EFFECTS OF NITROGEN FERTILISATION AND WEED CONTROL ON NUTRITION AND GROWTH OF A FOUR-YEAR-OLD *ARAUCARIA CUNNINGHAMII* PLANTATION IN SUBTROPICAL AUSTRALIA

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XU, Z. H., BUBB, K. A. & SIMPSON, J. A. 2002. Effects of nitrogen fertilisation and weed control on nutrition and growth of a four-year-old *Araucaria cunninghamii* plantation in subtropical Australia. Foliar nutrient concentration and stand growth of a four-year-old hoop pine (*Araucaria cunninghamii*) plantation, grown on a second-rotation site in subtropical Australia, were examined during a period of 18 months in response to application of nitrogen (N) fertiliser and chemical weed control (WC). Application of either N fertiliser at 50 kg ha^{-1} or WC of 3-m band spraying along tree rows with glyphosate at 3.6 litres ha^{-1} (48% active ingredient) resulted in similar, significant improvements in both N nutrition and stand growth in the 18-month period, compared with the control without any N addition or WC. A combination of both N addition and WC further improved the N nutrition and stand growth compared with either the N addition or WC alone. The WC mainly improved the stand N nutrition. Foliar nutrient concentration and stand growth data indicated that N deficiency was a major factor limiting the plantation productivity and there was no significant interaction in improving stand N nutrition and growth between the N addition and WC under the experimental conditions. Additional N fertiliser or WC or both would be required to improve the stand N nutritional status and enhance the plantation productivity 18 months after the initial N and WC treatments.

Key words: N nutrition - *Araucaria cunninghamii* - stand growth - weed control

XU, Z. H., BUBB, K. A. & SIMPSON, J. A. 2002. Kesan pembajaan nitrogen dan kawalan rumpai terhadap pemakanan dan pertumbuhan *Araucaria cunninghamii* di ladang berusia empat tahun di subtropika Australia. Tindak balas penggunaan baja nitrogen (N) dan kawalan rumpai kimia (WC) selama 18 bulan terhadap kepekatan nutrien daun dan pertumbuhan dirian pain bergelang (*Araucaria cunninghamii*) diuji di ladang berusia empat tahun yang ditanam di tapak kitaran kedua, di subtropika Australia. Penggunaan sama ada baja N sebanyak 50 kg ha^{-1} atau WC dengan semburan jalur 3 m di sepanjang barisan pokok menggunakan glifosat pada kepekatan 3.6 liter ha^{-1} (48% bahan aktif) menghasilkan peningkatan yang serupa dan bererti dalam pemakanan N dan pertumbuhan dirian dalam tempoh 18 bulan, berbanding kawalan tanpa penambahan N atau WC. Kombinasi penambahan N dan WC dapat meningkatkan pemakanan N dan pertumbuhan dirian berbanding penambahan N atau WC sahaja. WC kebanyakannya meningkatkan pemakanan N dirian tersebut.

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Data kepekatan nutrien daun dan pertumbuhan dirian menunjukkan bahawa kekurangan N merupakan faktor utama yang mengehadkan hasil ladang dan tiada interaksi bererti dalam meningkatkan pemakanan N dan pertumbuhan dirian antara penambahan N dan WC di bawah keadaan ujian. Penambahan baja N atau WC atau kedua-duanya perlu untuk meningkatkan status pemakanan N dirian dan seterusnya meningkatkan produktiviti ladang 18 bulan selepas rawatan awal N dan WC.

Introduction

Inadequate water supply and nitrogen (N) deficiency have been the major factors limiting the productivity of many forest plantation ecosystems in Australia and elsewhere (Vitousek & Howarth 1991, Osorio & Pereira 1994, Xu *et al.* 1995a, 2000, Bubb *et al.* 1998, 1999, Prasolova *et al.* 2000b). Both land management and environmental change can significantly impact terrestrial water-use efficiency and N cycling processes such as denitrification, leaching and immobilisation of available soil N (Polley *et al.* 1993, Stark & Hart 1997, Hall & Matson 1999, Robinson & Conroy 1999, Guinto *et al.* 2000, Mathers *et al.* 2000).

Almost all of the new hoop pine (*Araucaria cunninghamii*) plantations in south-east Queensland, Australia, have been established at second-rotation sites. Compared with other forest plantations comprising species such as *Eucalyptus* and *Pinus* in subtropical Australia hoop pine plantations have a much higher nitrogen (N) requirement (Bubb *et al.* 1999, Prasolova *et al.* 2000a). In recent years, there has been growing evidence of N deficiency in many young hoop pine plantations grown on the second-rotation sites immediately following the cessation of weed tending. This may be attributed to competition from weeds (particularly grasses) for water and available soil N, and a reduction in soil N supply due to a decrease in site N fertility resulting from the conversion of the first rotation to the second rotation. Therefore, application of N fertiliser and further weed control (WC) may be required to improve the stand N- and water-use efficiency, and hence enhance the plantation productivity. The objective of this study was to examine the responses in foliar nutrient concentration and stand growth during a period of 18 months following application of N fertiliser and WC to a four-year-old hoop pine plantation grown on the second-rotation site in subtropical Australia.

Materials and methods

The experimental site

The experimental site is located in a hoop pine (*A. cunninghamii*) plantation within the State Forest of Amamoor (26° 20' S, 152° 37' E), south-east Queensland, Australia, on a second-rotation site established for four years. Site preparation for establishment of the second-rotation hoop pine plantation consisted of a broadcast burn and inter-rows sown with a mixture of cereal and grasses (Japanese millet, carpet grass, kikuyu, broad-leaved paspalum and Wynn's cassia). The site was

planted in December 1992 at a stocking of 830 stems ha^{-1} with 2.4 × 5.0 m spacing. Routine tending with glyphosate applied at 3.6 litres ha^{-1} (48% active ingredient) and atrazine at 10 litres ha^{-1} (50% active ingredient) was carried out until the plantation aged two years. The average temperature at this area is 25 °C in summer and 14 °C in winter, and the average annual rainfall is about 1200 mm (Prasolova *et al.* 2000a). One 0–40 cm soil profile was sampled from each of the three experimental blocks for chemical analyses and soil classification before the experiment was commenced. Overall, the soil is classified as Ferralsol according to the FAO Soil Classification and detailed soil chemical properties (means of the three soil profile data) are presented in Table 1.

Experimental design and management

The experiment employed a complete factorial design, testing two factors of fertilisation (nil N vs. 50 kg N ha^{-1}) and weed control (nil WC vs. WC), with three replications for each of the four treatments (control, 50 kg N ha^{-1}, WC, and 50 kg N ha^{-1} and WC). Prior to the treatments applied, the hoop pine plantation was covered with a dense sward of grass weeds (particularly kikuyu and Rhodes grass) and trees were exhibiting widespread symptom of chlorosis commonly associated with N deficiency. Ammonium nitrate (34% N) (50 kg N ha^{-1}) was hand-applied in bands at either side of the tree rows of the relevant plots receiving the N addition in March 1997. The WC treatment involved of 3-m band spraying along the planting rows of the corresponding plots with glyphosate at 3.6 litres ha^{-1} (48% active ingredient) at the commencement of the experiment when the N fertiliser was applied. There were 42 trees (3 rows by 14 trees) in each of the 12 gross experimental plots (0.050 ha each), with three replications for each of the four treatments. The central 10 trees in each gross plot were used as the net plot (0.012 ha per net plot) for growth measurements and foliar sampling. Isolation of one row at either side of the net plot tree row and two trees at either end of the row was carried out to prevent cross-contamination of the treatments for a period of about two years.

Height and diameter at breast height (dbh) for trees in the net plots were measured, first at the commencement of the experiment in March 1997, and then six months and 18 months after the treatments. Basal area was calculated as reported by Xu *et al.* (1995a) and Bubb *et al.* (1999). Foliar sampling was done as reported by Xu *et al.* (1995b) and Bubb *et al.* (1999) when the stand growth measurements were undertaken. Briefly, a small branch of hoop pine foliage (*ca.* 1–2 years old) was collected from the northern (sunny) side of the upper crown of each sample tree. Four trees in each plot were sampled and the branchlet materials combined to produce a composite foliar sample for each plot. The foliar samples were then oven-dried at 70 °C immediately after collection and ground to pass through a 0.5-mm sieve for chemical analyses.

Chemical and statistical analyses

Chemical analyses for soil (pH, organic C, total N, total P, available P, exchangeable K, cation exchange capacity and electric conductivity) and plant (N, P, K, Ca, Mg, Na, Cu, Zn, Mn, and Fe concentrations) samples were performed as reported by Xu *et al.* (1995a, b). Statistical analyses and graphing were undertaken with STATISTICA 1999. Preliminary statistical analyses, using the complete factorial model of analysis of variance (ANOVA), which included the two main factors of N application (0 and 50 kg N ha^{-1}) and weed control (nil WC and WC) and their interactions for both tree growth and foliar nutrient data, indicated that there were no significant interactions between the N application and weed control treatments, and WC mainly improved stand N nutrition. Following the preliminary statistical analyses, a simplified model of ANOVA, including the four treatments as a single N application factor (a randomised complete block model with three replications for each of the four treatments), was used for the data analyses. Then the treatment means of tree growth and foliar nutrient data were compared with the Duncan's multiple range test.

Results and discussion

Stand growth

At the commencement of the experiment (before the treatments were applied), there were no significant differences in stand development in terms of tree height, dbh and basal area (BA) of the four-year-old hoop pine plantation (Table 2). After six months of the treatment applications, more than 90% increase in height increment was recorded in the plots receiving 50 kg N ha^{-1} with or without the WC, compared with that of the control receiving neither N addition nor WC. However, dbh and BA increments after the six months did not differ significantly between the treatments, indicating that dbh and BA growth of the hoop pine plantation was less responsive to the N addition and WC compared with height growth. Compared with the control at 18 months after the treatments, either the N addition or WC enhanced height increment by about 41%, but a combination of 50 kg N ha^{-1} and WC produced a significant 85% increase in height increment, about twice that of the increase from the N addition or WC alone. There was no significant interaction in improving height increment between the N addition and WC since a combination of the two treatments resulted in about twice that of either treatment alone. Also, no interactions in tree growth and foliar nutrient concentration between the N and WC treatments were significant as indicated by the ANOVA results of the complete factorial model testing the main factors of N application and weed control as well as their interactions. This suggested that N deficiency was a major factor limiting stand productivity and WC significantly improved stand growth by reducing competition of weeds for available soil N instead of available soil water. This indicated that WC mainly improved stand N nutrition, which was similar to that receiving 50 kg N ha^{-1}. The dbh and BA

Table 1 Chemical properties in the 40-cm soil profile of the experimental site in subtropical Australia[a]

Soil depth (cm)	pH	Organic C (%)	Total N (%)	Total P (mg kg^{-1})	Available P (mg kg^{-1})	Exch. K (cmol kg^{-1})	CEC (cmol kg^{-1})	EC (dS m^{-1})
0–10	7.2	6.06	0.372	584	36.0	0.969	45.8	0.147
10–20	6.8	4.10	0.313	511	11.4	0.653	39.6	0.093
20–30	6.7	3.26	0.286	461	4.3	0.540	36.6	0.079
30–40	6.7	3.01	0.258	410	5.2	0.502	35.1	0.077

[a]Soil pH (1:5 H_2O), organic C, total N, total P, available P, exchangeable K, cation exchange capacity (CEC) and electric conductivity (EC) were determined as reported by Xu *et al.* (1995a) and Prasolova *et al.* (2000a)

Table 2 Stand growth responses of a four-year-old hoop pine plantation to nitrogen (N) fertilisation and weed control (WC) in the first 18 months after application of N and WC treatments

Treatment [a]	Initial stand in March 1997[a]			6 months after treatments[b]			18 months after treatments[b]		
	H (m)	DBH (cm)	BA (m^2 ha^{-1})	HI (m)	DBHI (cm)	BAI (m^2 ha^{-1})	HI (m)	DBHI (cm)	BAI (m^2 ha^{-1})
Control	3.29 a[c]	5.31 a	7.62 a	0.22 b	0.76 a	2.21 a	1.12 b	2.13 b	6.92 b
50 kg N ha^{-1}	3.39 a	5.39 a	8.33 a	0.43 a	0.80 a	2.45 a	1.59 ab	2.48 b	8.67 ab
WC	3.29 a	5.23 a	7.35 a	0.23 ab	0.74 a	2.14 a	1.58 ab	2.63 b	8.93 ab
50 kg N ha^{-1} + WC	2.96 a	4.94 a	6.59 a	0.42 ab	0.89 a	2.50 a	2.07 a	3.24 a	11.16 a

[a]Stand growth measured at the commencement of the experiment: H - tree height; DBH - diameter at breast height; BA - basal area.

[b]Height increment (HI), DBH increment (DBHI) and BA increment (BAI) 6 or 18 months after application of the treatments.

[c]Means within a column followed by the same letter are not different from each other at the 5% level of significance by Duncan's multiple range test.

increment 18 months after the treatments of N addition plus WC were 52 and 61% respectively, higher than those showed by the control. Application of N fertiliser at 100 kg ha^{-1} to a five-year-old hoop pine plantation at a second-rotation site in south-east Queensland, Australia has significantly improved stand growth after about two years of the N addition, with 45 and 44% increases respectively for BA and volume increments (Bubb *et al.* 1999). The results of existing N fertilisation experiments with hoop pine plantations grown at second-rotation sites in Queensland, Australia indicated that periodical annual growth increments from the application of N fertiliser at rates up to 600 kg ha^{-1} would at least last six to eight years after the N addition and would maintain the growth improvements thereafter (Xu *et al.* 2000).

Foliar nutrient concentration

At the commencement of the experiment, there were no significant differences in foliar N, P, K, Na, Ca and Mg concentrations of the four-year-old hoop pine plantation between the treatments as shown in Table 3. After six months of the treatments, either the N addition or WC significantly improved foliar N concentration from 0.69% for the control to about 1.18%. A combination of the N addition and WC resulted in a further increase in foliar N concentration to about 1.62% compared with that receiving either the N addition or WC alone. This indicated that either the N addition at 50 kg N ha^{-1} and WC or about 100 kg N ha^{-1} would be required to improve stand N nutritional status for enhancing the plantation productivity under the experimental conditions. At six months after the treatments, no significant differences in other foliar nutrient concentrations existed between the treatments. After 18 months of the treatments, there were no significant differences in foliar nutrient concentrations between the treatments, except for foliar Ca concentration which was the highest (1.35%) in the control, followed by the N addition (1.19%), and finally, either the WC alone or the N addition in the presence of WC (about 0.94%).

The differences in foliar Ca concentration between the treatments may be attributed to the tissue growth dilution effects as reported by Xu *et al.* (1995b). Foliar N concentration at 18 months after the treatments (0.75–0.92%) did not differ significantly between the treatments. This concentration is lower than that of 0.90–1.00% critical foliar N concentration of hoop pine plantations suggested by Bubb *et al.* (1999). This indicates that additional N fertiliser or WC or a combination of both N addition and WC would be required to further improve stand N nutritional status and enhance the plantation productivity 18 months after the initial treatments of the four-year-old hoop pine plantation. In practice, application of N fertiliser at about 100 kg N ha^{-1} would be more economically attractive than the 50 kg N ha^{-1} applied in the presence of WC. This is especially so since N deficiency was a major growth-limiting factor and WC mainly improved stand N nutrition (to the extent equivalent to application of 50 kg N ha^{-1}) by reducing weed competition for N instead of the water which was much less growth-limiting as shown in Table 2.

Table 3 Foliar nutrient responses of a four-year-old hoop pine plantation to nitrogen (N) fertilisation and weed control (WC) in the first 18 months after application of N and WC treatments

Treatment	Foliar nutrient concentration									
	N (%)	P (%)	K (%)	Cu (mg kg^{-1})	Zn (mg kg^{-1})	Na (%)	Ca (%)	Mg (%)	Mn (mg kg^{-1})	Fe (mg kg^{-1})
					Initial sampling in March 1997 [a]					
Control	0.54 a[b]	0.134 a	1.45 a	nd[c]	nd	0.041 a	1.37 a	0.307 a	nd	nd
50 kg N ha^{-1}	0.49 a	0.139 a	1.36 a	nd	nd	0.036 a	1.41 a	0.344 a	nd	nd
WC	0.52 a	0.120 a	1.35 a	nd	nd	0.039 a	1.38 a	0.371 a	nd	nd
50 kg N ha^{-1} + WC	0.49 a	0.134 a	1.37 a	nd	nd	0.055 a	1.50 a	0.374 a	nd	nd
					Foliar sampling 6 months after the treatments applied					
Control	0.69 c	0.162 a	1.07 a	5.11 a	27.5 a	0.083 a	1.55 a	0.412 a	nd	nd
50 kg N ha^{-1}	1.18 b	0.156 a	1.04 a	5.34 a	23.7 a	0.036 a	1.42 a	0.328 a	nd	nd
WC	1.19 b	0.213 a	1.40 a	7.67 a	29.5 a	0.045 a	1.08 a	0.317 a	nd	nd
50 kg N ha^{-1} + WC	1.62 a	0.180 a	1.26 a	7.43 a	32.8 a	0.054 a	1.02 a	0.283 a	nd	nd
					Foliar sampling 18 months after the treatments applied					
Control	0.81 a	0.210 a	1.24 a	6.09 a	29.1 a	0.049 a	1.35 a	0.290 a	139.6 a	21.6 a
50 kg N ha^{-1}	0.92 a	0.182 a	1.27 a	5.92 a	26.2 a	0.033 a	1.19 b	0.319 a	64.0 a	20.4 a
WC	0.84 a	0.201 a	1.67 a	6.00 a	27.5 a	0.036 a	0.95 c	0.326 a	76.6 a	25.0 a
50 kg N ha^{-1} + WC	0.75 a	0.168 a	1.57 a	5.75 a	23.7 a	0.031 a	0.94 c	0.235 a	62.8 a	18.3 a

[a] Initial foliar sampling was undertaken at the commencement of the experiment in March 1977.

[b] Means within a column at a sampling time followed by the same letter are not different from each other at the 5% level of significance by Duncan's multiple range test.

[c] nd: not determined.

Relationships between foliar N concentration and stand growth

There was a significant, positive linear relationship between foliar N concentration six months after the treatments of the four-year-old hoop pine plantation and height increment (Figure 1) as well as dbh increment after 18 months of the treatments (Figure 2). Again, this has highlighted that N deficiency was a major factor limiting stand productivity and that application of 50 kg N ha^{-1} with or without WC could significantly enhance the productivity of the plantation through improved stand N nutrition.

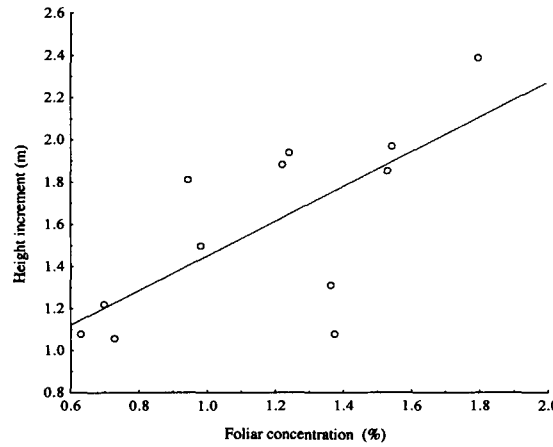

Figure 1 Relationship between foliar N concentration (x) of a four-year-old hoop pine plantation six months after application of N fertiliser at 50 kg N ha^{-1} and weed control treatments and height increment (y) 18 months after the treatments applied: $y = 0.629 + 0.822\ x$ ($r^2 = 0.49$, $n = 12$, $p < 0.05$)

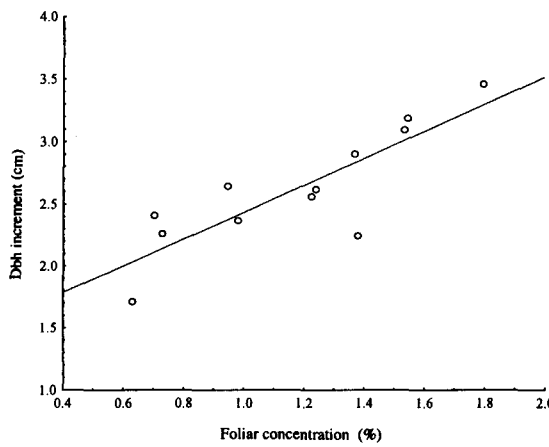

Figure 2 Relationship between foliar N concentration (x) of a four-year-old hoop pine plantation six months after application of N fertiliser at 50 kg N ha^{-1} and weed control treatments and dbh increment (y) 18 months after the treatments applied: $y = 1.35 + 1.08\ x$ ($r^2 = 0.71$, $n = 12$, $p < 0.001$)

Conclusions

The N deficiency was a major factor limiting the productivity of the four-year-old hoop pine plantation on the second-rotation site in subtropical Australia. Application of either 50 kg N ha^{-1} or WC alone improved the stand N nutrition and growth in the first 18 months following the treatments, with WC resulting in the responses of both foliar N concentration and stand growth similar to those of the N addition alone. A combination of both the N addition and WC almost doubled foliar N concentration response after six months of the treatments and stand growth increment after 18 months compared with either the N addition or WC alone. This indicated that WC mainly improved stand N nutrition and there was no significant interaction in increasing foliar N concentration or stand growth between the N addition and WC. More than 50 kg N ha^{-1} would be required to enhance productivity of the hoop pine plantation for the first 18 months. Additional N fertiliser may be required to further improve the stand N nutrition and growth after 18 months of the initial treatments.

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