New Zealand Forest Site Management Cooperative

WHOLE TREE THINNING TRIAL SERIES (AK1053/1, RO2093 and WN379): RESULTS TO FIVE YEARS AFTER TREATMENT

By

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ABSTRACT

A series of three trials were established in 1986 and 1987 to quantify the effect of different thinning techniques on residual crop growth and nutrition, at sites with low, medium and high nitrogen availability. The site with low nitrogen availability was on recent sands in the sand dune plantations of the Woodhill Forest; the site with medium nitrogen availability was on Tarawera scoria in the Tarawera Forest; and the site with high nitrogen availability was on deep Taupo pumice in the Crohane Forest. The thinning treatments included: thin to waste; production thin; and whole tree thin. A split plot design was utilised for evaluating tree response to nitrogen fertiliser additions, with split plot treatments being "with" and "without" the addition of nitrogen fertiliser.

Retention or removal of thinning slash had no significant effect on foliar N concentrations at any of the three sites. After five years there was no significant growth response to retention or extraction of thinning slash at any of the sites. Additions of nitrogen stimulated significant growth responses at the site with low nitrogen availability; but not at sites with medium or high N availability.

KEYWORDS:

Pinus radiata, nitrogen, thinning, biomass, growth response, fertiliser

INTRODUCTION

Radiata pine is the main plantation species grown in New Zealand. It grows to a size suitable for clearfelling in around 30 years and is generally planted at stockings between 800 and 1500 stems per hectare. A stand is usually thinned at least once, down to a final crop stocking of anywhere between 200 and 500 stems per hectare.

The timing of a thinning operation and operation utilisation level often depends on whether there is market available for the products, ie. posts, poles or pulp. Stands are usually thinned to waste during the first thinning. Second thinnings may be either another waste thin or a "production" thin. The stand is usually held longer prior to a production thinning so that a larger piece size is available for the market. Production thinnings generally occur between plantation age 10 and 15 years.

Production thinning traditionally involves delimbing the tree motor-manually on-site, followed by removal using some mechanical means, eg. rubber-tyred skidder, Bell logger, or tractor. In Scandinavia and North America, the same operation would usually be performed by a feller processor, with reduced costs, greater through-put, less labour turnover and fewer accidents than the motor-manual method traditionally used in New Zealand.

New Zealand has been slower than Australia to adopt mechanised thinning methods. Some of the factors contributing to this are: the steep nature of much of the recently afforested land; radiata pine branches are considered to be thicker and "tougher" than those of the tree species for which the machinery was originally developed; the high capital cost of the machinery; and the on-going maintenance costs. However, in recent years, a range of machines have been imported and trialed in New Zealand, and if they prove to be cost effective, they may very likely become more common place.

Nutritional considerations

The distribution of branch material on the site will depend on the method of thinning and the type of machine used. Some feller-processors tend to leave the branches distributed uniformly across the site, eg. motor-manual delimbing. Others operations, eg. grapple skidder and flail or gate delimbing systems, may concentrate the branches at a central point away from the stump. Thus "whole tree" harvesting may occur when there is no intention of utilising the branch material. Single-grip harvesters tend to concentrate the branch material on the thinning tracks. Residues from single-grip harvesters may be used as a road bed to reduce compaction of wet ground by harvest and forwarding equipment.

In the Northern Hemisphere, whole trees, including branch material and foliage may be chipped for utilisation as heating fuel or material for the board industries (Jonsson 1987). The branch material may also be collected and chipped after a thinning operation, leaving virtually no slash on the site to decompose and supply valuable nutrients to the residual trees, which has the same effect on the site as whole tree thinning.

Madgwick (1977) stated that the branches and foliage contain a large (usually more than 50%) proportion of the total nutrients in the above ground biomass. Many of New Zealand's exotic afforestation sites are marginal or low in one or more nutrients (Will, 1975). It is well established that radiata pine productivity on coastal sands is markedly increased by the addition of nitrogen (Beets and Madgwick, 1987) and when a stand is thinned there is a high demand for nitrogen for crown expansion (Peter Beets, *pers. comm.*). Nitrogen is most likely to limit growth during periods of rapid crown expansion, particularly on sites with low N availability. Thus removal of branches and foliage would reduce on-site nutrient cycling, reduce site nutrient capital, and may reduce post-thinning growth rates. In Norway, Tveite (1983) had shown that a growth reduction of between 7 and 10 % occurred in residual trees following whole tree thinning.

Kukkola and Mälkonen (1997) evaluated Norway spruce growth following various thinning regimes in Finland. He found that production thinning, where slash was retained on site, consistently produced higher volume yields than whole tree thinning over a 15 year period. The addition on NPK fertiliser enhanced growth in both treatments to the same relative extent.

Because of the increased likelihood of mechanised harvesting techniques being used in New Zealand in the near future on sites that are likely to be limiting in one or more nutrients, a series of three trials were established in 1986 and 1987. The main objective of the trials was to quantify the effect of different thinning techniques on the residual crop tree growth and nutrition, on sites with low, medium, and high nitrogen availability. An earlier paper summarised growth and nutrition in the first year after trial establishment (Hunter *et al.* 1989). This report presents the results for the three trials to five years after the trial establishment.

OBJECTIVES

The objectives of the trial series were to:

- determine whether the growth of residual crop trees was affected by thinning intensity, ie. removing different amounts of tree biomass during thinning operations; and,

- determine whether nitrogen availability was a major factor limiting growth at each site, by application of nitrogen fertiliser; and indirectly, whether nitrogen availability was limited by greater thinning intensity, and therefore the reason for differences in crop tree growth.

SITE SELECTION AND THINNING METHODS

The details for each trial site are summarised in Table 1.

Table 1. The trial details at each site

Forest	*Woodhill*	*Tarawera*	*Crohane*
Location = Compartment No.	226/2/2	1780 & 201*	200 & 220
Plant year (tree age when trial established)	1976 (10)	1975 (12)	1975 (12)
Crop stocking prior to thinning treatments	1600 sph	750 sph	880 sph
Residual crop stocking after thinning	750 sph	400 sph	300 sph
Method of extraction used	Hand	Skidder	Skidder

sph = stems per hectare
* Neighbouring compartments of Tarawera and Rotoiti Forests are used for the trial

Woodhill (AK 1053/1)

A trial was established in a first rotation 10 year old radiata pine stand in Cpt 226/2/2 at the northern end of Woodhill Forest (70 km north west of Auckland). The soil type is recent sand on stabilised coastal sand dunes close to the Tasman Sea. Topography of the trial site is flat to gently rolling, and is typical of much of the area.

The stand was planted in 1976 and was tended on a "pole" regime ie. no prune and a late first thin. Therefore the stand was still at original crop stocking of 1600 sph when the trial was established in the autumn of 1986. The trial area was thinned using chainsaws and the different extraction methods

were imposed manually. Residual crop stocking was 750 sph. Average piece size was < 0.1 m^3; therefore, it was decided to remove the stem and whole trees by hand after they were cut into manageable size pieces. Plot sizes could thus be kept to a minimum and the overall size of the trial reduced, since there was no need for machinery access avenues to be established. Hand removal minimised the amount of site disturbance to the area.

Tarawera (RO 2093)

A second trial was established in the spring of 1987 in a first rotation stand planted in 1975, bounding neighbouring Cpt 1780 of Tarawera Forest and Cpt 201 of Rotoiti Forest (50 km southeast of Rotorua). It will be referred to as Tarawera Forest in this report. The soil type is derived from a shallow mantle of Tarawera scoria (gravelly pumice - 100 years b.p.) over Taupo pumice. The stand had been waste thinned from 1800 sph to 750 sph in 1982 and was unpruned. The residual crop stocking after the trial thinning was 400 sph. A local forest gang used chainsaws for the thinning operation, and a rubber tyred skidder was used for extraction. There were a number of small steep-sided volcanic mounds throughout the area, which caused some manoeuvring difficulty for the skidder. The trial layout involved leaving access avenues between every second row of plots so that any one plot could be serviced from at least one side for extraction of thinning material. These procedures kept site disturbance to a minimum, and avoided compaction of skid trails within the plots.

Crohane (WN 379)

A third trial was established during the autumn of 1987 bounding Cpts. 200 and 220 of Crohane Forest (midway between Napier and Taupo) on a first rotation stand after pasture. The site was sloping 10-15° to the south in half the plots and the remainder of the trial area was on a relatively flat river terrace. The soil type is a deep Taupo pumice (2000 years b.p.) overlying mudstone. The stand was planted in 1975 at 1500 sph and thinned to waste in 1980 to 880 sph. Pruning to 6 metres on 300 sph had been carried out prior to trial establishment. The thinning operation was conducted using a chainsaw gang and extraction was by means of a rubber-tyred skidder. The residual stocking after trial thinning was 300 sph.

Plots were located within one or two plot widths from the road edge. This provided sufficient space adjacent to plots for skidder operations and thinning removals, and reduced disturbance to the plots.

SITE FERTILITY

The atlas of radiata pine nutrition in New Zealand (Hunter *et al.*, 1991) classifies forest sites as either deficient, marginal or satisfactory for a number of elements; and predicts a low, medium or high probability of encountering a nutrient deficiency on a site.

The nitrogen nutritional status at the time of trial establishment was compared with predictions of the nutritional atlas for each of the sites, and are presented in Table 2.

Table 2. Nutritional N status (based on 1 year old foliage) at time of trial establishment and the corresponding map colour and average fertility for each site (from Hunter *et al.*, 1991).

SITE	*Atlas Colour (Page 6)*	*Predicted Average N Fertility*	*% N at Trial Establishment*
Woodhill	Dark orange	Marginal - Deficient	1.25% N
Tarawera	Bright yellow	Marginal	1.45 % N
Crohane	Dark green	Satisfactory	1.48% N

TREATMENTS:

The core design for the trials involved three types of thinning treatments:

1. *WASTE* - where the trees were felled and left on site.
2. *PRODUCTION* - where the trees were felled and delimbed and the stem removed. The branches, tops and foliage remained on site.
3. *WHOLE TREE* - where the entire tree (stem, branches and foliage) were removed off site.

These thinning treatments were applied to split plots, with and without nitrogen additions.

A complete list of the treatments at each trial site is presented in Table 3.

Table 3. Treatments at each site (✓ = present × = not present). Shaded area represents the "core" treatment design.

Treatment	*Woodhill*	*Tarawera*	*Crohane*
Waste thin	✓	✓	×
Waste thin + N	✓	✓	×
Production Thin ¥	✓	✓	✓
Production Thin + N	✓	✓	✓
Whole Tree Thin	✓	✓	✓
Whole Tree Thin + N	✓	✓	✓
Unthinned §	✓	✓	✓
Plus Lotus	×	✓	✓
Plus Lupin	✓	×	✓
Additional Slash	✓	✓	×

¥ Tops < 10cm diameter at Woodhill and Tarawera, and tops <7.5 cm diameter at Crohane were left on site

§ Woodhill had no first thin so was standing at the planted stocking (1600 sph). Crohane and Tarawera were both thinned to waste prior to trial establishment therefore their "unthinned" treatments had stockings of 880 and 750 sph respectively).

Additional treatments were included at some of the trial locations, but are not discussed in this report. These include:

Untreated control (unthinned, unfertilised).
Additional slash (where thinning slash was dumped, remained unthinned).
Yellow lupin (*Lupinus arboreus* Sims) and/or Maku lotus (*Lotus uliginosus* "Grasslands Maku") oversowing as an alternative source of N.

Each treatment was replicated three times and randomly allocated to the trial plots. Table 4 shows the sizes of the inner and outer plots and the number of measurement trees per plot for the thinned and unthinned treatments.

Table 4. Plot sizes for each trial

Trial Site	*Woodhill*	*Tarawera*	*Crohane*
Inner plot size (ha)	15 x 15 m	22 x 22 m	25 x 25 m
Outer plot size (ha)	25 x 25 m	42 x 42 m	41 x 41 m
Measurement trees/ plot - thinned (unthinned)	17 (32)	19 (25)	19 (55)

At Woodhill four larger plots of 38 x 38m with an inner measurement plot of 28 x 28m were established in order that Stage II of that particular trial could be continued when a second thinning would take place in late 1991. Three of these plots were the waste plus N treatment, and the fourth an unthinned plot.

METHODS:

Fertiliser Application

Urea fertiliser (46%N) was hand broadcast at a rate of 200 kg N/ha over each of the "plus nitrogen" plots, immediately after thinning was completed.

Nitrogen Pools

To quantify the amount of nitrogen in various ecosystem components at each site, soil samples, forest floor litter samples, and above-ground tree biomass samples were collected prior to thinning. Understorey vegetation was not included as it was confined to the odd scattered pampas grass (*Cortaderia selloana*) clump at Woodhill; light shrubby hardwoods at Tarawera; and grazed pasture with a small amount of blackberry at Crohane.

A. Soil sampling

Soil samples from across the entire trial area were taken with a Hoffer tube from the top 10 cm of mineral soil, and analysed for total nitrogen using methods described by Nicholson (1984).

B. Forest floor sampling

To account for any site variation, seven randomly located 0.25m^2 litter samples were removed from the forest floor down to the mineral soil in each of the three unfertilised plots per thinning treatment (ie 63 squares at Woodhill and Tarawera and 42 at Crohane), dried at 70°C, weighed dry, finely ground using a Wiley mill, and then analysed for total N and P concentrations (Nicholson, 1984). Nitrogen content and oven-dry quantity of litter were calculated on an individual plot basis, averaged over the number of plots used at each site, and then expanded to a per hectare basis.

C. Above-ground biomass

(i) Field procedure

To quantify the amount biomass and nitrogen removed during thinning, destructive sampling of ten trees was performed prior to the thinning operation. Sample trees were selected randomly from strata representing the range of diameters present at each site. Sample trees were felled, total height, diameter at breast height and height to the first green branch was measured. The green crown length was derived using the total height minus the height to first green branch, and divided into 5 zones of equal length (Hunter, unpublished data). All the dead branches below the first green branch plus any other dead branches present from the green zones were removed and combined together for weighing. A representative branch from each of the zones was selected while still attached to the tree. This was identified by a numbered tag. All the branches in each zone (including the tagged branches) were pruned flush with the stem (one zone at a time) and weighed together in their respective zones. The sample branch was then removed from the pile and weighed separately. This branch was taken back to the laboratory for further sub-sampling and chemical analysis. The dead branches were similarly weighed in the field and a sample branch selected and retrieved for further sub-sampling and analysis. The stem was cut into manageable lengths and weighed. Five to seven, 3 cm thick disks were cut from the stem and also weighed and labelled with an indelible pencil. These were returned to the lab for further processing and analysis. All wet weights of the tree components were recorded on field forms.

(ii) Laboratory procedure
In the laboratory each of the green sample branches was subdivided into age classes of foliage (1 year old, 2 year old, 3 year old, 4 years plus), and branchwood. Stem disks were subdivided into bark and wood. The dead branch was cut up and kept as a complete sample. The samples were dried at 70°C, weighed, finely ground, and chemically analysed for total N and P.

(iii) Biomass estimates
The Genstat (Lawes Agricultural Trust, 1980) program was used to calculate the wet/dry weight ratio for the tree components, and a component proportion ratio from the field samples and dry weights of the subsamples. This was then converted to a per hectare basis for the thinned and unthinned plots using the basal area ratio method described by Madgwick (1981) such that :
plot weight = (Σ sample tree weight) / (Σ sample tree basal area) x (plot basal area).

Nitrogen and phosphorus contents were calculated using the oven dry weights of wood and foliage and the corresponding nutrient concentration from tissue analysis.

The amount of stemwood contained in the top portion that was left on site after production thinning was estimated at each site. During the thinning operation, ten tree tops were collected at random; the corresponding DBH of the stem removed was measured; branches were removed and the stem weighed green in the field. The wet/dry weight ratio was calculated from the biomass and used to convert the green sample to a mean dry weight per stem. The number of stems per hectare removed multiplied by the mean dry weight gave an estimate of the amount of stemwood remaining on site after production thinning.

Trial measurement

All measurement trees in each plot were measured for diameter at breast height (1.4 m above ground) and a selection of ten trees per plot measured for total height. The trials were measured immediately after trial establishment, and every winter for the next three years and then again after five years. The data was entered onto the FRI Permanent Sample Plot (PSP) system.

Foliage sampling

Foliage was collected from a random selection of 7 to 10 trees per measurement in February or March for the first two years after treatment at Crohane and Tarawera, and for the first 3 years at Woodhill. One-year-old foliage was sampled using shot guns and placed in paper bags. Chemical analysis of the tissue was conducted using methods described by Nicholson (1984).

Additional foliage samples were collected at Crohane and Tarawera 8 years after treatment (1995), but not at Woodhill since another thinning had taken place in 1991 and Stage II of the trial had been initiated.

Statistical analysis

Statistical analysis of biomass and corresponding nutrient data was conducted using Genstat (Lawes Agricultural Trust, 1980) as described above. Analysis of variance was conducted for 5-year increment in plot basal area, mean top height and volume using the SAS statistical package (SAS Institute, 1982). Analysis of variance of foliage nitrogen concentrations and a Duncan's Multiple Range Test (SAS Institute, 1982) were conducted to determine whether the treatments were significantly different.

RESULTS

Site nitrogen contents

Soil nitrogen at the Woodhill site was very low (Table 5). The Tarawera site contained more total N in the soil than Woodhill but much less than that of Crohane, which had the highest amount of the three sites.

The amount of forest floor litter was similar at Crohane and Tarawera, where the stands had virtually closed canopy prior to thinning. This was in contrast to Woodhill stands, which were more open.

Above-ground biomass of trees at Crohane contained considerably more kg N/ha prior to thinning than either Woodhill or Tarawera, which had similar amounts (Table 5). Nitrogen content differences were a function of the amount of biomass present in the trees and different nitrogen concentrations present in the tree components on each site (Hunter, unpublished data).

Table 5. Concentration of total nitrogen in the top 10 cm of mineral soil; the amounts of nitrogen (kg/ha) in the forest floor; and N and P content in trees prior to thinning (refer also N data from Hunter *et al.* 1989; P data from Hunter, unpublished data).

Site	*Soil N Total N %*	*Forest Floor N kg N/ha*	*N in trees kg N/ha*	*P in trees kg P/ha*
Woodhill	0.01	78	260	45
Tarawera	0.15	235	268	64
Crohane	0.63	240	392	83

The amount of phosphorus contained in the trees is presented in Table 5 for background comparative information. However, phosphorus will not be discussed in this report, as it was our objective to look at the N status of the trials and how they are affected by the thinning treatments. Phosphorus fertility is expected to be sufficient at all three sites, based on experience and as predicted by the atlas of radiata pine nutrition for New Zealand (Hunter *et al.* 1991).

The nitrogen content and dry weight of the tree biomass material before and after whole tree and production thinning at each site is shown in Table 6. Note that the amount of material removed by whole tree thinning should correspond to the amount of material added to the site after a waste thinning operation. In this trial series, any difference between the whole tree thinning removals and waste thinning additions were due to plot-by-plot variation.

Table 6. Dry weight and nitrogen content of the stand (kg/ha) at the three sites before and after thinning showing the amount of material removed off site and that added to the forest floor (from Hunter, unpublished data).

	Above-ground biomass - Before Thinning (kg/ha)		*Above-ground Biomass - After Thinning (kg/ha)*		*Amount Removed Off Site (kg/ha)*		*Slash Retained On Site (kg/ha)*	
SITE	*Weight*	*N content*	*Weight*	*N content*	*Weight*	*N content*	*Weight*	*N content*
WHOLE TREE THINNED								
Woodhill	140363	260	77199	142	63164	118	0	0
Tarawera	167305	268	93413	163	73893	105	0	0
Crohane	185195	392	72606	154	112589	238	0	0
PRODUCTION THINNED								
Woodhill	140363	260	77199	142	41732	37	21421	81
Tarawera	167305	268	93413	163	45317	43	28574	62
Crohane	185195	392	72606	154	76720	78	35868	160

Growth 5 years after trial establishment

Tree DBH and total height were measured for each plot. The FRI PSP system was used to convert tree measurements to basal area and volume estimates on a per hectare basis. Basal area, height, and volume for treatments at each site and for each measurement year are presented in Appendices A-C.

(i) Basal area

Thinning treatments had no significant effect on basal area increment over the 5-year period. At Woodhill and Crohane there was a response to urea additions (Table 7).

Table 7. Mean 5-year basal area increment (m^2/ha) for each treatment at each site.

Treatment	*Woodhill*		*Tarawera*		*Crohane*	
Waste	12.1		20.9		N/A	
Production	11.3		15.4		19.5	
Whole Tree	11.7		18.1		17.5	
Waste Plus N	17.5		16.7		N/A	
Production Plus N	15.4		20.3		19.2	
Whole Tree Plus N	15.9		17.6		22.4	
SIGNIFICANCE	Fert	0.0380	Fert	NS	Fert	0.0439
Pr > F	Thin	NS	Thin	NS	Thin	NS
	Fert*Thin	NS	Fert*Thin	0.0110	Fert*Thin	0.0255

NS = Not significant; N/A = Treatment not included at this site

The fertiliser X thinning interaction at Tarawera and Crohane indicated that the response to adding fertiliser varied by the thinning treatments. At Tarawera, fertiliser increased basal area increment after production thinning, but not after waste or whole tree thinning. At Crohane, fertiliser increased basal area increment following whole-tree thinning, but not after production thinning. The significant fertiliser X thinning interaction at Crohane suggests thinning slash increased N availability at this site; although foliar N results from Crohane do not support this conclusion. The Tarawera results do not support this conclusion either.

(ii) Mean Total Height

Thinning treatments did not affect height growth at any site. At Woodhill, the addition of fertiliser had a significant effect on height growth over the 5-year period. Urea additions did not affect height growth at Tarawera and Crohane.

Table 8. Mean 5-year total height increment (m) for each treatment at each site.

Treatment	*Woodhill*		*Tarawera*		*Crohane*	
Waste	4.3		8.6		N/A	
Production	5.1		8.7		8.7	
Whole Tree	5.2		9.1		9.7	
Waste Plus N	6.4		8.5		N/A	
Production Plus N	6.5		8.3		9.2	
Whole Tree Plus N	5.7		8.5		8.8	
SIGNIFICANCE	Fert	0.0150	Fert	NS	Fert	NS
Pr > F	Thin	NS	Thin	NS	Thin	NS
	Fert*Thin	NS	Fert*Thin	NS	Fert*Thin	NS

NS = Not significant; N/A = Treatment not included at this site

(iii) Volume

Thinning treatments had no significant effect on volume increment over the 5-year period (Table 9). The addition of fertiliser only had a significant effect at Woodhill.

Table 9. Mean 5-year volume increment (m^3/ha) for each treatment at each site.

Treatment	*Woodhill*		*Tarawera*		*Crohane*	
Waste	113.9		281.7		N/A	
Production	116.8		213.3		234.2	
Whole Tree	122.9		259.7		226.3	
Waste Plus N	177.9		234.8		N/A	
Production Plus N	162.8		255.0		240.6	
Whole Tree Plus N	157.9		234.9		262.2	
SIGNIFICANCE	Fert	0.0509	Fert	NS	Fert	NS
Pr > F	Thin	NS	Thin	NS	Thin	NS
	Fert*Thin	NS	Fert*Thin	NS	Fert*Thin	NS

NS = Not significant; N/A = Treatment not included at this site

Foliar N concentrations

Foliage from the trials was collected for tissue analysis 1 and 2 years following fertiliser application at Tarawera and Crohane; and after 1, 2, and 3 years at Woodhill. A trial-wide foliage sample was collected prior to thinning and fertilising, which provided an initial estimate of fertility for each site. An interpretation of pre-trial nutritional status for N, based on the nutritional atlas of Hunter *et al.* (1991) (Table 2), indicates that Woodhill N fertility was marginal (1.25 % N), and both Tarawera and Crohane were marginal to adequate (1.45 and 1.48 % N, respectively) (Table 10).

Table 10. Foliar N concentration (%) for the years following trial establishment for each site. Means followed by the same letters within a column are not significantly different (p=0.05).

	N Concentration (%)							
TREATMENT	*N Initial*		*Year 1*		*Year 2*		*Year 3*	
WOODHILL								
Waste minus N	1.25		0.96	c	1.13	a	0.99	a
Production minus N	1.25		0.92	c	1.01	a	0.94	a
Whole Tree minus N	1.25		0.98	c	1.08	a	0.95	a
Waste plus N	1.25		1.53	a	1.10	a	1.09	a
Production plus N	1.25		1.49	a	1.18	a	1.08	a
Whole Tree plus N	1.25		1.27	b	1.08	a	0.95	a
TARAWERA								
Waste minus N	1.45		1.39	b	1.25	ab		
Production minus N	1.45		1.38	b	1.34	b		
Whole Tree minus N	1.45		1.42	b	1.32	ab		
Waste plus N	1.45		1.71	a	1.49	ab		
Production plus N	1.45		1.65	a	1.35	a		
Whole Tree plus N	1.45		1.61	a	1.42	ab		
CROHANE								
Production minus N	1.48		1.54	a	1.47	a		
Whole Tree minus N	1.48		1.56	a	1.49	a		
Production plus N	1.48		1.57	a	1.46	a		
Whole Tree plus N	1.48		1.65	a	1.39	a		

DISCUSSION

Site nitrogen contents

Several authors have estimated the amount of N in Woodhill Forest soil (Baker *et al.*, 1986 and Gadgil, 1976). Gadgil (1983) showed that sand dune sites such as this have low reserves of nitrogen in the soil, and it is present in mostly unavailable forms to the trees.

These relative amounts of N correspond to the results from the three intensive harvesting trials on similar sites reported by Smith *et al.* (1997), although the mineral soil N concentration at Crohane was even higher than that of the Kinleith site.

The amount of N added to the forest floor during a production thinning (eg 81 kg/ha for Woodhill) is greater than the amount removed from the site with commercial materials (eg 81 kg N in 21.4 tonnes of thinning slash compared to 37 kg N in 41.7 tonnes of biomass removed in harvest at Woodhill). This is because thinning slash is mainly N-rich branch and foliage material versus N-poor stem wood. Stem wood (including bark) removals by production thinning contained approximately 50% of the amount of N that was present in the foliage and branches retained on site, although the stemwood accounted for around twice as much of the biomass.

To replace the amount of N removed from the site by whole tree thinning, a forest manager would need to apply up to 238 kg N/ha at Crohane and less than half of that at Woodhill and Tarawera. If the stand had been waste thinned, all N in thinnings would be retained on site.
By production thinning, 60-70% of the N in the thinned trees is returned to the site via foliage and branches (= amount added by production thin / amount removed by whole tree thin).

Traditionally, the recommendation for N application after thinning is 200 kg N/ha (as urea). After a waste thinning operation, Crohane should be adequately supplied with N, forest managers may not need to fertilise. At Tarawera and Woodhill however, if the site was whole tree thinned it would lose 105 and 118 kg N/ha respectively, and about 60-80 kg N/ha would be returned by the addition of slash during production thinning. A forest manager should certainly consider fertilising on sites such as these, since they would have a high probability of a volume response to N additions, especially at Woodhill.

Basal area growth

The greatest basal area gain at Crohane was consistently in the whole tree thinning +N treatment (Figure 1b). These results do not agree with Finnish studies conducted by Kukkola and Mälkonen (1997), who found that over a 15 year period, whole tree thinning +N produced lower volume growth responses compared with production thinning +N. However, note that during the first 4 years after trial establishment at Crohane, the whole tree thinned treatment without fertiliser has less basal area increment than the production thinned treatments. This response is similar to those observed by Tveite (1983).

Foliar N response

The three sites selected for this study were on the same soil types as the three intensive harvesting trials reported by Smith *et al.* (1997). Stands at the Woodhill and Crohane sites were similar to stands at Woodhill Forest intensive harvesting trial AK1029 and Kinleith Forest trial FR188 in their response to fertiliser additions (Table 10), and in their pre-fertiliser N fertility levels, as predicted by the nutritional atlas (Hunter *et al.*, 1991). Woodhill, as predicted, has a high probability of being N deficient in the future, which proved correct within two years after nitrogen fertiliser was applied to the site. Crohane had a low probability of becoming deficient in the future, which was confirmed by

foliage samples 8 years after fertiliser application, collected in 1995, that showed the average N concentration, regardless of treatment, to be around 1.47 % N.

Tarawera on the other hand, had an average foliar N concentration of 1.18 % N eight years after fertiliser application, which is considered to be in the deficient range. This does not correspond to results reported by Smith *et al.* (1997), although the intensive harvesting trial at Tarawera is considerably younger (age 9). These results support the colour code of yellow in the nutritional atlas for the Tarawera scoria soils since the stand foliar levels dropped to a low level (1.2 % N), but did so more than 5 years after low levels were reached at Woodhill.

Older trees are known to respond differently over time than younger trees on certain soil types. It should be noted that most forest managers would not normally sample foliage on trees older than 20 years, since they would not consider applying fertiliser for economic reasons. The database supporting the nutritional atlas (Hunter *et al.* 1991) was based on younger trees than we are considering in this report.

CONCLUSIONS

Nutritional atlas interpretation

Based on this study, we recommend that codes (and colours) describing fertility for N in the radiata pine nutritional atlas for New Zealand (Hunter *et al.* 1991) be interpreted as follows:

Deficient (Orange): Fast decline of foliar N reaching deficient levels (<1.2 % N) during initial canopy closure (about age 3-5 years). A substantial response can be expected following fertiliser additions, as indicated by foliar N and growth responses at Woodhill Forest.

Marginal (Yellow): Slow decline of foliar N, marginal to satisfactory N concentrations during initial canopy closure, but deficient later in the rotation (about age 20). Small to no gains to N fertiliser, shown by Tarawera Forest foliar N and growth.

Satisfactory (Green): Foliar N remains above marginal levels during initial canopy closure, and not predicted to become deficient. No response to fertiliser additions, as shown by Crohane foliar N and volume results.

The effect of thinning slash on the site

This series of trials showed no significant growth response or change in foliar N concentrations to retention or extraction of thinning slash.

Life of the trial

We recommend trial series similar to these be monitored over a longer period of time. For example, the Finnish studies reported by Kukkola and Mälkonen (1997) were monitored over 15 years, and are ongoing. Results observed early in the life of a trial may be contradicted later, as we know that young tree growth patterns are different than seen in older trees. This concern should be reflected in future trial designs.

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Appendix A. Unadjusted basal area (m2/ha) at each study site, including basal area before treatment (year 0) and five years after trial establishment.

			Years since treatment						
TRIAL	*FERT*	*THIN*	*0*	*1*	*2*	*3*	*4*	*5*	*5yr inc.*
AK1053	no	normal	18.1	20.3	22.5	25.0	.	29.4	11.3
		waste	17.9	20.6	22.8	25.5	.	30.0	12.1
		tree	19.8	22.4	24.6	27.4	.	31.4	11.7
	yes	normal	19.1	22.3	25.5	29.2	.	34.4	15.4
		waste	18.8	22.3	26.1	30.4	.	36.4	17.5
		tree	18.7	21.9	25.6	29.2	.	34.6	15.9
	ALL		18.7	21.6	24.5	27.8	.	32.7	14.0
RO2093	no	normal	21.0	23.7	27.1	.	33.3	36.3	15.4
		waste	28.5	32.2	37.0	.	44.6	49.4	20.9
		tree	25.7	28.8	32.7	.	39.9	43.8	18.1
	yes	normal	22.0	25.4	30.4	.	38.3	42.3	20.3
		waste	24.0	27.2	31.4	.	37.8	40.8	16.7
		tree	23.1	26.3	30.6	.	37.2	40.7	17.6
	ALL		24.0	27.3	31.5	.	38.5	42.2	18.2
WN379	no	normal	18.9	22.8	26.8	30.8	34.8	38.4	19.5
		tree	17.7	21.0	24.8	28.4	31.4	35.2	17.5
	yes	normal	19.4	23.5	27.6	31.4	34.6	38.6	19.2
		tree	19.5	23.8	28.4	32.7	36.7	42.0	22.4
	ALL		18.9	22.8	26.9	30.9	34.4	38.6	19.7

Appendix B. Unadjusted mean height (m) at each study site, including height before treatment (year 0) and five years after trial establishment.

			Years since treatment						
TRIAL	*FERT*	*THIN*	*0*	*1*	*2*	*3*	*4*	*5*	*5yr inc.*
AK1053	no	normal	15.2	15.9	16.9	18.3	.	20.3	5.1
		waste	15.0	15.5	16.4	17.8	.	19.3	4.3
		tree	15.0	15.7	17.0	18.4	.	20.2	5.2
	yes	normal	15.4	16.2	17.7	19.5	.	21.9	6.5
		waste	15.3	16.3	17.7	19.3	.	21.8	6.4
		tree	15.4	16.0	17.3	19.0	.	21.1	5.7
	ALL		15.2	15.9	17.2	18.7	.	20.8	5.5
RO2093	no	normal	19.6	21.3	23.3	.	26.4	28.1	8.7
		waste	19.6	21.3	23.3	.	26.5	28.2	8.6
		tree	20.5	22.3	24.1	.	27.6	29.6	9.1
	yes	normal	20.7	22.6	24.4	.	27.7	29.0	8.3
		waste	20.8	22.6	24.8	.	27.8	29.5	8.5
		tree	19.9	21.3	23.3	.	26.4	28.4	8.5
	ALL		20.1	21.9	23.9	.	27.1	28.9	8.6
WN379	no	normal	18.6	19.9	21.6	23.6	25.1	27.4	8.7
		tree	18.6	20.4	22.1	24.1	25.8	28.3	9.7
	yes	normal	19.0	20.7	22.2	24.1	25.5	28.1	9.2
		tree	18.5	20.1	21.4	23.6	25.8	27.3	8.8
	ALL		18.6	20.3	21.9	23.8	25.5	27.8	9.1

Appendix C. Unadjusted volume (m3/ha) at each study site, including volume before treatment (year 0) and five years after trial establishment.

			Years since treatment						
TRIAL	FERT	THIN	0	1	2	3	4	5	5yr inc.
AK1053	no	normal	104.4	120.9	142.1	170.0	.	221.3	116.8
		waste	102.6	120.6	140.7	169.5	.	216.4	113.9
		tree	111.7	130.9	154.5	187.1	.	234.6	122.9
	yes	normal	110.2	134.3	165.3	207.9	.	272.9	162.8
		waste	109.6	136.1	170.3	216.1	.	287.5	177.9
		tree	108.1	130.4	164.3	204.1	.	266.0	157.9
	ALL		107.8	128.9	156.2	192.5	.	249.8	142.0
RO2093	no	normal	149.3	182.3	226.5	.	311.2	362.6	213.3
		waste	199.2	242.8	301.1	.	409.0	480.9	281.7
		tree	187.3	226.8	275.5	.	380.9	446.9	259.7
	yes	normal	164.3	204.7	259.5	.	365.4	419.3	255.0
		waste	183.5	219.9	275.6	.	365.8	418.3	234.8
		tree	166.1	199.6	251.3	.	342.2	401.0	234.9
	ALL		174.9	212.7	264.9	.	362.4	421.5	246.6
WN379	no	normal	131.6	166.3	207.6	258.2	307.5	365.7	234.2
		tree	124.0	158.8	199.5	245.4	286.9	350.3	226.3
	yes	normal	137.5	176.8	218.9	268.2	311.4	378.1	240.6
		tree	134.8	177.5	222.1	273.2	325.2	397.0	262.2
	ALL		132.0	169.9	212.0	261.2	307.8	372.8	240.8