (1993a) found that derived measures of tree size were well related to nut number and NIS yield. While CSA was promoted when N was applied during the vegetative growth phase, this treatment required the heaviest pruning. Little is known about the critical aspects of cashew canopy management that contribute to high nut yield and quality. The results of this work show however, that both CSA and N timing will be important considerations of canopy management in commercial practice.

While this study clearly defined the most appropriate time to apply N for high NIS and kernel yield, the most appropriate rates were not well defined because of limited N rates. The greatest NIS and kernel yield was achieved when N was applied during December–April at the high rate. The relationship between tree age and size and N rate for this treatment is shown in Table 5.1. Nitrogen rate can also be expressed as rate per m^2 of CSA and provides a means of determining N rate for various tree sizes. The mean N rate (g/m^2 of CSA) applied over the term of the study, excluding the 1996 rate, was 17.9 with consistent yield of about 210 g NIS/m^2 of CSA. This rate, as shown by this study, is adequate to produce high NIS and kernel yields for the tree sizes and planting density (208 trees/ha) of this study. The 1996 rate, which was about 80% greater than the mean of the other years, increased canopy productivity to 305 g NIS/m^2 of CSA. This rate, however, produced excessive vegetative growth in 1996 and is unlikely to be sustainable.

Table 5.1 Relationship between nitrogen rate and tree age, canopy dimensions and productivity for the vegetative (December–April) N application at the high rate. 1995–1997 data are from O'Farrell *et al.* 2000.

Tree age (years)	Tree canopy dimensions (m)		N rate per annum		Canopy productivity (g NIS/m^2 of CSA)
	Height	Diameter	g/tree	g/m^2 of CSA	
4 (1995)	2.9	2.7	600	15.4	241
5 (1996)	3.8	3.6	900	33.5	305
6 (1997)	4.8	5.1	900	18.1	207
7 (1998)	5.0	5.7	1200	20.5	199
8 (1999)	5.6	5.8	1200	17.5	211

5.2 Assessment of tree N requirement

The relationship between nutrient concentration in plant tissue and yield of a plant or plant part forms the basis of most schemes using plant analysis to diagnose plant nutrient status (Smith and Loneragen 1997). Our approach to developing a procedure to diagnose tree N status that would lead to a predictive procedure to guide N applications was to define the most appropriate index leaf and sampling time and to define nutrient ranges for healthy growth.

The N concentration of four leaf types was monitored during 1995–1997 (O'Farrell *et al.* 2000). Nitrogen concentration of the *ME* and *LMFF* leaves responded to N rate and timing and this was confirmed in 1998 and 1999. Both leaf types were easily recognisable and predicably available but, while on this basis suitable for commercial practice, their value for diagnosing tree N status is not known. Richards (1994), in his detailed study of leaf nutrient concentrations of cashew in the Northern Territory, concluded that a leaf of the *ME* type was the most suitable to sample because it displayed relatively low seasonal variability in N concentration.

In all years of the study, N concentration of *ME* and *LMFF* leaves varied between sampling dates within their respective sampling periods. There was therefore no time of nutrient stability on which to base a sampling time. Richards (1994) also reported a lack of stability of N concentration over time. To overcome this he proposed that leaf samples should be taken twice in the phenological cycle to guide fertiliser applications. The first sample should be taken just after the peak new year flush (March) to assess fertiliser need in relation to flowering and the second at flowering initiation (May–June) to assess fertiliser need in relation to nut yield. Based on the results of the present study, the second sampling time of Richards (1994) would be too late in the phenological cycle for trees growing in the Dimbulah area. An application of N at this time in this area, if required, would risk post-November nut drop. Richards (1993b) cautioned the application of N near or after flowering commences because of the risk of undesirable vegetative growth. We previously proposed that leaf samples should be taken twice during the phenological cycle, a pre-vegetative assessment in November–December and a pre-floral assessment in April–May (O'Farrell *et al.* 2000). The pre-vegetative assessment was seen as the more important, because of the impact of vegetative growth on CSA and the results of this study over the five years supports this.

Unfortunately, the limited availability of suitable trees (O'Farrell *et al.* 2000) constrained the experiment to only two rates of N. This was insufficient to develop a response curve relating growth or yield to N concentration and therefore to define critical N concentrations. In fact, at this time there are no definitive yield-nutrient response relationships published for cashew (Grundon 1999) from which to draw extrapolations of critical nutrient concentrations. When N was applied during December–April at the high rate, leaf N concentration was usually above 2.0% in the *ME* leaf and above 1.5% in the *LMFF* leaf over the years 1996–1998. This treatment produced the greatest NIS and kernel yield and suggests that these concentrations are at least sufficient to achieve high yields. They are certainly comparable to concentrations associated with healthy growth reported by others (Richards 1993a, Table 9).

5.3 Soil fertility and leaching

High concentrations of NO_3-N measured in leachate at a depth of 1 m indicate that the method of N fertiliser management used in this experiment is not sustainable in terms of potential N loss from the production system and degradation of soil and water quality. These concerns are consistent with broader opinion. Nitrogen movement from agricultural systems is recognised as a threat to surface and ground water quality (Keating *et al.* 1995) and soil acidification is a national soil degradation issue (Evans 1991). The results of the current study also have implications for perennial and semi-perennial crops, such as mango, lychee, longan and bananas, grown on well-drained soils of northern Australia where summer rainfall dominates and N fertilisers are applied.

Ammonium nitrate was applied in monthly applications to maximise N uptake by the tree. Despite this, up to 39% of the N applied was calculated to have leached to a depth of 1 m. The substantial decrease in mean soil profile pH of two units over the five years is attributed to nitrate leaching from the ammonium based N fertiliser used (Helyar 1976). This decrease reduced the effective cation exchange capacity of the soil profile and hence the capacity of the soil to retain cations such as K, Ca and Mg.

It is not known if the N leached to 1 m was lost from the production system. The depth to which the roots were extracting soil water and the rate of leaching would have influenced this. In this soil root activity can extend to at least 1.2 m as measured, and possibly deeper. Nable (1996) described the root system of cashew in this soil down to 2.5 m but cashew roots are known to extend to 5 m, depending upon soil characteristics (Falade 1984, Tsakiris and Northwood 1967). Little control can be exercised over drainage depth during rainfall but irrigation management should control drainage to the region of major root activity, suggested to be 1.2 m.

The application of N between December and April is recommended but this timing coincides with the wet season when uncontrollable soil drainage during high intensity rainfall occurs in the sandy soils at Dimbulah. Improvements in N fertiliser management can be achieved by matching tree demand for N more closely than was achieved in this study. This would require more frequent and smaller applications to maximise tree N uptake and minimise leaching losses. Fertigation would be the only practical and economical method of achieving this. In addition, N sources that do not cause soil acidification should be used. These include calcium nitrate, potassium nitrate, and to a lesser extent, calcium ammonium nitrate. Slow release N fertilisers that are currently very expensive may also reduce leaching losses.

The improvement of N fertiliser management by changing application techniques and/or forms has the potential to reduce N rates required for high yield. The leaching events examined at 1 m over three wet seasons showed that a mean reduction of rate of applied N of 25% may be possible. The reduction would be less if N uptake by roots deeper than 1.2 m occurred.

While the experiment was not designed to measure rates of P fertiliser required for high productivity, bicarbonate P accumulation between 1995 and 1997 showed that the application rate of 100 kg/ha during this time greatly exceeded that removed by the crop and leaching. In contrast, the 5 kg P/ha applied between 1997 and 2000 was insufficient to prevent bicarbonate P concentrations from halving. Application rates of 16 to 25 kg P/ha for 4 to 6 year old trees, respectively, have been recommended from other research at this site (N. J. Grundon, pers. comm.) and are consistent with the soil P trends measured.

The dramatic changes in soil pH and P concentrations demonstrate the importance of regular soil testing as a tool for long term monitoring of fertiliser programs. Because of the depth of roots of cashews, sampling to at least 1 m is recommended each year.

6. Implications

The impact of N management practices defined from this work on cashew production at Cashews Australia, Dimbulah, north Queensland, has been described previously (O'Farrell *et al.* 2000). The total planted area of commercial cashew in Australia has been stable at 300 ha since about 1995. Large increases in the area under cashew at Wildman River in the Northern Territory are currently being planned (Bob Teasdale, pers. comm.). Information from this study has been incorporated with other nutrition information in the *Cashew information kit* (Grundon *et al.* 1999) and serves as a complete guide for cashew nutrition programs in Australia in the future.

7. Recommendations

The results of this work over the five years (1995–1999) endorse recommendations made previously (O'Farrell *et al*. 2000), which included the:

1. Development of industry standards for NIS and kernel moisture and nut assessment methodology;
2. Selection of varieties with early season flowering and nut drop tendency; and
3. Development of sophisticated crop management systems.

It was also recommended that further work be undertaken to confirm the effects of N on cashew growth and nut yield; to develop a diagnostic procedure to guide N nutrition practices; and to develop fertigation technology for use in cashew. Further work is still required to define N rate and a diagnostic procedure and to develop fertigation practices. The most appropriate time to apply N has been well defined from this work, but definition of the most appropriate rates and a diagnostic procedure have been constrained by limited N rates. While the work showed that N should be applied during the vegetative growth phase, it also showed that large quantities of N are potentially leached when N is applied at this time because of wet season rainfall.

Research should also be undertaken to define canopy management practices for cashew in Australia. Canopy surface area was shown to be primarily responsible for NIS and kernel yield and this is important information for such research. Large cashew plantations of 500 ha are envisaged as necessary for Australia production (Chacko *et al*. 1998) and it is likely that the cost of pruning will dictate that trees be maintained in hedgerows. At this time nothing is known about the response of cashew to pruning in this manner.

8. Intellectual Property

This work showed that N applied during the vegetative growth phase of cashew promoted NIS and kernel yield and early season nut drop. This is important information for successful commercial cashew nut production in the Dimbulah area, where cool winter temperatures slow the seasonal development of the tree. Floral growth and nut maturation occurs later in the year compared with warmer areas, such as the Northern Territory, thus increasing the risk of crop loss from monsoon rain.

The information cannot be protected by patent for commercial advantage. It has been extended to industry during the course of the Project and has also been used to define N fertiliser recommendations in the *Cashew information kit* (Grundon *et al.* 1999). In all communications of the information to date, and those intended (publication in scientific journals), due recognition has and will be given to contributing parties. Copyright restrictions will ensure appropriate acknowledgment of contributors.

9. Communication Strategy

The results of this study have been extended to industry, agri-business and cashew research workers by personal communication and site walks. The trial has served as an on-farm demonstration of a *'whole systems best practice'* management of cashew incorporating not only N (and other nutrient) management but also, fertigation, soil water monitoring and irrigation, insect control and pruning. Canopy productivity levels of the trial were double that reported for industry by Grundon (1998). The results of this study have been incorporated in the *Cashew information kit* (Grundon *et al.* 1999) and will be published in a scientific journal.

10. References

Chacko, E., O'Farrell, P. and Blaikie, S. 1998. Nuts. In: The New Rural Industries. *A Handbook for Farmers and Investors*, (ed. K. W. Hyde) Rural Industries Research and Development Corporation, Canberra, pp. 415–421.

Dagg, M. and Tapley, R. G. 1967. Cashew nut production in Southern Tanzania. V. Water balance of cashew trees in relation to spacing. *East African Agricultural and Forestry Journal*. **33**, 88-94.

Evans, G. 1991. Acid Soils in Australia. 38p. (Bureau of Rural Resources, Department of Primary Industries and Energy: Canberra).

Falade, J. A. 1984. Variability in soils and cashew tree size. *Journal of Plantation Crops*. 12(1), 30-37.

Grundon, N. 1998. Fertilising cashews: Validation of fertiliser strategies in North Queensland. RIRDC Publication No 98/122, 42 p. (Rural Industries Research and Development Corporation Barton, Australia).

Grundon, N. 1999. Agronomy. In: Overview of Australian cashew literature. Technical Report No 25/99. CSIRO Land and Water, Australia, pp. 12-21.

Grundon, N., O'Farrell, P., Hinton, A., Kulkarni, V., Leonardi, J., Blaikie, S., Richards, N., Armour, J., Shearer, P., Duncan, I. and Hood, S. (1999). *Cashew Information Kit*. Department of Primary Industries, Queensland. III. Series: Agrilink your growing guide to better farming.

Gunn, R. H. and Cocks, K. D. 1971. Potentialities for cashew in northern Australia. *The Journal of the Australian Institute of Agricultural Science* **37**, 25-31.

Haarer, A. E. (1954). The cashew nut. *World Crops* **6**, 95-96.

Helyar, K.R. 1976. Nitrogen cycling and soil acidification. *The Journal of the Australian Institute of Agricultural Science*, 217-221.

Keating, B. A., Bauld, J., Ellis, R., Weier, K. L., Sunners, F. and Connell, D. 1995. Leaching of nutrients and pesticides to Queensland groundwaters. In*: Proceedings of Conference of Downstream Effects of Land Use*. (eds. H.M.Hunter, A.G. Eyles, and G.E. Rayment), pp 151-164.

Littleboy, M., Freebairn D. M., Silburn, D. M., Woodruff, D. R. and Hammer, G. L. 1999. PERFECT. A computer simulation model of Productivity Erosion Runoff Functions to Evaluate Conservation Techniques. Queensland Department of Natural Resources/Queensland Department of Primary Industries. 51p.

Nable, R. O., Blaikie, S. J. and Grundon, N. J. 1996. Where are the cashew roots? Working Papers of the Eight Cashew Research and Development Workshop August 6, Kuranda, north Queensland. 38-42.

Northcote, K. H. 1971. *A Factual Key for the Recognition of Australian Soils, Third Edition*. Rellim Technical Publications, Glenside, SA, 123p.

O'Farrell, P., Armour. J. and Reid. D. 2000. The effect of nitrogen on cashew in north Queensland. RIRDC Publication No 00/24, 54p. (Rural Industries Research and Development Corporation: Barton, Australia).

Ohler, J. G. 1979. *Cashew*. Koninklijk Instituut voor de Tropen, Amsterdam, Netherlands, 260p.

Richards, N. K. 1993a. Cashew tree yield, growth and macronutrient status, as influenced by fertiliser applications. In: Cashew Research in Northern Territory, Australia, 1987-1991. Technical Bulletin No. 202. Department of Primary Industries and Fisheries, NT, Australia, pp. 1-16.

Richards, N. K. 1993b. Evolving cashew orchard systems for the Northern Territory. In: Cashew Research in Northern Territory, Australia, 1987-1991. Technical Bulletin No. 202. Department of Primary Industries and Fisheries, NT, Australia, pp.39-49.

Richards, N. K. 1994. Leaf Analysis as a Guide to Nitrogen, Phosphorus and Potassium Status, and Yield and Growth of Cashew in the Killuppa Soil of the Northern Territory. MAgrSc Thesis. 153p. (The University of Queensland: Brisbane, Queensland).

Smith, F. W. and Loneragan, J. F. 1997. 1. Interpretation of plant analysis: Concepts and principles. In: *Plant Analysis: An Interpretation Manual*. (eds. D. J. Reuter and J. B. Robinson). CSIRO Publishing, Collingwood, Australia, pp. 3–33.

Teixeira, L. M. S. 1988. 9. Diseases. In: *Cashew Tree Culture in Northeast Brazil* [*a Cultura Do Cajuerio No Nordeste Do Brazil*] (ed. V. d. P. M. S. Lima). Fortaleza, Brazil, pp. 156-179.

Tsakiris, A. and Northwood, P. J. 1967. Cashew nut production in Southern Tanzania. IV. The root system of the cashew nut tree. *East African Agricultural and Forestry Journal*. **33**, 83-87.