SOIL DISTURBANCE AND AMELIORATION AT RIVERHEAD FOREST: TRIAL ESTABLISHMENT, FIRST YEAR GROWTH, AND PIEZOMETER STUDY

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Report No. 101 Date June 1998

Confidential to participants of the NZ Forest Site Management Cooperative

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Abstract

Cultivation by ripping and bedding had large effects on growth with 17% increases in height, and 29% increases in root collar diameter; survival increased from 83% to 91%. Although compaction decreased seedling survival by 10% to 73%, this was not statistically significant. Compaction had no effect on seedling height or root collar diameter. Fertiliser Nitrogen (N) increased height by 14% but had only a minimal effect on root collar diameter and no effect on survival. There was no response on seedling height, diameter or survival with the addition of Phosphorus (P) as well as N, and also no effect on seedlings of the level of disturbance (blocking).

Significantly elevated seedling survival in both ripped treatments (ripped, and compacted then ripped) was probably due to a combination of a lowered water table and increased volume of macropores in the rip zones. Together these increase the oxygen supply to seedling roots. Mortality may have been exacerbated by an unusually wet winter and spring after planting, followed by an unusually dry summer and autumn that included an 8-week period in mid-summer when there was negligible available soil moisture.

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1. INTRODUCTION

1.1 Maramarua Trial

At Maramarua Forest, a Forest Research soil disturbance trial (AK917) established in 1982, demonstrated major losses in productivity as the result of soil disturbance (loss of litter, loss of top-soil), and compaction, after 4 years. After 11 years, although there were indications that the disturbed clay soils were being ameliorated by the crop, there were still very clear growth differences between disturbed and control conditions.

The two major issues associated with extrapolating the results to a field setting were:

- the treatments were imposed evenly across a plot, and therefore did not reflect the physical soil forest environment in production forestry where disturbance and compaction vary dramatically across the terrain. In a forest setting the effects of the various disturbances are integrated by individual trees as their roots grow across disturbance types and by stands of trees. Thus, the observation at AK917 for amelioration of soil disturbance by the crop cannot be translated into a "field" setting because of the nature of the treatment installation.
- the treatments did not include physical amelioration of "disturbed" conditions.

1.2 Riverhead Compaction and Amelioration Trial Hypotheses

The outcomes of the AK917 trial at Maramarua Forest are being further pursued at Riverhead Forest in a trial on similar clay soils, designed to answer the questions of amelioration of harvest-related soil damage. The trial is examining the effect of minimal and moderate levels of harvesting-induced soil disturbance and three amelioration treatments (ripping, N fertiliser, and N + P fertiliser) on soil physical and chemical properties and tree growth and nutrition.

The hypotheses being tested at the Riverhead trial are:

- Increasing harvesting disturbance results in decreasing tree growth.
- Growth of trees in compacted soils is limited by lack of oxygen in winter (wet soil conditions) and by high soil resistance to root extension in summer (dry soil conditions) i.e. the "window" of time for root/shoot growth is shortened in compacted soils.
- Tree growth can be improved by ripping both disturbed and undisturbed soils.
- The effects of ripping and fertilising will result in divergent growth of treated and untreated stands.
- The biggest gains in tree growth will come from combining ripping and fertiliser additions which simulate nitrogen (N) input by legumes and phosphate (P) input from fertiliser.
- 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)

– decreasing availability of N via increased leaching, increased denitrification due to longer periods of anaerobic conditions, and lower root activity.

1.3 Riverhead Trial Design, Treatments and Installation

The power of a factorial design was employed to examine the effects of compaction, ripping and fertilising. To have at least four repetitions for each treatment in the conventional sense, i.e., without reference to internal replication through the use of a factorial design, three independent fertiliser treatments (control, N, N and P together) were decided on in place of a 2 by 2 factorial (with and without P, and with and without N).

Compaction

C1 = no traffic, C2 = moderate traffic

Details of the compaction and ripping treatments are in Simcock and Dando (1996) and Simcock *et al.* (1997b). A rubber-tyred skidder was used to compact 40% to 50% of the plot area in alternate 4 m wide bands along the contour.

Ripping

R1 = no ripping, R2 = single pass ripping and bedding

The amelioration treatment was carried out to an average depth of 70 cm using a winged tine. Four bedding discs floated behind the tine.

Fertilisation

F1 = no N or P fertiliser, F2 = non-limiting N fertiliser, F3 = non-limiting N and P fertiliser

In first rotation stands at Riverhead, P is the primary limiting factor. Once the deficiency is overcome, N becomes the next limiting nutrient. Evidence for this was demonstrated at the Riverhead PARR trial. Sampling of soil, litter and foliage of mature trees at the site before harvest reflected the application of more than 2 t/ha superphosphate during the second rotation and indicated that P was unlikely to be a limiting factor (Simcock *et al.*1997a).

Ideally, a uniform level of soil disturbance was required across the trial. However, hauler harvesting causes a gradient of disturbance increasing towards the skid landing. To account for this primary disturbance the plots were grouped into four blocks representing low, low-medium, medium and high disturbance that was based on a visual assessment of about 100 points in each plot, after McMahon (1995). The experiment consisted of a total of 12 treatments each replicated four times in a randomised block design. Each plot was 40 metres by 40 metres with a 20 m by 20 m internal measurement plot.

The compaction and amelioration treatments were installed in November 1996 and February 1997 respectively. GF28, topped seedlings were planted in winter. Fertiliser treatments were imposed (control, N broadcast as urea @ 50 kg/ha, N and P as Sechura rock @ 50 kg/ha). All seedlings were assessed for height and diameter some weeks after planting, to allow for "settling" of the ripped and bedded soils.

2. RESULTS

2.1 Rainfall and Soil Moisture

The winter and spring of 1997 was unusually wet; a result of high rainfalls in June and September. This was followed by an unusually dry summer and autumn, 1998, in which every month from October 1997 to April 1998 had less than average rainfall, with the exception of February (Fig. 1). From mid-December to mid-February there was negligible readily available soil moisture for plant growth (Table 1).

Table 1. Rainfall and soil moisture from August 1997 to May 1998 at the Riverhead Compaction and Amelioration Trial. Evapotranspiration is based on mean monthly values for Whenuapai, calculated using the Penman equation. Available moisture calculation is based on a readily available moisture of 80 mm in the surface 0.5 m of soil and the soil being at field capacity (fully wetted) on 10 August 1997.

End-date of Fortnight	Measured rainfall (mm)	Evapotranspiration (mm)	Rainfall surplus or deficit (mm)	Available water for seedlings (mm)
25 August 1997	23	17	6	80
8 September	60	14	46	80
22 September	71	27	44	80
6 October	195	31	164	80
20 October	58	37	21	80
4 November	8	43	-35	45
17 November	74	48	26	71
1 December	23	51	-28	43
15 December	29	59	-30	13
29 December	37	59	-22	0
12 January 1998	0	62	-62	0
28 January	14	71	-57	0
9 February	0	49	-49	0
23 February	78	55	23	23
9 March	30	47	-17	6
22 March	61	40	21	27
6 April	22	38	-16	9
20 April	17	25	-8	1
4 May	10	22	-12	0

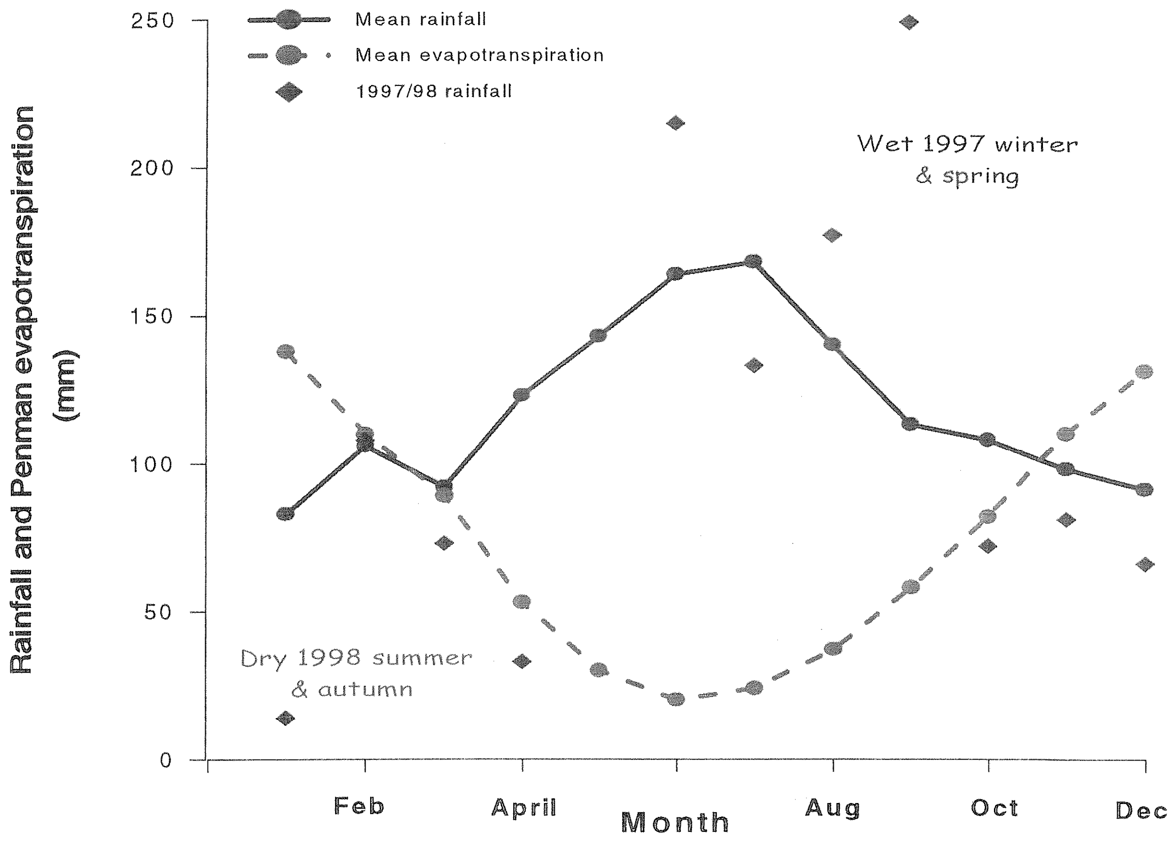


Fig. 1: Mean rainfall and evapo-transpiration and 1997/98 rainfall for Riverhead Forest.

2.2 Soil Physical Properties

Compaction halved air capacity — the volume of large, normally air-filled pores (equivalent spherical diameter of 0.03 mm) — in the 5 to 180 mm depth to volumes considered detrimental to root growth (Table 2). Ripping and bedding fully ameliorated this degradation and nearly doubled the "natural" (pre-disturbance) air capacity. Ripping appeared to be more effective at improving soil physical properties in the surface 100 mm than in the 100 to 180 mm depth. Detailed soil physical properties are presented in Simcock *et al.* (1997).

Table 2: Measured physical properties of Whangaripo clay loam after application of treatments at the Compaction and Amelioration Trial. N – the number of 100 mm diameter cores analysed. ODR is Oxygen Diffusion Rate, Bold numbers indicate values that probably limit root growth

Treatment	Soil Physical Measurement, Mean ± Standard deviation			
	Bulk Density Tm^{-3}	Macroporosity % v/v	Air capacity % v/v	ODR @ -5 kPa x $10^{-8} gO_2\ cm^{-2}\ min^{-1}$
Topsoil (5-85 mm)				
Control, n=65	1.00 ± 0.18	13.5 ± 7.1	15.5 ± 7.4	29 ± 22
Compacted, n=70	1.13 ± 0.18	5.7 ± 4.7	**7.1 ± 5.4**	**17 ± 14**
Ripped, n=49	0.85 ± 0.14	24.0 ± 7.7	25.7 ± 7.6	44 ± 25
Compacted & Ripped, n=39	0.91 ± 0.14	19.0 ± 7.7	20.8 ± 7.6	38 ± 27
Subsoil (100-180 mm)				
Control, n=42	1.17 ± 0.07	6.7 ± 2.9	**8.1 ± 2.9**	**18 ± 5**
Compacted, n=23	1.19 ± 0.10	**3.4 ± 1.8**	**4.0 ± 1.9**	**17 ± 10**
Ripped, n=24	0.98 ± 0.15	12.2± 6.4	13.7± 6.3	32 ± 22
Compacted & Ripped, n=19	1.06 ± 0.11	7.4 ± 4.9	**8.6 ± 5.1**	22 ± 13

2.3 Seedling mortality and growth

The most significant and dramatic effect was that of ripping on tree survival ($P<0.01$); fertiliser and ripping also had significant effects on growth (height and root collar diameter, r.c.d). The gradient of soil disturbance across the entire trial site caused by cable logging did not affect tree growth (Table 3 — blocking is reported as four levels of "disturbance"). As there were no interactions between treatments on pines, only the main effects are reported.

Cultivation by ripping and bedding markedly increased seedling survival ($P<0.01$) (Fig. 3c). Cultivation also had highly significant effects on tree heights, from 64 cm uncultivated seedlings, to 75 cm (Fig. 3a) and r.c.d, from 14 mm for uncultivated seedlings to 18 mm (Fig. 3b).

The analysis presented in Table 3 groups together all compacted plots, whether they were subsequently ripped or not. Soil physical measurements show that plots that have been compacted and subsequently ripped have properties very similar to those that have only been ripped. We, therefore, carried out an additional analysis that compared the four separate physical treatments, control, ripped, compacted, and compacted and ripped. Table 4 shows the mean and standard error of the four treatments.

While compaction reduced seedling survival by 10%, this was not significant (p=0.17 for pairwise comparison with control). Compaction had no significant effect on height or root collar diameter compared with the control treatment (Fig. 2a, 2b; Table 4). This result reflects the variability of moisture content across the trial site. In drier plots, the effects of wheel passage was difficult to detect, and in very wet sites soil was displaced to form a 20 to 30 cm high ridge, with a reduced compactive effect (Appendix 1).

Table 3. Analyses of Variance for the effect of soil treatment on pine tree height, root collar diameter and survival after 1 year.

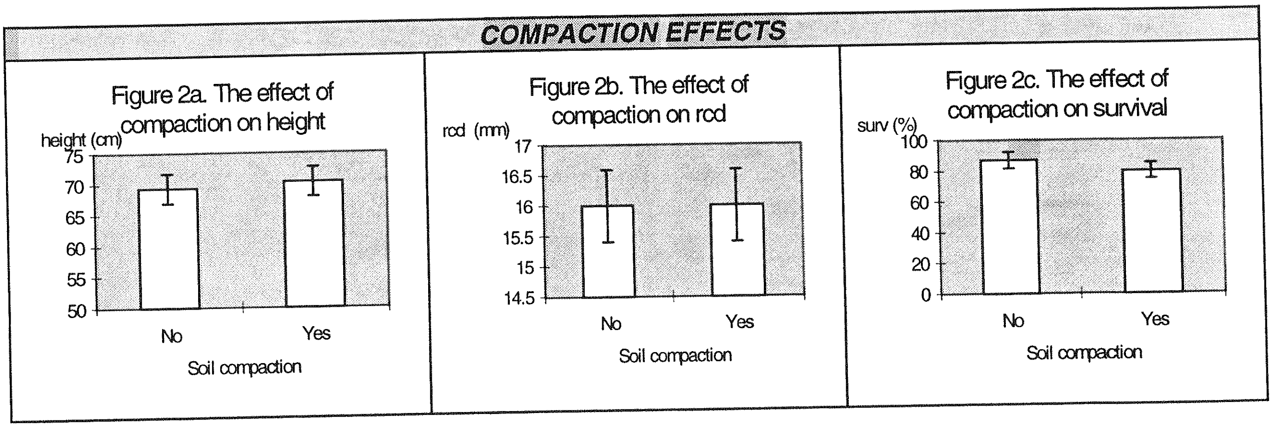
		Height		Root Collar Diameter		Survival	
S of V	D.F	Pr	Sig	Pr	Sig	Pr	Sig
COVARIATE	1	0.0030	***	0.2594	NS	-	-
DISTURB	3	0.1641	NS	0.1740	NS	0.2962	NS
FERT	2	0.0076	***	0.0847	NS	0.8414	NS
COMPACTN	1	0.6815	NS	0.7562	NS	0.1900	NS
FERT*COMPACTN	2	0.7576	NS	0.9216	NS	0.4079	NS
RIP	1	0.0006	***	0.0001	***	0.0080	***
FERT*RIP	2	0.3454	NS	0.4723	NS	0.7669	NS
COMPACTN*RIP	1	0.5441	NS	0.8382	NS	0.1967	NS
FERT*COMPACTN*RIP	2	0.2749	NS	0.3316	NS	0.6150	NS
DISTURB*FERT	6	0.1180	NS	0.6726	NS	0.3081	NS
DISTURB*COMPACTN	3	0.5175	NS	0.3075	NS	0.6958	NS
DISTURB*RIP	3	0.1101	NS	0.8358	NS	0.1280	NS

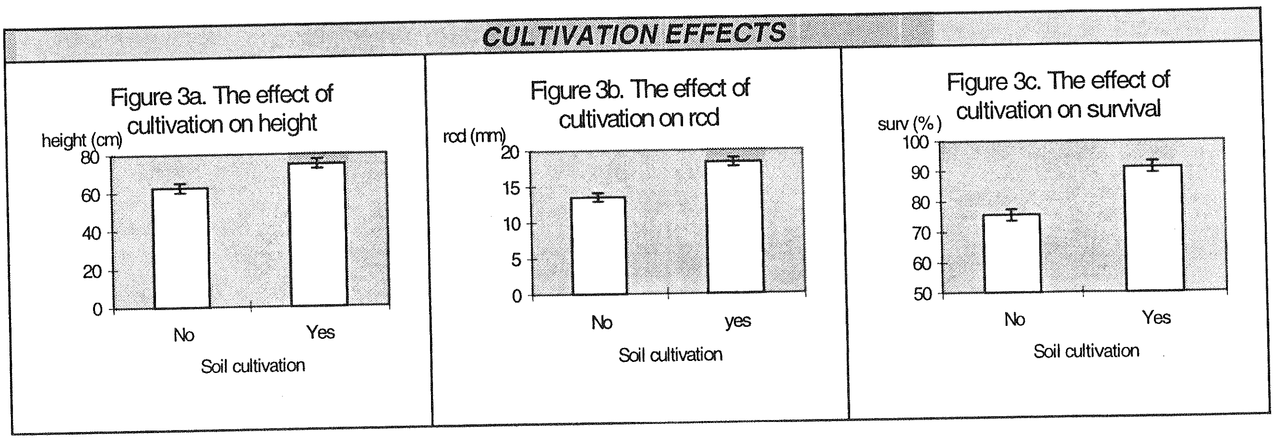
Table 4: Means of seedling survival, height and root collar diameter one year after planting. standard errors are given in brackets, letters indicate significant differences at p<0.05.

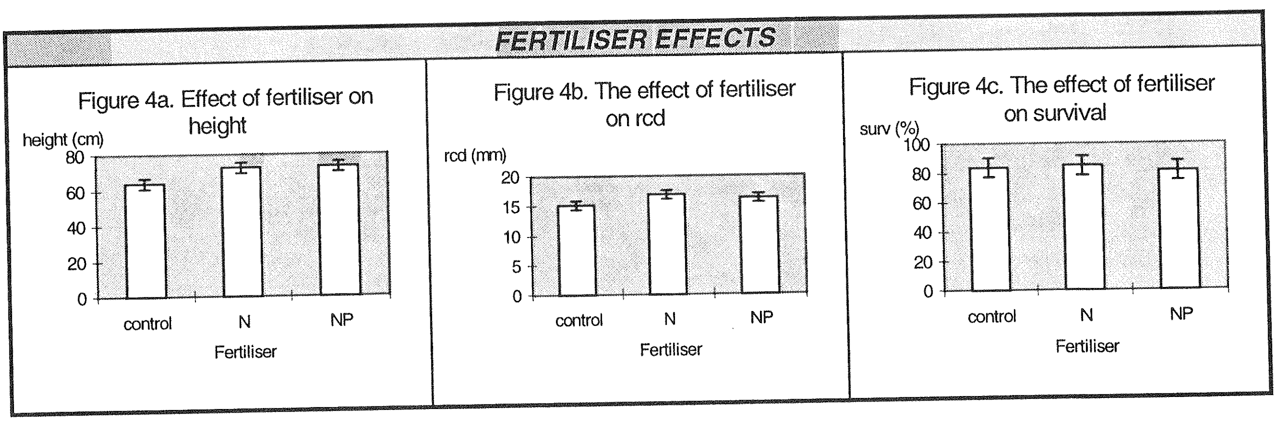
Treatment	Survival (%)	Height (cm)	R.C.D (mm)
Control	83 (4) a	66.1 (2.8) bc	13.9 (0.6)
Rip	91 (4) b	74.8 (2.7) a	18.1 (0.6)
Compacted	73 (4) a	63.6 (3.0) c	13.9 (0.6)
Compacted & Ripped	91 (4) b	74.6 (3.2) ab	18.4 (0.6)

Nitrogen fertiliser significantly improved seedling heights over one year: from 64 cm (controls) to 73 cm (P<0.01)(Figure 4a). Nitrogen increased r.c.d marginally (P=0.08) (Figure 4b). Addition of phosphate fertiliser did not further improve seedling heights or r.c.d. Fertiliser had no significant effect on tree survival (Figure 4c).

Figures 2-4. Main effects of compaction, cultivation and fertilisation on height, root collar diameters and survival. Error bars are LSD P0.05.





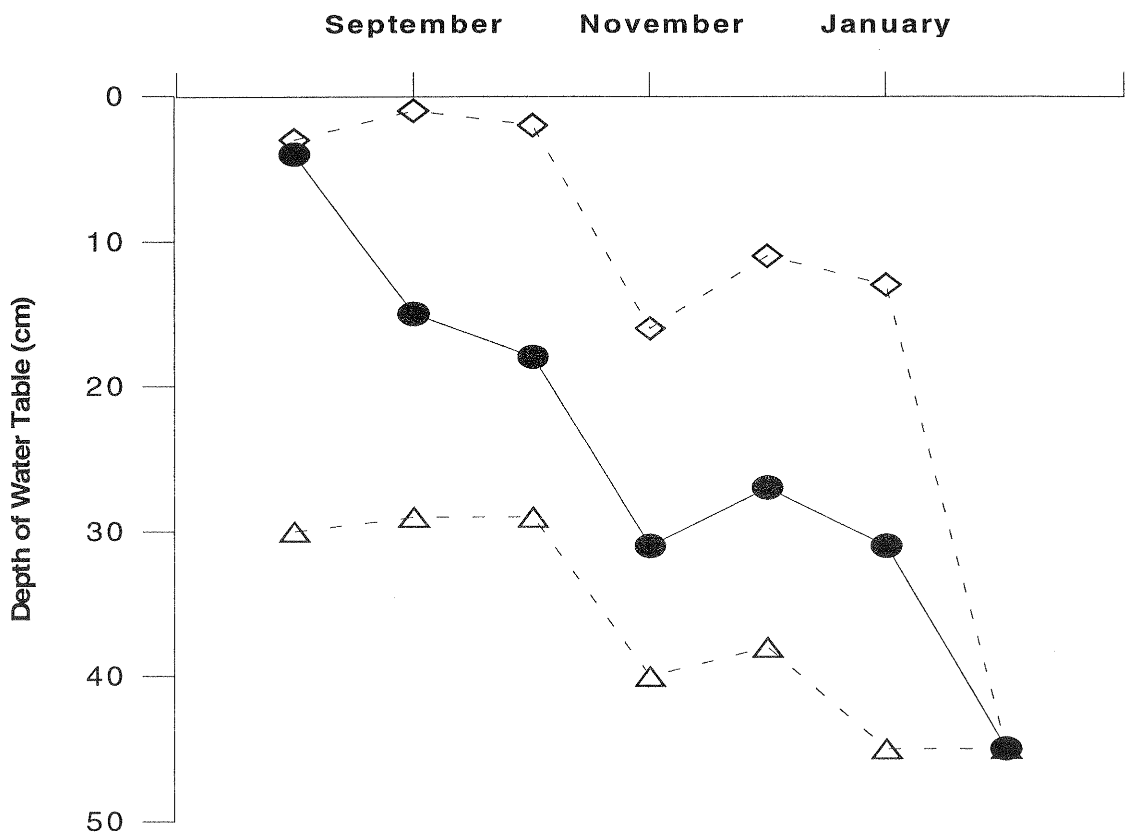


2.4 Water Table Depth

In August 1997, 108 piezometers were installed in control, compacted and ripped treatments in clusters of three beside 36 seedlings. At each seedling chosen a piezometer was installed within 10 cm of the seedling stem, and two piezometers 1 m uphill from the seedling, away from the treatment zone. The depth to the water table and health of each seedling was measured every fortnight from August 1997 to April 1998. Seedlings were graded from 1 (dead) to 3 (healthy but not actively growing) to 5 (growing vigorously).

Piezometers showed the variability between sites in the same plots. At some sites the water table was only below 45 cm depth in February, at the end of a prolonged period of low rainfall (Fig. 6). Monitored seedlings died mainly in October and February.

Fig. 6: Water table depth at 3 piezometers representative of dry (Δ), moist (●) and wet (◆) sites from August 1997 to April 1998. Dry sites were most common in ripped areas; wet sites were most common in compacted areas.



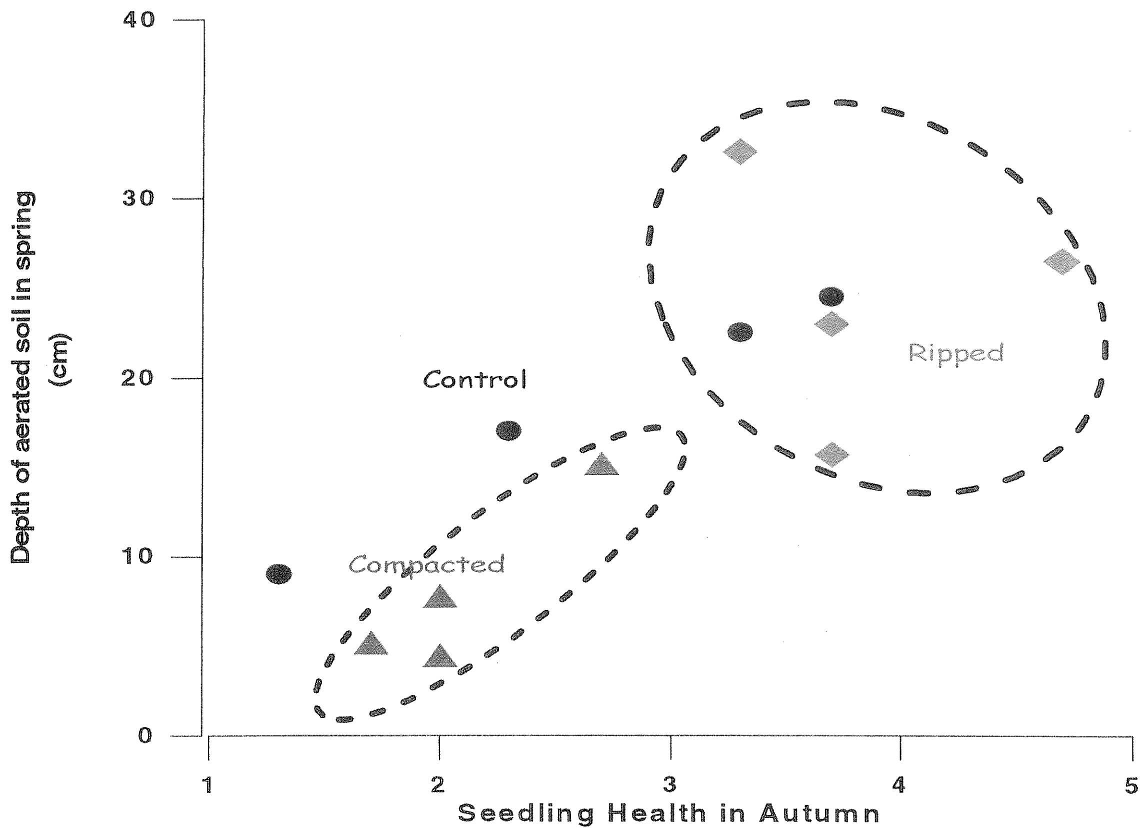


Fig. 7: Tree health at the time of mensuration (May 1998) and the depth of aerated soil in the critical spring period for compacted (Δ), ripped (◆) and control (●) treatments. Each point represents a plot (the mean of three trees). Dotted lines surround compacted and ripped clusters $r^2 = 0.65$.

No healthy seedlings were monitored where the water table was less than 10 cm below the soil surface in spring (Fig. 7). The healthiest seedlings were at sites that had more than 20 cm of aerated soil. A straight-line regression for Fig 7 has an r^2 of 0.65, indicating that there are other influences on seedling survival in addition to the depth of the water table. Ripping increased the depth to the water table, compaction had the opposite effect. Both treatments decreased the variability of water table depth within the treated areas.

3. CONCLUSION

Revisiting our hypotheses, in the light of first year results, shows:

- Increasing harvesting disturbance does not result in decreasing tree growth for the range of disturbances we investigated (for the blocking levels we used).
- Growth of trees in compacted soils is limited by lack of oxygen during periods of excess soil moisture.
- Tree growth can be improved by ripping both compacted and natural soils following hauler harvesting.
- The biggest gains in tree growth were with combining ripping and nitrogen fertiliser.

Ripping had a marked positive effect on tree survival, seedling height and seedling root collar diameter ($p<0.001$), whether the soil had been compacted beforehand or not. Compaction had no significant effect on seedling survival, height or root collar diameter.

It appears that compaction degraded the clay soils by decreasing the number of large, air-filled pores and by decreasing the depth to the water table. Where the water table was deep before compaction, this has not resulted in limiting conditions; however, in marginal plots, the decreased volume of large pores, combined with a water table closer to the soil surface, resulted in conditions inhospitable for seedling growth. In these plots seedlings planted into the alternate compacted strips had high mortality, in contrast with the alternate uncompacted rows (Appendix 2).

4. ACKNOWLEDGEMENTS

We wish to acknowledge the contributions of the Foundation for Research, Science and Technology (CO4505), Carter Holt Harvey Forests Limited, and the New Zealand Forest Site Management Cooperative. The authors would like to express appreciation to all those who assisted with management and monitoring of the trial site, in particular David Fish, Andrew Lee-Cooper and Phil Wright (Carter Holt Harvey Forests). Thanks to Mark Kimberley for his statistical expertise and Anne Austin for editorial comments.

5. REFERENCES

McMahon,S. 1995. Survey method for assessing site disturbance. *Logging Industry Research Organisation project report* 54. 16p.

Simcock,R. and Dando,J. 1996. Riverhead compaction and amelioration trial: research plan and pre-harvest site assessment. Landcare Research Report. 37 pp.

Simcock,R., Dando,J., Parfitt,R., Skinner,M. and McMahon,S. 1997a. Compaction and amelioration: a stand-scale trial on northern clay soils. In: Sustainable Forest Management Workshop *'Research development to improve future decisions'* NZ FRI, Rotorua, 29-30 April 1997. Pp 17-18. and McMahon,S. 1997.

Simcock,R. McMahon,S. Dando,J. and Ross.C. 1997b. Riverhead compaction and amelioration trial: Report on 1996/97 Year. Landcare Research Report. 29 pp.

Simcock, R., Skinner,M., Smith, C.T., Murphy,G., Firth, J., Ross, C., Dando, J. and Graham, J. 1998. The response of clay soils and radiata pine to increasing soil disturbance and ameliorative ripping. Ninth North American Forest Soils Conference Abstracts.

New Zealand Meteorological Service. 1980. Summaries of climatological observations to 1980. *New Zealand Meteorological Service miscellaneous publication 177.*

APPENDIX ONE

Riverhead Compaction and Amelioration Trial. In very wet sites, passage of the skidder wheels displaced soil, forming a 20-30 cm high ridge, with a reduced compactive effect. Seedlings planted into these ridges were growing actively in June 1998 (plot 2).

APPENDIX TWO

Riverhead Compaction and Amelioration Trial. Four adjacent rows in the central 20 by 20 m cores of plot 17. Seedlings planted into the alternate compacted strips have high mortality, in contrast to the alternate uncompacted rows where seedlings are actively growing, June 1998.

Appendix 2a: Rows 2 (compacted soil) and 3 (uncompacted soil)

APPENDIX TWO

Riverhead Compaction and Amelioration Trial. Four adjacent rows in the central 20 by 20 m cores of plot 17. Seedlings planted into the alternate compacted strips have high mortality, in contrast to the alternate uncompacted rows where seedlings are actively growing, June 1998.

Appendix 2b: Rows 3 (compacted soil) and 4 (uncompacted soil)