NZFRI TRIAL AK345: COMPACTION & AMELIORATION OF TREE GROWTH AND FOLIAR NUTRITION AT AGE 4 IN AN IMPERFECTLY-DRAINED CLAY SOIL

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Abstract

This study at Riverhead Forest was undertaken in 1997 to continue our research on harvest related soil damage, initiated at Maramarua Forest in the early 1980's. The Riverhead trial was disigned to yield information on the prospects for overcoming soil damage through ameliorative treatments. At this site the design enables us to quantify the effect of two levels of harvesting-induced soil compaction and three ameliorative treatments (ripping, N fertiliser, N and P fertiliser) on soil properties and tree growth and nutrition. Cultivation by ripping and bedding continues to benefit tree growth, whether or not the soil was compacted. From the second year, tree growth and volume have been similar in compacted and control plots at both individual tree and stand scale. At age 4, trees in ripped soils are, on average, 9% or 46 cm taller than those in unripped plots (mean height 5.5 m), with 8% greater diameter at breast height. Ripped plots have more trees due to 13% lower mortality of seedlings in the first 2 years. However, 88% survival in ripped plots is probably unacceptably low for a commercial operation.

Application of 50 kg N /ha and 50 kg P/ha in the first year of the trial maximised mean tree height and diameter compared with unfertilised treatments, with about a10% growth advantage (mean 50 cm greater height and 10 mm greater DBH). Tree growth on this thirdrotation site is primarily limited by nitrogen (N), as more than 250 kg P/ha spread between 1969 and 1977 has resulted in residual P levels adequate for tree growth on these old clay soils – mean foliar P concentrations are greater than or equal to 0.12%. Foliar N concentrations in these 4-year-old trees are marginal in all treatments (1.3 to 1.4 %), but above the fertiliser intervention level of Carter Holt Harvey Forests. Estimated total tree N and P mass is greater in N+P than N only treatments.

Forest establishment in these fertilisedthird-rotation, imperfectly drained Ultic soils is maximised by cultivation to improve seedling survival and early growth, and N+P foliar concentrations are elevated well above criticallevels. The trial will be remeasured in 2003, when canopy closure should have occurred, which should allow for more definitive conclusions on the benefit of N+P fertilisation and convergent growth of cultivation treatments.

TABLE OF CONTENTS

1. INTRODUCTION

At Maramarua Forest, the NZFRI soil disturbance trial AK917 demonstrated major losses in tree productivity after 4 years as the result of soil disturbance: from loss of litter, loss of top-soil, and compaction (Skinner *et al*. 1989). After 15 years, the volume of trees in litter-removed treatments had recovered to that of trees in undisturbed (control) treatments. However, tree volume in highly disturbed treatments (without topsoil and compacted) was reduced by 45 to 54% due to poorer N and P nutrition and unfavourable soil physical conditions. Three major issues were associated with extrapolating the results of AK917 to a field setting:

- Treatments were uniformly imposed across each plot, and therefore did not reflect the reality of production forestry where soil disturbance varies across a cutover in a dendritic or fingered pattern, excluding skid sites.

- Individual effects of soil removal and soil compaction were not able to be separated

- There was no treatment showing the effect of ameliorating soil disturbance and compaction.

Results of the AK917 trial at Maramarua Forest are being further pursued at Riverhead Forest in a trial designed to quantify the effect of two levels of harvesting-induced soil compaction and three ameliorative treatments (ripping, N fertiliser, N and P fertiliser) on soil properties and tree growth and nutrition.

2. EXPERIMENTAL APPROACH

The following hypotheses are being tested:

- Increased soil disturbance results in decreasing tree growth.

- Growth of trees in heavily compacted soils is limited by lack of oxygen in winter (or wet soil conditions) and by high soil resistance to root extension in summer (or dry soil conditions), i.e. the "window" for root/shoot growth is shortened in compacted soils.

- Tree growth can be improved by cultivating both disturbed and undisturbed soils.

- Cultivating and fertilising will result in divergent growth of treated and untreated stands.

- The biggest gains in tree growth will come from combining cultivating and fertiliser additions that simulate nitrogen (N) input through legumes and phosphate (P) input from phosphate rock.

- Compaction decreases nutrient availability to trees by:
  - restricting root extension (i.e. limiting the size of the "pot"), thus reducing P uptake (although there is more P per unit volume of compacted soil)
  - limiting the availability of N via Both restricted root growth, and anaerobic conditions during periods of waterlogging (lack of oxygen which is required for NH_4-Nuptake).

3. TRIAL DESIGN, TREATMENTS AND INSTALLATION

A factorial design was used to examine compaction, ripping and fertilising. Three independent fertiliser treatments (nil = control, N, N+P) were used instead of a 2 by 2 factorial (+/- P and +/- N) to ensure four replicates of each treatment in the conventional sense, i.e. without reference to internal replication through the use of a factorial design.

The Treatments

- Compaction:
  - C1 = no traffic
  - C2 = moderate traffic

Details of the compaction treatments are described in Simcock *et al*. (1997). A rubber-tyred skidder was used to compact 40% to 50% of the plot area in 4-m-wide bands along the contour. The degree and area of compaction was comparable to light disturbance associated with operational impacts. GPS recording of a ground-based harvesting system on similar soils and topography under moist soil conditions showed that about 2/3 of an operational setting can be traveresed to some degree, and 3 passes lowered topsoil macroporosity to levels marginal for seedling establishment (Simcock *et al*. 2000). This was the pass number used in the compaction treatment.

- Cultivation:
  - R1 = no cultivation
  - R2 = single pass ripping and bedding

- Fertilisation
  - F1 = no N or P fertiliser
  - F2 = N fertiliser (50 kg N as urea
  - F3 = N and P 50 kg P as Sechura phosphate-rock fertiliser

In first rotation stands at Riverhead, P is the primary limiting factor. Once the P deficiency is overcome, N becomes the next limiting nutrient, as demonstrated at the Riverhead PARR trial (AK1055). Pre-harvest litter, soil, and foliar sampling at the AK345 trial site indicated that available P was unlikely to be a limiting factor (Simcock & Dando 1996). N and P fertiliser was applied to maintain foliar concentrations above intervention levels.

Blocking and plot installation

Hauler harvesting of the 9-ha trial area caused a typical gradient of fingers of disturbance increasing in intensity towards the skid landing. This primary disturbance was taken into account by blocking the trial area into low, low-medium, medium and high disturbance, based on a visual scoring of points along four transects in each 40 by 40 m plot (Simcock *et al.* 1997). The experiment consisted of a total of four blocks of 12 treatments in a randomised block design.

Treatment application and measurements

The compaction and amelioration treatments were installed 1996/97. Half the plots were ripped to an average depth of 0.60 to 0.7 m with a single-winged tine followed by four discs. GF 28, topped seedlings were planted at 1250 stems/ha and fertiliser treatments of 50 kg N/ha as urea and 50 kg P/ha as Sechura phosphate rock were imposed in October 1997. All seedlings were assessed for height and diameter after "settling" had occurred in the cultivated soils.

In August 1997, piezometers were installed within 150 mm of three randomly chosen seedlings in each of six replicate compacted, ripped and control plots. A fourth piezometer was installed in each plot in August 1998. Water table and seedling height were measured every fortnight until February 1999, when the seedlings were about 2 m high. A rain gauge recorded daily rainfall throughout this period. Details of these results are reported in Skinner *et al.* (1998). Climate data (temperature, rainfall, humidity, radiation) are now measured about 800 m from AK345.

In February 2001, foliar samples were taken from trees in each plot to assess the effectiveness of fertiliser applications at maintaining non-limiting N and P. Foliar samples were also analysed for Ca, K, Mg, Cu, B, Mn, Fe and Zn. In late winter 2001, height, RCD and DBH were assessed for each tree in the central 20 by 20 m core of each plot. A crude formula, d^2h was used to calculate tree volume. The concentration of foliar N and P was converted into mass using a formula from Madgwick (1994).

Statistical analysis
A single ANOVA with three components was run in SAS to investigate the effects of:
- ripping – ripped vs unripped treatments
- fertiliser – pair-wise comparisons of control, N and N+P treatments
- compaction – comparisons of control, compacted, ripped, and compacted then ripped plots (stand scale). This split was made because soil physical measurements showed that ripping completely ameliorated soil compaction. As a result, any impact of compaction would be masked if data from compacted and ripped plots were combined with data from plots that had only been compacted. The effect of compaction on individual trees was investigated by comparing trees in compacted and uncompacted rows within compacted plots.

4. RESULTS AND DISCUSSION

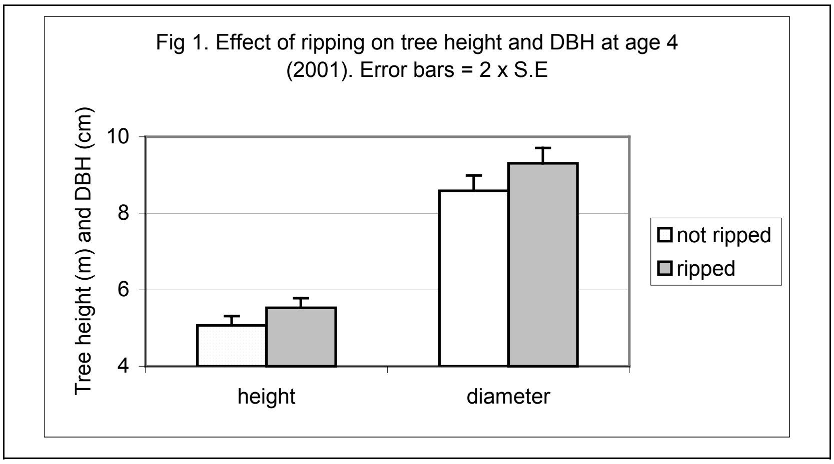
4.1 Growth
Overall height of 4-year-old trees ranged from 0.5 to 8.0 m; the overall site mean was 5.4 m (median 5.5 m). A slight skew towards small trees indicated suppression of these trees was starting to occur (Appendix One). DBH ranged from 0 (for trees under 1.2 m height) to 153 mm; the overall site mean was 91 mm (median 92 mm).

There were no significant interactions between treatments for any tree growth parameter (height, DBH or volume); P values for interactions were above 0.47. There was no blocking effect ($p>0.05$??, indicating no impact of disturbance as assessed visually in 1996; P values were between 0.08 and 0.19. There were interactions between some treatments forN and P foliar concentrations.

4.2 Effect of ripping and mounding
Ripping is beneficial. There is evidence that ripping has increased mean tree height ($p=0.01$), DBH ($p=0.03$), volume ($p=0.02$) and survival ($p<0.01$) (Fig. 1, Appendix Two). The growth advantage of ripping, however, appears to decrease over time. While 2-year-old trees in ripped plots were 14% taller and had 25% greater RCD than those in unripped plots, the benefits for 4-year-old trees were a 9% increase in mean tree height and an 8% increase in mean tree DBH.

Ripping and bedding increased mean survival from 75% (unripped plots) to 88% at 1250 stems/ha by a combination of lowering the water table and increasing air-filled pore space in the upper 200 mm of the soil profile (Skinner *et al.* 1998). Death of seedlings in ripped plots was generally caused by ineffective ripping and/or bedding, for example, inadequate water drainage from the rip due to lack of fall, which lead to ponding and a saturated root zone in which seedlings rotted.

Figure 1. Effect of cultivation on tree growth at age 4 years

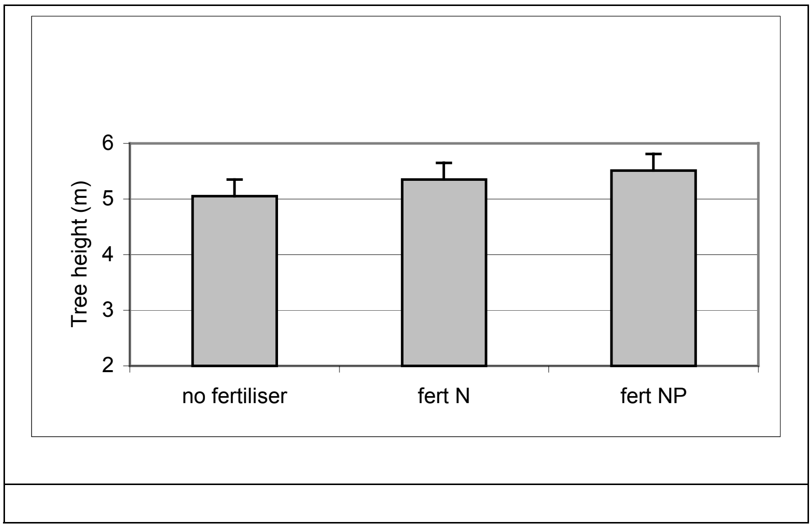


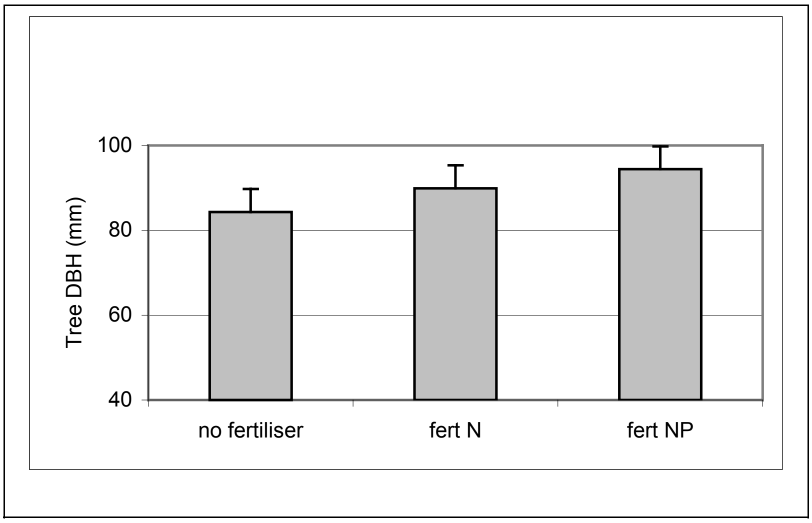
4.3 Effect of N and P fertiliser

Mean values of foliar P showed no limitation to growth. N concentrations were marginal for all treatments, but above the CHH Forests intervention level (Appendix Three). In spring 2001, 50 kg N/ha was applied to N and N+P treatment plots.

There was a significant growth response to N+P fertiliser despite non-limiting (albeit marginal) foliar N concentrations. Trees in the N+P treatment showed significant increases in height (p=0.04) and diameter (p=0.01) over those in the unfertilised (control) treatment (Figs 2a & 2b, Appendix Three). Applying only N gave an intermediate, non-significant growth response. Fertiliser had no effect on tree survival.

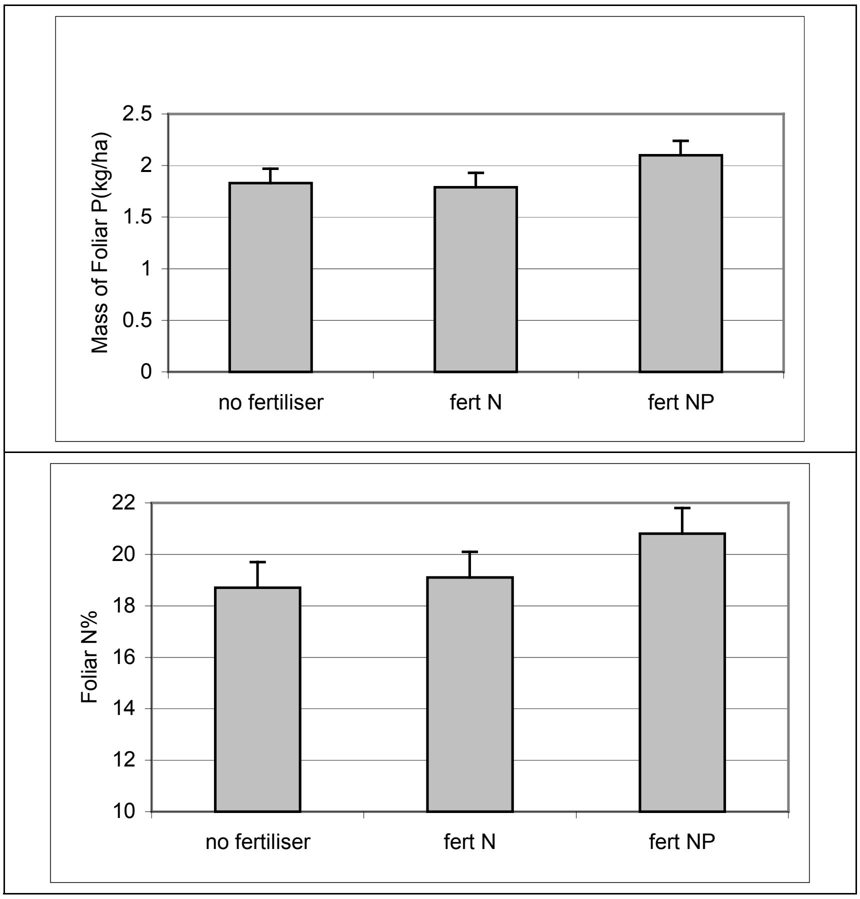
Figures 2a and 2b. Effect of N and P fertiliser on tree height and diameter (DBH) at age 4 (2001). Error bars = 2 x S.E





Applying N and P fertiliser together increased the foliar concentration of P ($p=0.01$), and the calculated mass of P ($p=0.01$) and N ($p=0.02$) in the 4-year-old trees (Figs 3a, 3b). Foliar P and tree-P mass increased significantly only in the NP treatment (Appendix 3). Foliar P was affected by ripping ($p=0.01$); however, close examination of treatment effects (Table 1) showed foliar P was only depressed in the ripped + N treatment. This may be due to growth dilution in the absence of additional P as the ripped +N treatment had some of the largest trees. Foliar P was not suppressed in the unripped + N treatment which had smaller trees (Table 1, column d^2h).

Figures 3a and 3b. Effect of fertiliser on mass of foliar P and N at age 4



Simple treatment effects on foliar N cannot be reported as the ANOVA showed a significant interaction between ripping and fertilisation (p=0.01). Closer examination of treatments showed foliar N was only depressed in the Rip+N treatment (Table 1).

Table 1. Effect of ripping and fertilisation on %P and %N in foliage. Results with different letters indicate significant differences at p<0.05.

Treatment	%P	D^2H (an indicator of potential growth dilution)	% N
NO Rip + N	0.132 b	197 a	1.34 b
+N +P	0.140 b	214 ab	1.33 b
control	0.135 b	178 a	1.35 b
Rip + N	0.113 a	225 b	1.26 a
+N +P	0.134 b	235 b	1.39 b
control	0.129 b	208 ab	1.36 b

4.3 Effect of compaction

The intensity of compaction applied over half of each compacted plot had no significant effect on stand-scale parameters measured on 4-year-old trees (Appendix 3). Analysis of Foliar N showed some evidence of a response to compaction (p=0.04). The potential interaction between compaction and N was investigated by comparing the mean foliar N of compacted vs. compacted and ripped treatments; this analysis showed no significant effect of N at a plot scale (Appendix 3).

At an individual tree scale, mean survival of trees planted in compacted soil was lower than control plots, although survival in both treatments was variable (Table 2). Seedlings that survived the first 4 years experienced no residual impact of compaction on growth, probably because their root systems have been able to exploit favourable soils adjacent to compacted zones (the compaction was applied in strips).[1] Foliar P in 2000 and 2001 was greater in trees planted in compacted zones, probably as a result of decreased diffusion distances from soil matrix to root surface. P is highly immobile in clay soils.

Table 2: Effects of compaction on individual trees; means of trees growing in compacted strips vs. means of trees growing in control (uncompacted) strips. Results with different letters indicate significantly different results at p<0.05.

Treatment	Height (m)	DBH (mm)	Survival (%)
Control row	5.0 a	89 a	75 b
Compact row	4.9 a	85 a	66 a
Standard Error	0.1	3	3
Ho Probability	0.79	0.38	0.05
Treatment	**2001 Foliar P (%)**	**2001 Foliar N (%)**	**2000 Foliar P (%)**
Control row	0.128 a	1.22 a	0.125 a
Compact row	0.145 b	1.27 a	0.135 b
Standard Error	0.002	0.03	0.003
Ho Probability	0.01	0.27	0.03

4.5 Future trial assessment

The trees will be measured in winter 2003, when canopy closure should have occurred within the plots. Histograms of tree height and diameter data will indicate whether there are significant

[1] for a discussion of the effect of compaction on survival see Skinner *et al.* (1998) or Simcock *et al*. (2000)

numbers of light-suppressed trees, in which case analyses will use H100, i.e. height of the tallest 100 trees per hectare equivalent. The following parameters could be added, if resources allow:

- Quantification of the litter layer (mass, N and P), if developed. Litter could be thicker in plots with N and P fertiliser and could be a significant N pool?
- A measure of tree foliage that allows a reasonably accurate estimate of kg N, P in the tree and foliage without destructive biomass testing
- Measurement of those piezometers installed in 1997/98 to monitor lowering of the watertable as the tree canopy closes.

5. CONCLUSIONS

The initial hypotheses are revisited, taking into account the results of 4 years of tree growth:

- Increasing soil? disturbance results in decreasing tree growth.
  ***No evidence from this trial** – treatment replicates were stratified into four blocks using a visual disturbance assessment of the plot surface. There was no significant block effect.*

- Growth of trees in heavily compacted soils is limited by lack of oxygen in winter (or wet soil conditions) and by high soil resistance to root extension in summer (or dry soil conditions) i.e. the "window" for root/shoot growth is shortened in compacted soils.
  ***Yes** for wet conditions – Oxygen diffusion rates were slower and air-filled pore volume was significantly lower in compacted soils. Laboratory testing of cone penetration resistance of this soil under different moisture and compaction shows that resistance greatly increases in dry soil conditions.*

- Tree growth can be improved by cultivating both disturbed and undisturbed soils.
  ***Yes** – ripping and bedding improved tree growth over the first 4 years.*

- The effects of cultivating and fertilising will result in divergent growth of treated and untreated stands.
  There are early indications of convergent growth between ripped and unripped stands. In contrast, fertilising with both N and P appears to be maintaining c.10% growth advantage over unfertilised plots.

- The biggest gains in tree growth will come from combining cultivating and fertiliser additions that simulate nitrogen (N) input by legumes and phosphate (P) input from phosphate rock.
  ***No** – the largest 4-year old trees are in ripped plots, and unripped but N+P fertilised plots.*

- Compaction decreases nutrient availability to trees by:
    - restricting root extension (i.e. limiting the size of the "pot"), thus reducing N uptake
    - decreasing the availability of N via lower root activity and possibly increased denitrification.

  The alternating strips of compaction at this site means seedlings can quickly exploit favourable areas so as to increase the size of the pot. Roots of 1-year-old and 2-year-old seedlings grow quickly out of hostile soils into favourable areas, e.g., a 1-year old seedling had a 1-m-long root extending into a patch of decomposed ponga stump where it proliferated. Foliar N was similar in trees growing in compacted and uncompacted sites. Foliar P was greater in individual trees in compacted rows in 2000 and 2001.

6. ACKNOWLEDGEMENTS

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APPENDICES

1. Histogram (LHS) and Box plot (RHS) of tree height from all plots.

The histogram shows a slight skew, or tail, towards small trees, indicating suppression of small trees is starting to occur. We decided to use this data set. In 2003, canopy closure will probably have occurred, and light-suppressed trees will be removed from the 2003 analysis by using H100, i.e. height of the tallest 100 trees per hectare equivalent.

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8.25+*                                                   2              0
    .**                                                 15              |
    .*****                                              44              |
6.75+*****************                                 148              |
    .**********************************************    408           +-----+
    .**********************************************    406           *-----*
5.25+***************************************           351           |  +  |
    .*************************                         217           +-----+
    .****************                                  143              |
3.75+********                                           72              |
    .****                                               33              0
    .***                                                22              0
2.25+**                                                 18              0
    .*                                                   8              0
    .*                                                   3              0
0.75+*                                                   3              *
     ----+----+----+----+----+----+----+----+----+-
     * may represent up to 9 counts
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2. Effects of ripping

Treatment	Height (m)	DBH (mm)	Sqroot (D^2H)	Survival (%)
Control	5.07	86	199	74
Ripped	5.53	93	224	87
Standard Error	0.12	2	7	3.5
Ho Probability	0.01	0.03	0.02	0.01
Treatment	**Mass of P (kg)**	**Mass of N (kg)**	**Foliar P (%)**	**Foliar N (%)**
Ripped	1.91	18.9	0.136	1.34
Unripped	1.90	20.3	0.125	1.34
Standard Error	0.06	0.4	0.003	0.01
Ho Probability	0.92	0.03	0.01	0.76

3. Effects of fertilising

Letters indicate significant differences at $p < 0.05$; i.e., results with different letters are significantly different at p=0.05. N.S.D. = no significant difference.

Treatment	Height (m)	DBH (mm)	Sqroot (D^2H)	Survival (%)
Control	5.0 a	84 a	196 a	78 a
+ N	5.4 ab	90 ab	214 ab	84 a
+ N + P	5.5 b	94 b	226 b	79 a
Standard Error	0.15	3	9	4
Ho Probability Control to +N+P	0.04	0.01	0.02	N.S.D.
Treatment	**Mass of P (kg)**	**Mass of N (kg)**	**Foliar P (%)**	**Foliar N (%)**
Control	1.83 a	18.7 a	0.132 ab	1.36 b
+ N	1.79 a	19.1 a	0.122 a	1.30 a
+ N + P	2.10 b	20.8 b	0.137 b	1.36 b
Standard Error	0.07	0.5	0.003	0.02
Ho Probability Control to N+P	0.01	0.01	0.04	0.02

4. Effects of compacting 50% of stand (plot effects)

Comparison of control v compacted and compacted vs. ameliorated (compacted, then ripped). Letters indicate significant differences at $p < 0.05$, i.e. results with different letters are significantly different at p=0.05. N.S.D. = no significant difference. Source: p17-20 0924 Mon Dec 10 2001 1138

Treatment	Height (m)	DBH	Trans. D^2H	Survival (%)
Control	5.0 a	a	193 a	81 ab
Compacted	5.0 a	ab	200 ab	69 a
Ripped	5.5 b	b	226 b	88 b
Ameliorated	5.4 b	b	219 ab	88 b
Standard Error	0.2		10	5
Ho Probability for compaction	NSD	NSD	NSD	0.01 (comp v ameliorated)
Treatment	**Mass of P (kg)**	**Mass of N (kg)**	**Foliar P (%)**	**Foliar N (%)**
Control	1.86 a	18.4 a	0.134 b	1.33 a
Compacted	1.98 a	19.5 ab	0.137 b	1.36 a
Ripped	1.97 a	20.3 b	0.127 ab	1.32 a
Ameliorated	1.87 a	20.6 b	0.123 a	1.36 a
Standard Error	0.08	0.6	0.004	0.02 a
Ho Probability for compaction	NSD	NSD	0.01 (comp v ameliorated)	NSD