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Effects of Site Management in Pine Plantations on the Coastal Lowlands of Subtropical Queensland, Australia

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Abstract

Biomass and nutrient distribution in a 30-year-old slash pine (*P. elliottii*) plantation were estimated at clear fall to provide a basis for interpreting changes in the nutrient pools and tree responses to harvest residue management practices applied at the establishment of the second rotation. Total biomass at clearfall of a typical slash pine stand is 316 t ha^{-1}, of which 206 t ha^{-1} is removed in logs. Nitrogen and P removed in logs account for 7.6% and 3.4% of total N and P in the ecosystem. Residues remaining after logging contain 12% of the total N and 5.2% of the total P. Proper management of these residues is therefore critical for sustaining site productivity. Following clear falling, a long-term experiment was established to assess the impacts of harvesting residues and litter management regimes on soil fertility and productivity of the second crop F_1 hybrid between slash pine and Honduras Caribbean pine (*P. caribaea* var. *hondurensis*). The early results from this experiment show tree stem volume and above ground biomass production have been increased by 31% and 29% respectively at age 39 months by retaining litter and logging residues, compared with the treatment in which logging residues and litter were removed. Further improvements in tree growth have been achieved by doubling the quantity of residues retained and by controlling weed competition. Foliar nutrient concentrations indicated that N may play an important role in the maintenance of long term site productivity. Differences exist in the growth and foliar nutrient concentrations between the different hybrid families tested but all families responded similarly to the residue treatments. The presence of the residues increased soil moisture levels in the surface soil during a dry season. There was a marked reduction in the quantity of residue, especially the finer fraction, after 39 months. This study has contributed to an improved understanding of the soil and plant factors controlling productivity and provided a basis for more detailed studies on processes underpinning plantation sustainability.

Introduction

In Queensland, the exotic pine estate (129 497 ha) is comprised of 37% slash pine (*Pinus elliottii* Engelm.), 42% Honduras Caribbean pine (*P. caribaea* var. *hondurensis* Barr. et Golf.) and 18% the hybrid between these two taxa. Since 1991 most plantings have been with hybrids. In 1997/98, 90% of the pine plantings were with the hybrid and 97% of sites planted were second rotation areas. Typical rotation length is 30 years. Maintenance and improvement of long-term site productivity of plantations is an important goal of management.

Tiarks *et al.* (1998) have described the needs, objectives and basis of long-term experimentation for this international network, coordinated by the Center for International Forestry Research (CIFOR). Currently this is the only trial using a *Pinus* species. Two trials with eucalypts in Western Australia (O'Connell *et al.* 1999) are relevant to the work being undertaken in Queensland and will provide a useful contrast at a national level. Simpson *et al.* (1999) described the experimental site in

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southeast Queensland and reported the early results of the work which formed a part of the international network. Biomass and nutrient distribution in a typical rotation aged slash pine stand were also reported. The early responses of F_1 hybrid pine established in the second rotation under a range of logging residue management treatments showed that retention of logging residues did not affect survival but improved height growth by 11-24% at age 17 months. This paper provides further details on the experimental methods and recent results.

Site and Stand Description

Details of the experimental site were described by Simpson *et al.* (1999). The study was carried out at Toolara in Queensland, Australia (26°00'S latitude, 152°49'E longitude and 61 m altitude). The area has a humid subtropical climate, with a mean annual rainfall of 1354 mm. The site originally carried dry sclerophyll native forest which was cleared in 1959 for plantation establishment. Soils at the site are derived from Mesozoic sandstones, and are acidic, deep and sandy, and classified as Grey Kandosols (Isbell 1996) or Gleyic Acrisols (FAO 1974). Inherent soil fertility is low and large responses of the first rotation stand to the additions of P fertiliser were obtained (Simpson and Grant 1991, Simpson 1995). The soils are well-drained in the upper horizons but can become waterlogged for short periods during the wet season when the watertable rises within 50 cm of the soil surface.

The first rotation slash pine stand was planted in July 1966 at 1234 stems ha^{-1}. Fertiliser, 310 kg ha^{-1} Nauru rock phosphate (50 kg P ha^{-1}) was broadcast in 1966 and a further application of triple superphosphate (44 kg P ha^{-1}) was applied aerially in 1980. The stand was thinned at age 15.6 years to a stocking of 679 stems ha^{-1}, and clearfelled in November 1995, at age 29.4 years. The site index [average height (m) of the 50 tallest stems ha^{-1} at age 25 yr] of the area was 23.7, compared with a district average of 23.4 for the species. At clearfelling, the stand had a predominant height of 25.2 m, standing basal area of 39.6 m^2 ha^{-1} and standing volume to a 7 cm top end diameter of 325.4 m^3 ha^{-1}.

Allometric relationships were established from sample trees harvested from a 29.4-year-old first rotation slash pine stand and biomass nutrient pools estimated. Litter, underground biomass and soil nutrient pools were also estimated.

Experimental Design and Methods

The residue management trial consists of six treatments laid out as a randomised complete block experiment replicated four times. Gross plots are 12 rows by 12 trees at 3m x 3m spacing (0.13 ha) with a 6 m border and net plots of 0.058 ha. The treatments were:

BL_0	Removed both litter and logging debris + 50 kg P ha^{-1}.
BL_2	Retained both litter and logging debris + 50 kg P ha^{-1}.
BL_3	Applied double quantities of litter and logging debris + 50 kg P ha^{-1}.
BL_2 + Legumes	BL_2 + leguminous cover crops.
BL_2 - Weeds	BL_2 + complete weed control.
BL_2 - P	BL_2 without P fertiliser.

It was not possible with the equipment used to remove the small amount of litter/logging residue (< 10 t ha^{-1}) remaining in the BL_0 without excessive site disturbance. The normal residue treatments (BL_2) carried 60 t DM ha^{-1} (50.8 to 73.8 t ha^{-1}) of which approximately 40% was in the forest floor litter. Double residue (BL_3) treatment (140 t ha^{-1}) was not intended as an operational alternative, but to widen the treatment effects on tree growth and soil processes.

The slash management treatments were applied in February 1996, 3 months after clearfalling, and surface biomass estimated for individual plots. Planting spots were prepared using an excavator-mounted rotary cultivation head. Pre- and post-planting herbicides were applied in the first year along the planting rows. The plots were planted in May 1996 at 3 x 3 m spacing (1111 stems ha^{-1}) with container-grown F_1 hybrid seedlings raised from seed collected from six separate orchards. Each orchard was comprised of a single family of slash pine which was mass-pollinated following emasculation. The same families were represented in two old and two young orchards and the same pollen used in mass pollination but a degree of self pollination occurred in the older orchard as a result of difficulty in achieving complete emasculation. Seed source identity was retained. Triple superphosphate was applied to supply 45g P $seedling^{-1}$ in all treatments except for BL_2-P. A mixture of legume seeds containing lotononis (*Lotononis bainesii*), Wyns cassia (*Cassia rotundifolia*) and Maku lotus (*Lotus pedunculatus* cv Maku) was sown on three occasions in the BL_2 + Legumes treatment. The legumes were slow to develop and in 1999 covered < 50% of the area.

Tree height and diameter were measured annually. Foliar samples of the most recent fully formed fascicles from the basal spring whorl developed in the season prior to sampling were collected in August 1998 and August 1999. Fifty fascicles from each of four trees were combined to give a composite sample for each sample. Biomass and nutrient pools in the above ground tree fractions were estimated immediately before non-merchantable thinning of the stand at age 39 months. following the same principles used for the biomass sampling of the first rotation stand. Sample trees, representing the diameter distribution of the stand, were harvested. Weights and nutrient concentrations of the tree components were determined. Allometric relationships were established and biomass and nutrient contents estimated. Slash residues were sampled at age 0 and 30 months by taking five one-metre square samples per plot, and at 39 months with two similar samples per plot. After collection, the material was sorted into size classes, oven dried and sampled for chemical analysis. Nutrient analysis of plant and soil samples was carried out by the Queensland Forestry Research Institute's chemistry laboratory (Collins 2000a, b). Gravimetric moisture content of the surface soil (0-10 and 10-20 cm) at the time of residue sampling (30 and 39 months) was recorded.

Results

Impacts of Harvesting and Site Preparation on Biomass/Slash and Nutrients

In this study, 80% of the biomass on the site was aboveground and contained between 72 and 78% of macronutrients in the biomass (Table 1). Between 52 and 72% of the macronutrients in the biomass were in the standing trees. The relatively low quantity of K in the litter is of note. Depending on the nutrient, between 16 and 28% of the nutrients in the biomass were in tree roots. Integrated logging removed 65% of the biomass, 39% of N and P, and 54% of K in the biomass. Details of the biomass and nutrient distribution in mature slash pine stands were reported in Simpson *et al.* (1999).

The weight of the aboveground biomass (including litter but excluding logs) was lower (46 t ha^{-1} than that harvested as merchantable timber (wood + bark) (206 t ha^{-1}) but both components contained similar quantities of nutrients, except for K (Table 1). Log harvest removed an estimated 7.6% of the N, 3.4% of the P and 171% of the exchangeable soil K, 16.3% of the exchangeable soil Ca and 5.6% of the exchangeable soil Mg in the ecosystem. While the loss of N and P from the pool through logging is relatively small, this loss is doubled if the logging residues plus litter were removed during site preparation at establishment of a second crop. Any acceleration of nutrient loss from a site would adversely impact on the maintenance of long-term site productivity unless replaced by fertiliser.

Table 1. Biomass and nutrient distribution in a 29.4-year-old slash pine stand at Toolara, Queensland

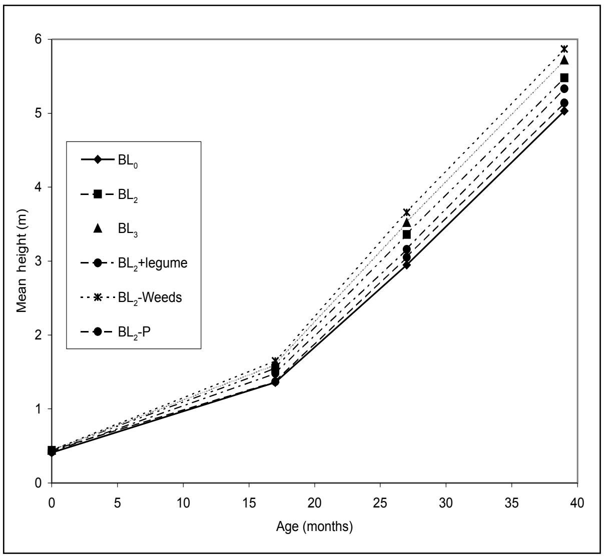
Component	Biomass	N	P	K	Ca	Mg
	(kg ha^{-1})					
Foliage	2 03	16.0	1.3	4.1	7.8	4.0
Branches and stem tip	24 18	48.1	3.7	17.0	68.2	17.5
Stem wood, bark (>7cm diam.)	205 74	189.1	10.8	63.2	170.3	64.6
Litter	19 80	98.2	4.3	4.7	83.4	20.3
Stump	33 00	38.3	2.1	11.1	20.7	10.7
Roots	30 94	95.7	5.1	16.4	71.6	22.2
Total biomass	315 69	485.4	27.3	116.5	422.0	139.3
Soil (to 120 cm)		1991	288	37[a]	1045[a]	1148[a]
Total ecosystem	315 69	2476	315	-	-	-

[a] Exchangeable cations determined in neutral ammonium acetate extract (Collins 2000b).

Survival and Growth

At the end of the first season seedling survival was 99% in all treatments. Trees grew little during the winter and no treatment effects were apparent by spring of the first year. Treatment differences became apparent during the following spring season. At age 17 months there was little difference in development of the trees in the treatments where litter was retained and P fertiliser applied. The legume treatment was ineffective (Fig. 1).

Figure 1. Height growth of hybrid pine to residue management treatments on a second rotation site at Toolara



At age 39 months, residue retention treatments had resulted in improved tree growth (Table 2); height by 8.9%, diameter by 11.6%, basal area by 23.9%, and total volume by 31.4%. Doubling the quantity of residues retained resulted in a further improvement in tree growth. Complete weed control markedly improved tree growth when compared with the single residue retention treatment (mean height increased by 7.1%, diameter by 17.7%, basal area by 38.5% and total volume by 52.1%). The legume treatment had no effect on tree growth. The treatment without P is equivalent to the nil residue plus P treatment. These differences are also reflected in current increments for diameter, basal area and total volume (Table 2).

The residue treatments had a major influence on biomass production, with retention of litter and logging residues improving tree biomass by 29% (Table 3). Double amounts of residues improved biomass by a further 17% and weed control resulted in an improvement of 38% over the single residue treatment. The increased production is accompanied by a corresponding increase in nutrient uptake.

Family Effects

Family variation in tree growth is shown in Table 4. There were significant differences between families but the family by residue interaction is generally non-significant. This suggests that the families responded in a similar fashion to residue management treatments.

Table 2. Effect of slash treatments on the stand growth at age 39 months

Treatment	Mean height	DBH	Basal area	Volume	Increment 27-39 months		
	(m)	(cm)	(m^2 ha^{-1})	(m^3 ha^{-1})	DBH (cm)	Basal area (m^2 ha^{-1})	Volume (m^3 ha^{-1})
BL_0	5.0	8.6	6.7	15.9	4.1	4.8	13.2
BL_2	5.5	9.6	8.3	20.9	4.2	5.6	16.8
BL_3	5.7	10.4	9.8	26.3	4.6	6.7	21.0
BL_2 + Leg.	5.3	9.3	7.8	19.4	4.3	5.5	15.9
BL_2 - Weed	5.9	11.3	11.5	31.8	4.6	7.3	24.4
BL_2 - P	5.1	8.9	7.1	17.2	4.2	5.1	14.2
LSD p=0.05	0.4	1.0	1.8	5.9	0.23	0.83	3.9

Table 3. Effect of slash treatments on aboveground tree biomass and nutrient pools at age 39 months

Treatment	Biomass	N	P	K	Ca	Mg
		(kg ha^{-1})				
BL_0	13 365	30.3	5.1	21.9	27.7	9.7
BL_2	17 292	39.3	6.4	29.7	36.2	12.2
BL_3	20 292	46.3	7.3	35.7	42.6	14.2
BL_2 + Leg	16 234	36.9	6.0	27.6	33.9	11.5
BL_2 - Weeds	23 920	54.6	8.5	42.8	50.3	16.5
BL_2 - P	14 678	33.3	5.1	24.5	30.6	10.5
LSD p=0.05	3 860	8.9	1.2	7.5	8.2	2.5

Table 4. Growth of six hybrid pine families at age 39 months

Family number	Mean height (m)	DBH (cm)	Basal area (m^2 ha^{-1})	Total volume (m^3 ha^{-1})	Increment 27-39 months.		
					Height (m)	Basal area (m^2 ha^{-1})	Total volume (m^3 ha^{-1})
1	6.1	10.6	10.1	28.3	2.3	6.6	22.1
2	6.1	11.0	10.8	29.6	2.4	7.2	23.5
3[a]	4.5	8.1	5.8	12.0	1.8	4.2	10.0
4[b]	5.7	10.5	9.8	25.8	2.2	6.7	20.7
5[b]	4.6	7.5	5.1	10.8	2.0	3.6	8.9
6[a]	5.7	10.4	9.7	25.1	2.2	6.6	20.2
Mean	5.4	9.7	8.5	21.9	2.2	5.8	17.6
LSD p=0.05	0.2	0.4	0.8	2.7	0.1	0.5	1.9
Interaction[c]	0.013	NS	0.011	0.001	NS	NS	0.001

[a - b] Family numbers with the same superscript have the same nominal parentage but originate from different-aged orchards and have a different degree of self-pollination; [c] Refers to the significance (p levels) of the family by residue interaction; NS = not significant.

Foliar Nutrients

For the initial collection, samples were kept separate for each family. The residue treatments had little effect on foliar concentrations of macronutrients. The K effect was significant with the trees in the nil residue treatment having the lowest foliar K concentrations and trees in the double slash treatment having the highest concentration (Table 5). The converse situation occurs for foliar Na concentrations which were significantly higher in the nil residue treatment than all other treatments. There were significant differences in foliar N, P, Ca, Mg, Na, and Zn concentrations between the families. The residue treatment by family interaction was not significant for any of the nutrients.

Foliar concentrations of P, K, Ca, and Mg were above the critical concentrations for both samplings, indicating that deficiencies of macronutrients were not a factor limiting tree growth (Table 6). Foliar N concentrations declined markedly between ages 27 and 39 months, especially in the nil residue treatment, suggesting that N nutrition over time may play an important role in maintenance of long-term site productivity. The addition of inorganic P fertiliser has not significantly improved foliar P concentrations at this age. Foliar K concentrations, although above critical concentrations, are lowest in the nil residue treatment.

Table 5. Effect of residue management on foliar nutrient concentrations of hybrid pines

Treatment	Foliar nutrient concentrations (%)											
	N		P		K		Ca		Mg		Na	
	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
BL_0	.90	.48	.12	.10	.39	.39	.35	.18	.14	.09	.10	.11
BL_2	.87	.57	.12	.09	.48	.46	.34	.18	.15	.09	.08	.07
BL_3	.91	.61	.11	.11	.59	.62	.33	.22	.15	.12	.07	.07
BL_2+ Leg	.94	.64	.12	.08	.53	.46	.34	.19	.14	.10	.08	.07
BL_2 - Weeds	.88	.55	.12	.09	.57	.51	.33	.17	.14	.10	.07	.08
BL_2-P	.89	.55	.10	.09	.53	.63	.34	.18	.14	.11	.07	.07
LSD p=0.05	NS	.071	NS	NS	.11	NS	NS	NS	NS	.02	.02	.02

[(a)] August 1998; [(b)] August 1999.

Table 6. Surface biomass at ages 0, 30 and 39 months in residue management treatments

Treatment	Age (months)	Logging residue plus litter (t ha^{-1}) < 1mm Fraction	> 1mm Fraction	Total
BL_0	0	6.37	2.61	8.98
	30	2.64	1.76	4.40
	39			2.84
BL_2	0	25.28	25.47	50.75
	30	11.18	19.43	30.61
	39			13.93
BL_3	0	56.98	84.45	141.43
	30	17.56	27.23	44.79
	39			24.89
BL_2+ Leg	0	22.73	33.65	56.38
	30	8.57	9.46	18.03
	39			12.32
BL_2-Weeds	0	25.33	32.65	57.98
	30	12.38	32.70	45.08
	39			21.18
BL_2-P	0	34.88	38.99	73.87
	30	14.85	22.77	37.62
	39			33.96
Mean	0	28.59	36.30	64.89
	30	11.20	18.89	30.09
	39			18.19

Decomposition of Residue

There was a marked reduction in the quantity of litter plus residue on the soil surface during the 39 months since establishment (Table 6). The reduction was most marked in the < 1mm fraction. Weeds contributed only a small proportion to the total surface biomass. Legume establishment has been variable and unsuccessful.

There was a strong positive, linear relationship (r^2 = 0.91) between soil moisture and quantity of residue at 30 months. At the time of sampling the soil was quite dry with gravimetric moisture contents in the range 7-12%. This relationship was poor (r^2 = 0.11) in the 39 month samples which were collected after rainfall and the soil moisture contents in the range 20-

25% (approaching field capacity). The litter plus logging residues apparently reduced evaporation from the soil surface during dry conditions.

The stand was thinned at 39 months to 694 stems ha^{-1} to remove the less vigorous and poorly formed stems with due regard to spacing. Estimates of aboveground biomass and nutrient content for thinned and remaining stems are summarised in Table 7 and for the aboveground tree components in Table 8. The distribution of biomass was as follows: wood 45%, foliage 28% and bark plus branches 26%. The proportion of the nutrient pools in the various tree fractions is vastly different from the biomass proportions. For N, 63% is in the foliage, compared with 10% in the wood (cf biomass figures of 28% and 45% respectively). For P and K approximately 55% is in the foliage and 22% in the wood whereas for Ca, 73% is contained in the foliage and only 11% is in the wood.

While 38% of the stems were thinned they contained only 26% of the aboveground biomass and between 25% and 28% of the nutrients in the biomass. There was no litter fall observed at age 39 months.

Table 7. Estimated above ground biomass and nutrient content of thinnings and remaining trees at age 39 months

Treatment	Stand component	Biomass t ha^{-1}	N (kg ha^{-1})	P	K	Ca	Mg
BL_0	Stand	9.89	22.5	3.7	16.7	20.6	7.1
	Thinnings	3.47	7.8	1.4	5.2	7.1	2.6
	Total	13.36	30.3	5.1	21.9	27.7	9.7
BL_2	Stand	12.79	29.1	4.7	22.4	26.9	8.9
	Thinnings	4.50	10.2	1.7	7.3	9.3	3.3
	Total	17.29	39.3	6.4	29.7	36.2	12.2
BL_3	Stand	14.94	34.1	5.3	26.7	31.4	10.4
	Thinnings	5.36	12.2	2.0	9.0	11.2	3.8
	Total	20.29	46.3	7.3	35.7	42.6	14.2
BL_2+ Leg	Stand	12.09	27.5	4.4	21.0	25.3	8.5
	Thinnings	4.14	9.4	1.6	6.6	8.6	3.0
	Total	16.23	36.9	6.0	27.6	33.9	11.5
BL_2-Weeds	Stand	17.19	39.3	6.1	31.1	36.2	11.8
	Thinnings	6.74	15.3	2.4	11.6	14.1	4.7
	Total	23.92	54.6	8.5	42.7	50.3	16.5
BL_2-P	Stand	10.82	24.6	4.0	18.6	22.7	7.6
	Thinnings	3.86	8.7	1.5	6.0	7.9	2.9
	Total	14.68	33.3	5.5	24.6	30.6	10.5

Table 8. Biomass and nutrient content of above ground tree components at age 39 months (prior to thinning)

Parameter	Biomass	Tree component N (kg ha^{-1})	P	K	Ca	Mg
Wood	7 910	6.7	1.5	6.7	4.2	2.1
Bark	2 750	5.1	0.8	4.5	2.1	1.5
Branch	1 920	3.0	0.5	2.3	3.8	1.3
Foliage	5 050	25.4	3.6	16.8	26.8	7.5
Total	17 630	40.2	6.4	30.3	36.9	12.4

Discussion

With more emphasis on improved productivity and profitability of plantations in Queensland, intensive silvicultural practices are being employed, for example improved genetic material is being deployed and more attention is being placed on implementing optimum site specific silvicultural prescriptions. These measures, which result in increased plantation productivity, are expected to increase nutrient demands on the site. As sustainable forest management is a goal, this study is aimed at helping to provide a scientific basis for identifying desirable inter-rotation management practices. The nutrient input-output budgets provide essential data for identifying potential long-term nutrient problems.

In this study, on an infertile site, retention of harvesting residues has resulted in improved plantation productivity. This result is similar to the 5-year results from a trial in Mississippi, USA where, on a low nutrient status site, litter and logging debris retention improved volume production of loblolly pine (*P. taeda*) by 40% (Tiarks *et al*. 1999). In a comparable trial with *P. taeda* in Louisiana, retention of litter and logging residue on a site high in nutrients and organic matter did not improve tree growth. O'Connell *et al.* (1999) found a similar pattern in young eucalypt plantations in southwestern Australia with no growth response to retained litter and residues on a relatively fertile site but significantly increased growth on a less fertile site.

In the Queensland trial, foliar N concentrations of the hybrid pines declined markedly between ages 2.2 and 3.2 years, especially in the nil residue treatment, suggesting that N may play an important role in the maintenance of long-term site productivity of these infertile sites. Retention of harvesting residues on site has resulted in improved plantation productivity. The mechanisms resulting in this improvement have not been clearly identified and are likely to include enhancement of soil physical, chemical and biological properties. These results indicate that improved moisture conditions under retained residues are a contributing factor, but several other mechanisms are also likely to be involved. Identifying and interpreting the significance and application of these factors to operational forestry present a challenge. Addressing this challenge is necessary if a reliable prognosis for the long-term maintenance of productivity of exotic pine plantations in Queensland is to be achieved.

Conclusions

The major findings of this study are:

The nutrient losses due to harvesting and the removal of litter and logging residue combined were significant and in some cases high in relation to the total and available nutrient pools in the ecosystem.

Survival of F_1 hybrid pines was not affected by the residue management treatments.

At 39 months, tree volume was improved by 31% as a result of retaining litter and logging residues; doubling the quantity of residues retained improved volume growth by a further 30%; complete weed control improved tree volume by 52% over residue retention alone; legumes had no effect and the slash retention without P treatment was the same as nil residue plus P treatment.

The increased tree growth was accompanied by a corresponding increase in nutrient uptake in tree biomass.

Major differences were found in the growth of different families but all families responded in a similar fashion to the residue treatments.

Foliar nutrient concentrations were above critical concentrations and little affected by the residue management treatments. Significant differences existed between families.

Foliar N concentrations declined markedly between ages 2.2 and 3.2 years, especially in the nil residue treatment, indicating that N may play an important role over time in the maintenance of long-term site productivity.

There was a marked reduction in the quantity of residue remaining by age 39 months and this reduction was most marked in the < 1 mm residue fraction.

In dry conditions residue retention increased moisture levels in the surface soil.

Acknowledgements

The research described forms part of the Queensland Forest Research Institute's programme funded by Queensland Department of Primary Industries. Some of the laboratory studies associated with this work were facilitated by the Institute's involvement in the Cooperative Research Centre for Sustainable Production Forestry.

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