THE SITE PREPARATION – TRIAL REVIVAL PROJECT:

SOIL PHYSICAL PROPERTIES and TREE ROOTING PATTERNS

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Contents

Summary

The effects of cultivation (ripping, bedding, or ripping and bedding) on forest soil physical conditions and tree rooting patterns were assessed at rotation end on 6 trial sites, established in the 1970s, in the Central Plateau and Northland. Soil strength profiles, surface relief and general tree rooting patterns were assessed. Soil physical properties were measured at two depths in both cultivated and uncultivated plots.

Bedding cultivation on a Kaingaroa soil (Pumice Soil) had negligible effects on soil physical properties, tree rooting patterns and wood production at tree rotation end, despite early benefits in tree performance from some frost protection. Winged ripping a Kaingaroa soil significantly improved soil physical conditions and rooting patterns into the welded subsoil. However, these improvements had no effect on wood production, despite early improvements to tree growth and stability. Ripping a Pokaka soil (Allophanic Soil), with an unwinged rock ripper, loosened a narrow zone of subsoil down to a maximum depth of about 80 cm. Intermittent narrow cavities remained in the subsoil at about 0.5 m along the ripper path after 25 years. Tree roots exploited the narrow zone of loosened subsoil, resulting in slight increases in wood production compared with unripped soil.

In contrast to the Central Plateau results, ripping Rangiuru clay (Ultic Soil) and Te Kopuru sand (Podzol) soils in Northland had relatively minor impacts on improving soil physical conditions near the end of the tree crop rotation. Wood production on the Te Kopuru sand was slightly reduced in cultivated plots. The opposite result, i.e. slightly increased wood production, was recorded for the Rangiuru clay. Ripping and bedding approximately doubled the topsoil depth in the bed for a Wharekohe silt loam (Ultic Soil) but ripping had no observable long-term effect on the impeding pan at about 30 cm depth. Wood production was slightly increased by cultivating the Wharekohe soil.

Modern forest cultivation machinery and techniques are likely to be more effective in loosening impeding subsoils than the cultivation methods used over 20 years ago because of technological improvements for forest soil cultivation. Rooting volume and tree production should be significantly improved from modern cultivation of North Island soils with impeding subsoils or pans.

1. Introduction

A series of cultivation trials were established in the 1970s and early 1980s by the Forest Research Institute on a variety of soils throughout New Zealand to examine the effects of cultivation and fertiliser at time-of-planting. The cultivation/fertiliser experiments were installed as split-plot factorials, with the main plots as the cultivation treatments (either ripping, or ripping and bedding) and fertiliser as sub-plots. Descriptions and early results from the North Island trials are presented in Williamson (1985), Hunter and Skinner (1986), Mason and Cullen (1986), and Mason et al. (1988). More recent reviews (Hunter-Smith et al. 1996 and Smith et al. 1996) summarize site preparation techniques in New Zealand and overseas.

Data on long-term effects of cultivation on wood production (tree productivity) from these trials were collected in the trials' main plots near rotation end (i.e. just before harvest). These results were reported in Skinner et al. (2001a,b).

The second component of the project was to examine soil physical conditions on a sub-set of the trials, covering a range of textural classes. Comparisons of soil physical conditions and rooting patterns between cultivated and uncultivated plots aimed to help provide explanations for the tree production results. This report presents the results of soil physical examinations for 6 of the North Island trial sites (Table 1).

Table 1 Trial identification, location, soil type, ownership at the time of sampling, and stand establishment year/age at sampling

Trial Identification	Location and Cultivation Treatments	Soil Type (classification)	Forest Managers	Stand Establishment Year (age at sampling)
RO1063	Kaingaroa Forest control and bedded	Kaingaroa loamy sand (Pumice Soil)	Timber Management Co.	1976 (26)
RO1964	Kaingaroa Forest control and ripped	Kaingaroa gravelly sand over silt loam (Pumice Soil)	Timber Management Co.	1978 (24)
WN261/2	Karioi Forest control and ripped	Pokaka loamy sand (Allophanic Soil)	Winstone Pulp International	1977 (25)
AK578/1	Aupouri Peninsula, Te Kao Forest control & ripped	Te Kopuru sand (Podzol)	CHH Forests	1973 (30)
AK578/2	Aupouri Peninsula, Te Kao Forest control & ripped	Rangiuru Clay (Ultic Soil)	CHH Forests	1973 (30)
AK662	Utakura Forest control and ripped&bedded	Wharekohe silt loam (Ultic Soil)	Utakura Seven	1975 (28)

Cultivation treatments were:
RO1063 – bedding (inverted discs) following shear-blading and burning
RO1064 – ripped one-way to about 40 cm with a V-shaped ripper on a Terex tractor
WN261/2 – ripped one-way to about 60 cm with an unwinged rock tine ripper on a D8 bulldozer
AK578/1&2 – ripped one-way to between 30 and 60 cm with an unwinged rock tine ripper on a bulldozer and then rotary hoed
AK662 – ripped one-way and bedded using the twin discs, double pass technique followed by rotary hoeing.

2. Objectives

- To measure soil physical properties across site cultivation treatments on a subset of trials, covering a range of textural classes
- To assess plant rooting patterns
- To correlate soil physical conditions and rooting patterns with changes in tree productivity resulting from the cultivation treatments

3. Methods

A control and two representative cultivated plots were selected for each trial.
Penetration resistance (soil strength) profiles were measured down to a maximum depth of 0.7 m, along a 3-m transect at right angles to the direction of cultivation (tree rows), using an Eijkelkamp recording penetrometer (*Penetrologger* model 06.15.01, 30°; 1.6 cm diam. cone at 2 cm/sec). The transects were located about 1m from trees and were centred on the middle of a row of tree trunks. Soil samples at 10 cm increments down to 70 cm were collected for moisture content profiles, to assess the effect of water contents on penetration resistances (data not presented here).

Microtopography of the ground surface along the same transect was measured from a horizontal (using an Abney level) string mounted on stakes above the highest point of the transect.

A trench was dug to a maximum depth of 1 m, or to an impenetrable[1] layer, using a small hydraulic excavator. A general profile description was made, and photographs taken, of tree rooting patterns and depths to mottling or an impenetrable layer.

Soil cores (about 600 cm^3) from 2 depths (in topsoil and subsoil horizons or upper and lower topsoils) were sampled within what was thought to be the cultivated zone for the cultivated treatments or in a similar location relative to the tree row in the control plot. Moisture release, using the methods described in Gradwell (1972), was used to assess macroporosity and total available water. Bulk density was measured from the cores. The data presented are the average of four replicates.

[1] Impenetrable is defined here as high strength, dense or cemented soil layers that tree roots cannot penetrate (although limited roots may go down cracks). A soil penetration resistance of 3 Mpa is regarded as critical for tree roots.

4. Results and Discussion

4.1 Central Plateau Sites

Soil strength[2] profile isopleths for the Central Plateau trials (RO1063, RO1964 & WN261/2) are given in Figs 1–3. The bedding zone of raised topsoil (see the surface relief profiles) shows as low strength (Fig.1) in trial RO1063 (Kaingaroa loamy sand) but otherwise there are negligible differences in soil strength profiles between cultivated and uncultivated soils.

In contrast, U-shaped zones of significantly loosened soil are clearly evident in the ripped zones of RO1964 (Kaingaroa sand, Fig. 2), extending about 1 m wide at 40 cm depth and down to a total depth of about 70 cm. These loosened zones also contain many tree roots, in contrast to negligible roots in the unripped, welded pumice subsoil. The ripped soil strength profiles contrast with unripped profiles, where the welded pumice becomes impenetrable (to the penetrometer) at about 30 cm depth.

Subsoil loosening to about 70 cm from ripping in a much narrower zone, about 10–20 cm wide, is also evident in trial WN261/2 (Pokaka loamy sand, Fig. 3). Both ripped sites had narrow cavities, akin to mole drains, about 10–15 cm wide between about 40 and 80 cm depth where the ripper had passed. Some natural lenses of low-strength subsoil were also seen in the unripped soil profile. Unlike the shattering effect of the winged ripper in the Kaingaroa soil, the straight shank ripper in the Pokaka soil (with subsoil layers of greasy silt loams, pumice gravels, and fine loamy sands) only loosened a thin band of soil down to about 80 cm but left intermittent cavities in the subsoil for 25 years. Tree roots particularly were concentrated down ripped zones and were even found in the cavities. However, there was also a scattering of tree roots throughout the subsoil in the unripped control soil.

Bulk density, macroporosity and total available water data for two depths are given in Figs 4–6; all the moisture release data are presented in the Appendix 1. Bedding (RO1063, Fig. 4) had no statistically significant effects on these soil physical properties, although the bedded subsoil (25–33 cm) showed a trend of lower bulk density and higher porosity than uncultivated subsoil. Total available water was slightly lower in the bedded topsoil (1–9 cm) compared with uncultivated.

In contrast, winged ripping the pumice soil (RO1964, Fig 5) significantly decreased bulk density and total available water, and increased macroporosity in the subsoil (25–38 cm) compared with no cultivation. Differences in the topsoil (1–9 cm) of these physical properties between ripping and no cultivation were insignificant.

Ripping the soil developed from andesitic ash and pumice at Karioi (WN261/2, Fig 6) had a major loosening effect on soil physical properties in the subsoil (30–43 cm) but not the topsoil (1–9 cm). Bulk density and total available water were significantly lower, and macroporosity higher in the ripped zone compared to uncultivated subsoil.

Figures 7–9 illustrate soil profiles and tree root patterns for the Central Plateau trials.

[2] Soil strength, as used in this report, is the same as penetration resistance

4.2 Northland Sites

Soil strength profile isopleths for the Northland trials (AK578/1&2, AK662) are given in Figs 10–12. Soil strength profiles (Fig.10) in the Rangiuru clay (trial AK578/2) reflect a pattern of naturally low- and high-strength zones. Ripped plot 1 has a 1.5-m-wide zone centred on the tree line with low strengths down to about 30 cm. Ripped plot 7 is characterised by relatively low soil strengths for a large portion of the profile. No obvious effects of soil loosening from ripping are apparent in the subsoil. Soil relief profiles do not give a strong indication of where the rip line was. The high strength, about 5 cm thick zone at about 40 cm was caused by a gravel layer within the clay. The gravel periodically prevented the penetrometer probe from being able to be pushed deeper and, thus, is the reason for the impenetrable areas on two of the profiles. There is evidence on one of the ripped plots that the ripper just disrupted this gravel layer, which might explain the more complete high-strength gravel layer in the unripped control plot. There was no strong evidence that rooting patterns were affected by ripping the Rangiuru clay soil.

Soil strength profiles for trial AK578/1 (Te Kopuru sand, Fig 11) are a strong contrast with the other trials. The penetrometer was unable to penetrate the bleached, silica-cemented sand E horizon, normally at about 30 cm, for both uncultivated and ripped plots. Cemented humus-iron pans extended to considerable depth (> 1m) beneath the E horizon. Low soil strengths were confined to the topsoil in all cases, although ripping may have resulted in extension of the low strength zone in plot 1 to about 40cm. However, in plot 7 there is a marked thinning of zones of low strength/topsoil from 30 cm to about 10 cm across the transect. Ripping thus had negligible observable impact on subsoil strengths and rooting patterns. Either the ripper did not penetrate the impeding pans or they re-cemented quickly after cultivation and before roots could penetrate the loosened soil and prevent re-cementation. Silica cementation causes the pan in the E horizon and humus, humus-iron complexes and/or iron cementation the underlying pans. Surface relief profiles give no indication where the rip lines were located.

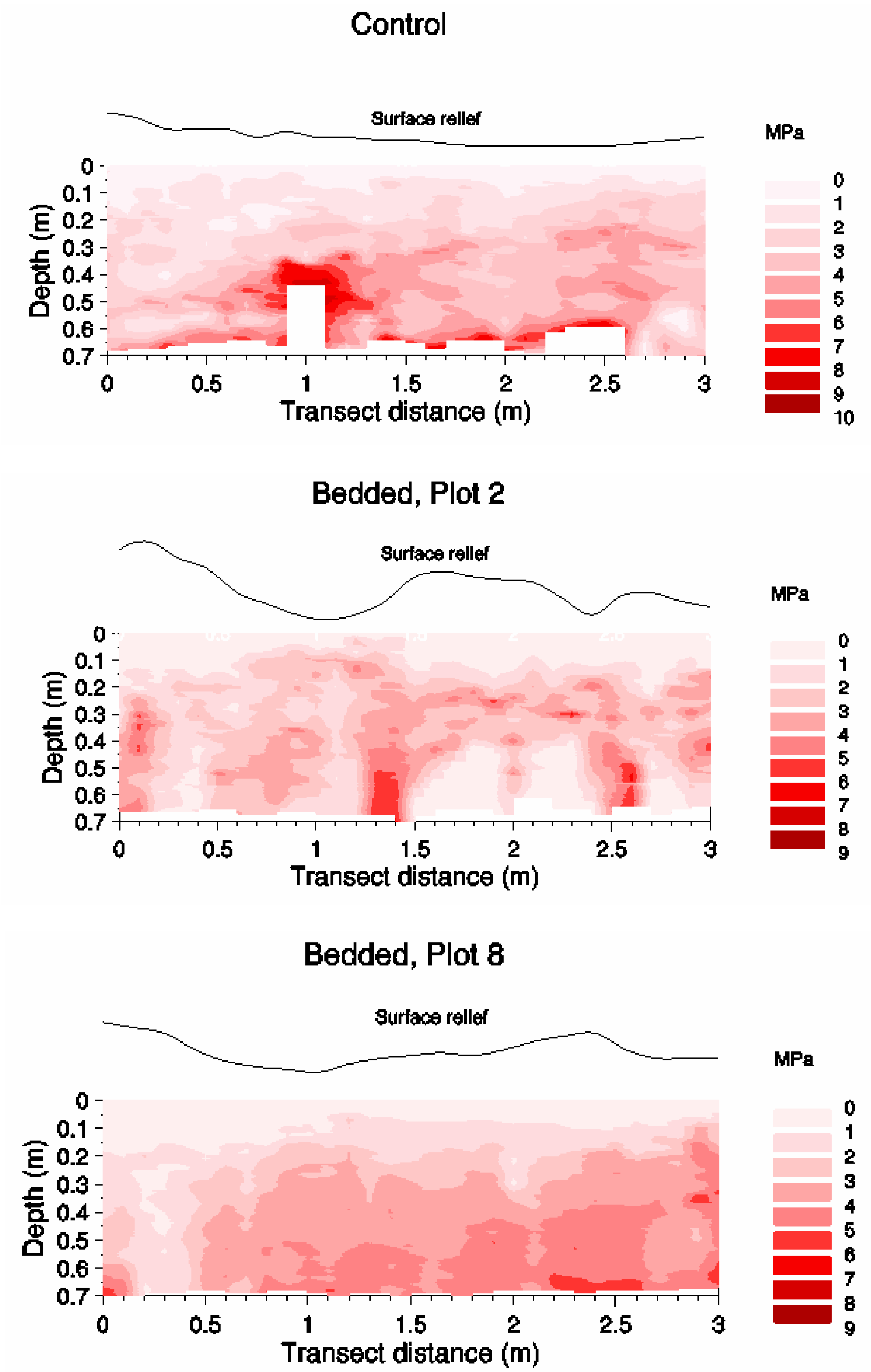

Fig. 1 Soil strength profile isopleths for RO1063, shear-blading and bedding trial.

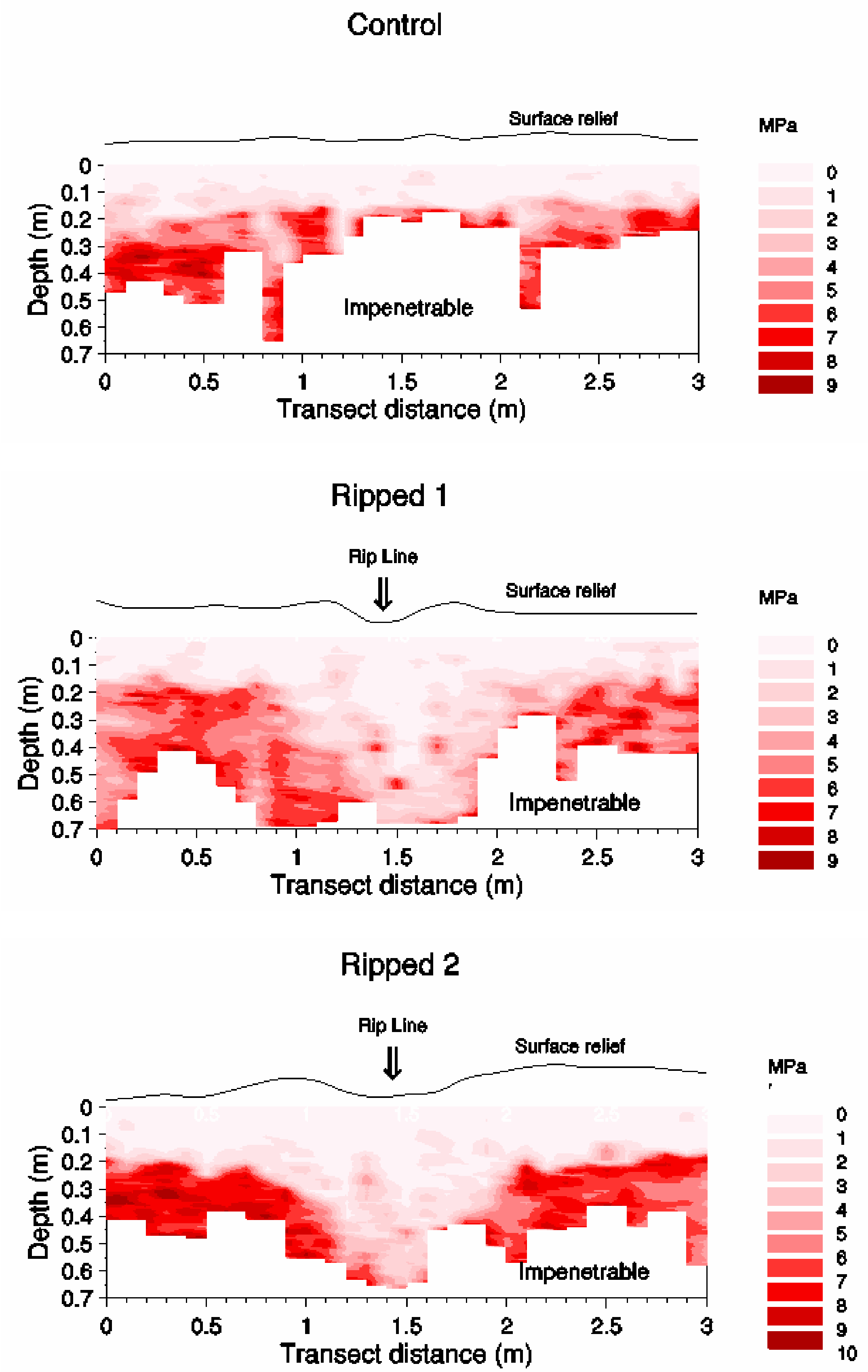

Fig. 2 Soil strength profile isopleths for RO1964, ripping trial.

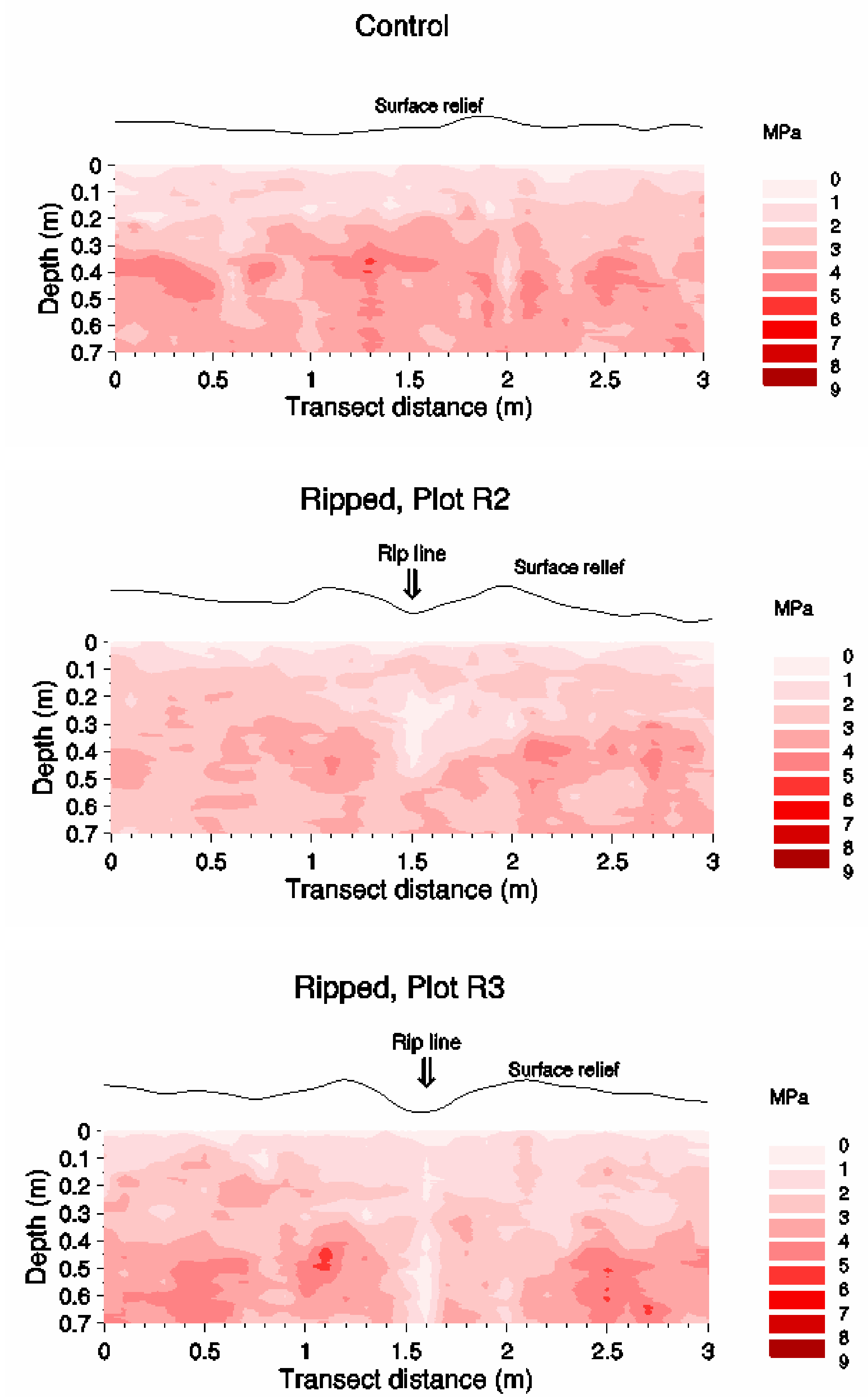

Fig. 3 Soil strength profile isopleths for WN261/2, ripping trial.

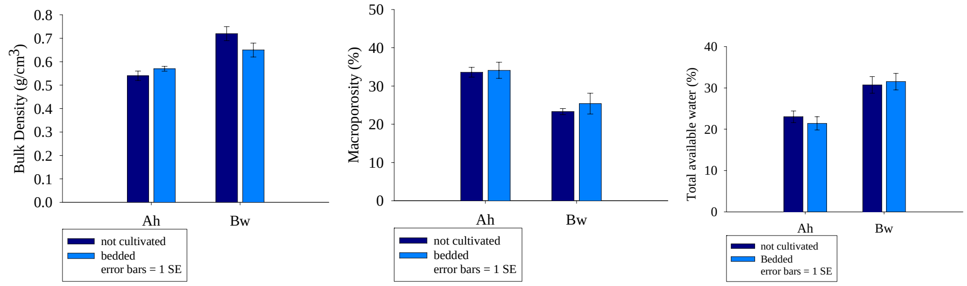

Fig 4 Bulk density, macroporosity and total available water at two depths (Ah 0–10 cm & Bw 20–40 cm) for RO1063, shear-blading and bedding trial.

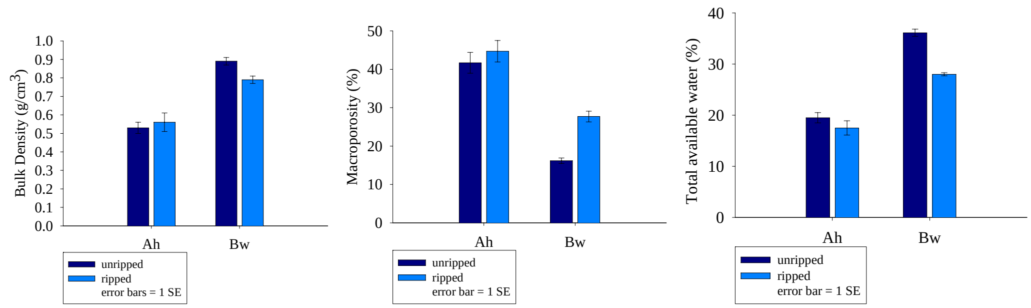

Fig 5 Bulk density, macroporosity and total available water at two depths (Ah 0–10 cm & Bw 20–40 cm) for RO1964, ripping trial.

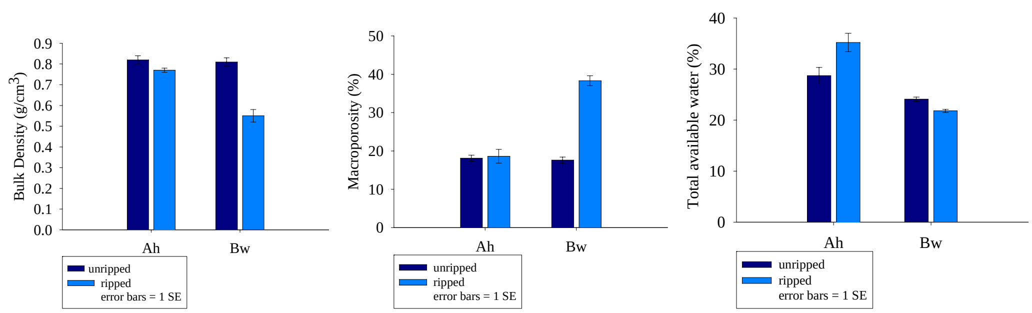

Fig 6 Bulk density, macroporosity and total available water at two depths (Ah 0–10 cm & Bw 30–50 cm) for WN261/2, ripping trial.

Fig 7 Effects of bedding on the soil profile and rooting patterns for trial RO1063.
The centre of the trench is aligned with the tree row. Scale marker is in 10-cm increments.

Figure 8. Effects of ripping on the soil profile for trial RO1964, showing significant tree roots in the loosened zone. Note the impeding welded pumice subsoil adjacent to the ripped zone. The centre of the trench is aligned with the tree row. Scale marker is in 10-cm increments.

Fig. 9 Effects of ripping on the soil profile for trial WN261/2, showing roots extending into the subsoil down the narrow ripped zone and a small cavity left by the unwinged ripper. Scale marker is in 10-cm increments.

Soil strength profiles at the Utakura site (Wharekohe silt loam, AK662, Fig. 12) illustrate the bedding effect through both surface relief and approximately doubling the depth of the low-strength, topsoil zone from about 15 cm deep in the uncultivated plot to about 30 cm in the cultivated. The impenetrable nature of the E horizon pan is clearly shown by the sudden rise in very high soil strengths at about 15 cm in the control and 30 cm under the bed. Rooting patterns were strongly aligned to the topsoil and thus were concentrated in the beds of the cultivated treatment. Only a few roots penetrated the lower topsoil horizon (Ah_2).

Bulk density, macroporosity and total available water for the Northland trials are presented in Figs 13–15. Cultivation resulted in a lower macroporosity in the ripped 0–10 cm AB horizon, and in higher total available water in the subsoil of the Rangiuru clay (AK578/2, Fig. 13). There is no rational reason for these results and they probably reflect soil variability rather than any real effects of cultivation.

Significantly lower bulk densities but higher macroporosities and total available water were recorded in the upper topsoil (Ah_1) of the ripped Te Kopuru sand (AK578/1, Fig. 14). This might reflect minor physical improvements from ripping in the surface soil layer. However, there were no significant differences for the lower topsoil (Ah_2).

Ripping and bedding increased the bulk density and decreased the total available water of the upper topsoil (Ah_1) compared with no cultivation of the Wharekohe soil at the Utakura site (AK662, Fig. 15). These results probably relate to soil compaction during the bedding process. There were no other differences in soil physical properties attributable to cultivation.

Tree rooting patterns and soil profiles are illustrated in Figs 16–18. A summary of effects of cultivation on tree rooting patterns and wood production is given in Appendix 2.

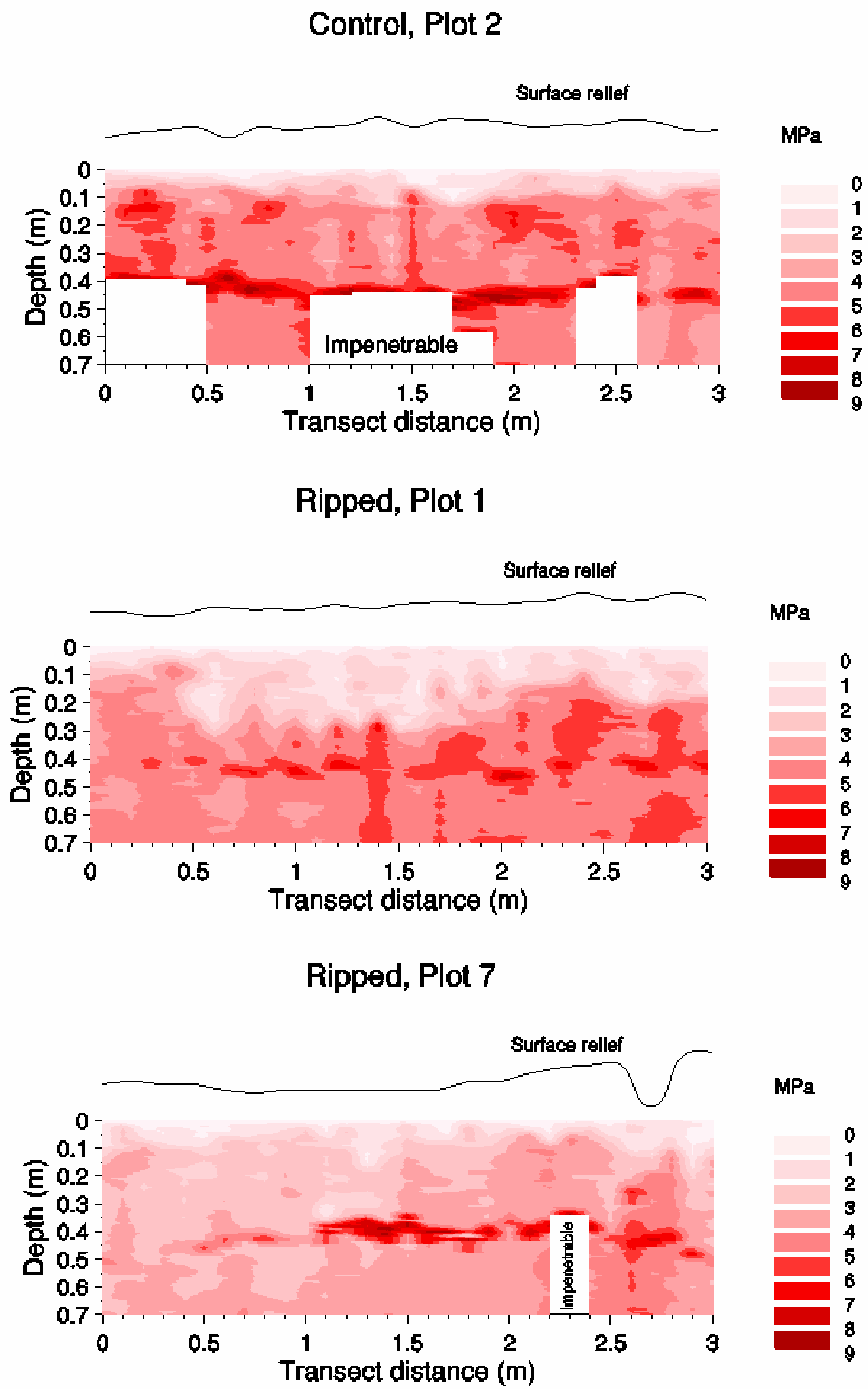

Fig. 10 Soil strength profile isopleths for AK578/2, ripping trial.

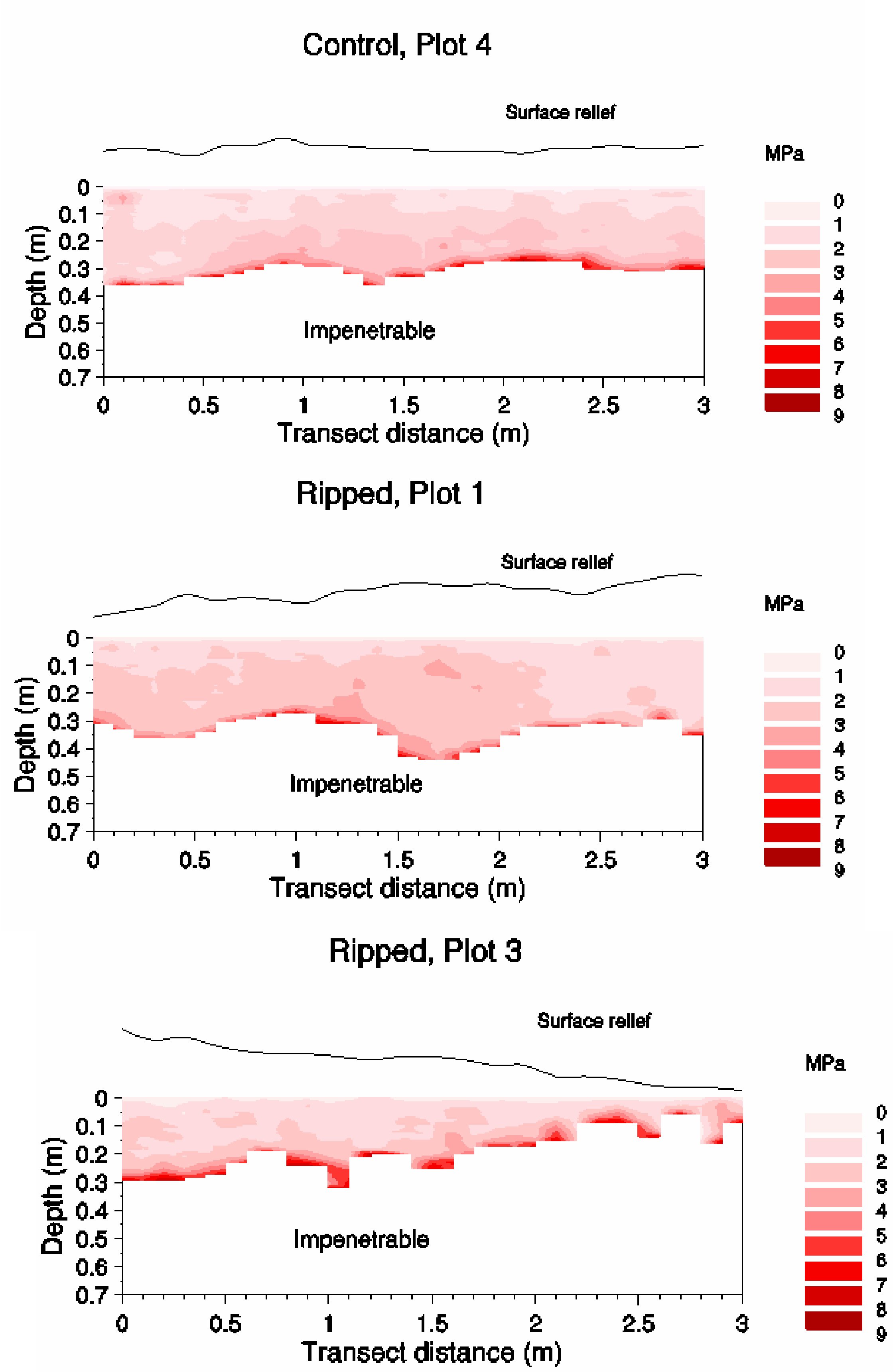

Fig. 11 Soil strength profile isopleths for AK578/1, ripping trial.

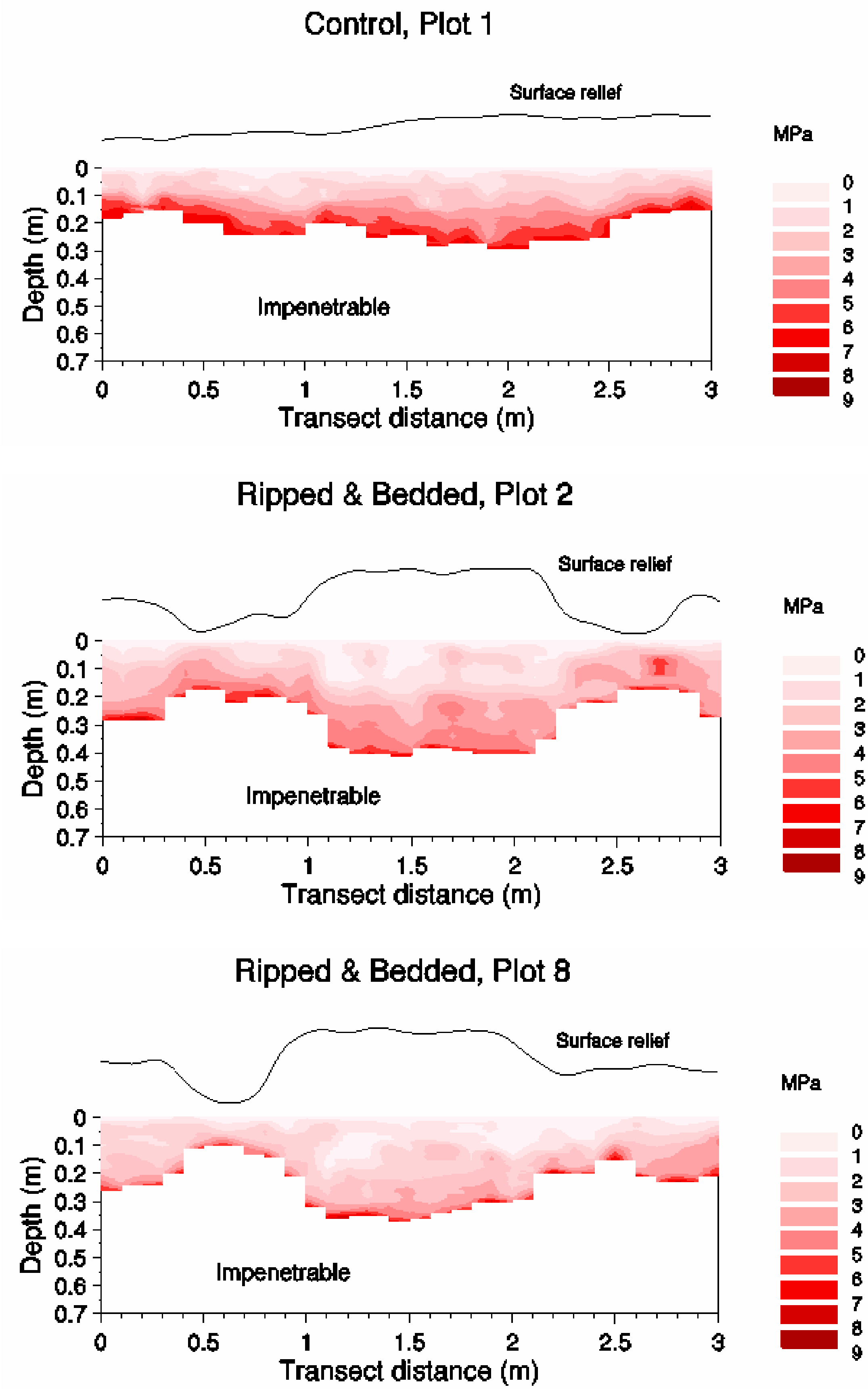

Fig. 12 Soil strength profile isopleths for AK662, ripping and bedding trial.

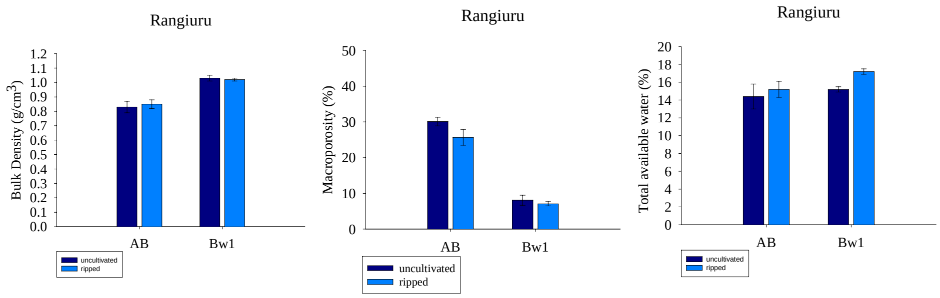

Fig. 13 Bulk density, macroporosity and total available water at two depths (Ah 0–10 cm & Bw 20–30 cm) for AK578/2, ripping trial.

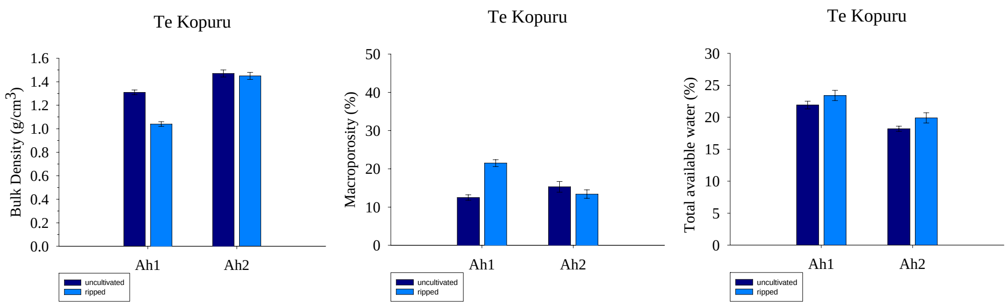

Fig. 14 Bulk density, macroporosity and total available water at two depths (Ah_1 0–10 cm & Ah_2 20–30 cm) for AK578/1, ripping trial.

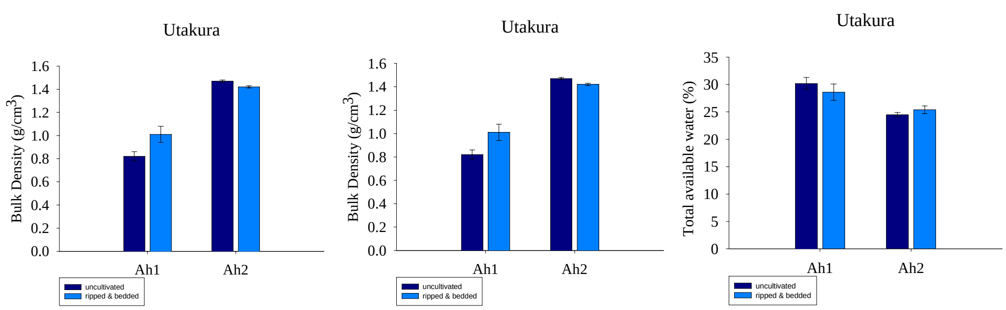

Fig. 15 Bulk density, macroporosity and total available water at two depths (Ah_1 0–10 cm & Ah_2 20–30 cm) for AK662, ripping and bedding trial.

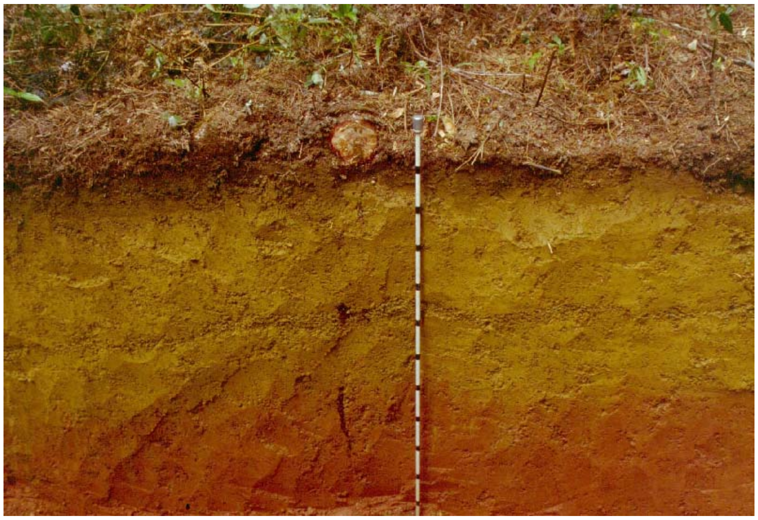

Fig. 16 Soil profile and tree rooting pattern of a ripped plot for trial AK578/2, showing negligible observable effects of ripping. Note the gravel layer at about 40 cm. The centre of the trench is aligned with the tree row. Scale marker is in 10-cm increments.

Figure 17. Soil profile and tree rooting pattern for a ripped plot for Trial AK578/1, showing negligible observable effects of ripping. Note that pine tree roots are limited to the topsoil horizons. The centre of the trench is aligned with the tree row. Scale marker is in 10-cm increments.

Fig. 18 Soil profile and tree rooting patterns for a ripped and bedded plot for Trial AK662. Note that tree rooting is limited to the topsoil and was unable to penetrate the underlying densipan. The centre of the trench is aligned with the tree row. Scale marker is in 10-cm increments.

5. Wood Production

Tree performance, as measured by wood production, is presented for the six North Is. trials in Fig. 19.

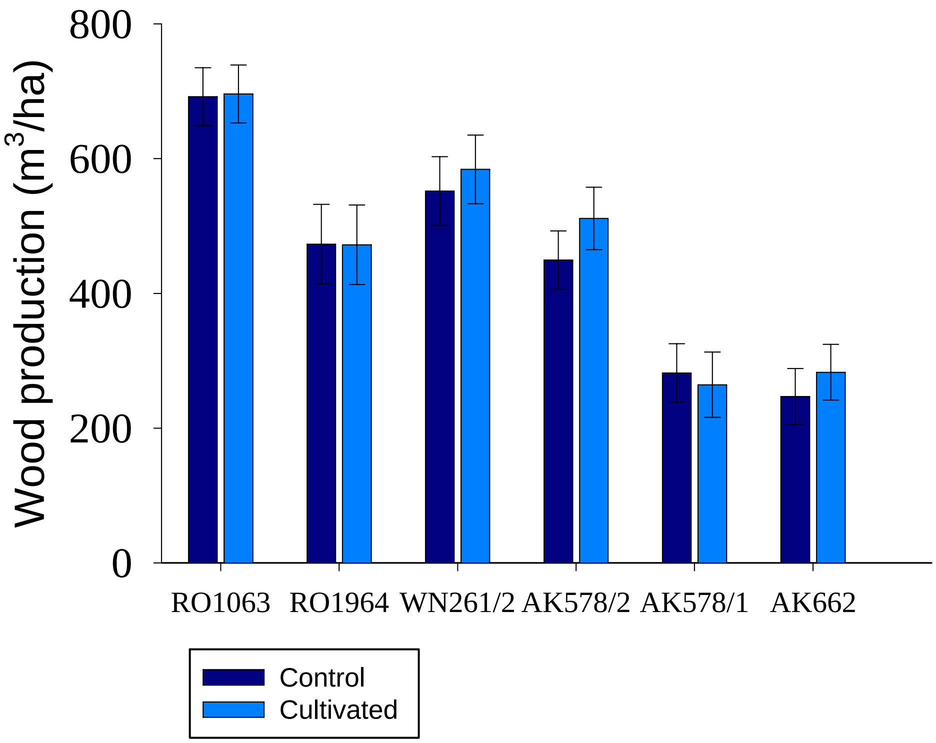

Fig. 19 Effect of cultivation on harvest wood volume at six North Is. trial sites (from Skinner et al. 2001b).

6. Conclusions

- Bedding cultivation was ineffectual in improving soil conditions, root growth or long-term (24 years) wood production in a Kaingaroa loamy sand (trial RO1063) on the Central Plateau, despite better frost tolerance at forest establishment.

- Ripping significantly improved subsoil physical properties and root penetration into the 'welded' pumice subsoil of a Kaingaroa gravelly sand (trial RO1964), persisting over 24 years. Wood production was not increased by ripping Kaingaroa gravelly sand, despite early advantages to tree growth and stability. Compensatory growth and sufficient soil nutrients in the topsoil for one tree crop rotation have overcome the disadvantages of not ripping the soil before planting.

- Ripping at Karioi (Pokaka loamy sand – Allophanic Soil, trial WN261/2) incorporated topsoil into the upper subsoil, improved soil physical properties and root penetration in a narrow subsoil slit; leaving 25 cm x 7 cm cavities at about 50 cm, containing many roots. Ripping marginally increased wood production (by 30 m^3/ ha) on this soil.

- Ripping Rangiuru clay (trial AK578/2) and Te Kopuru sand (trial AK578/1) soils in Northland had relatively minor impacts on improving soil physical conditions and rooting patterns at the end of a pine forest rotation. These results contrast with very obvious ripping effects on the Central Plateau cultivation trial sites.

- Ripping marginally increased wood production (+62 m^3/ ha) on the Rangiuru soil. Improved soil physical conditions and root penetration early in the rotation probably boosted initial tree growth. There is no evidence, however, of significant effects of cultivation on this soil at tree maturity.

- Ripping did not appear to enhance rooting significantly into the impeding E horizon (bleached sand) and underlying humus pan (Bhm) of the Te Kopuru soil, probably because the ripper did not significantly penetrate the pans. The non-significant difference in wood production between ripped and unripped areas on the Te Kopuru soil accords with the soil physical results and tree rooting patterns.

- Ripping and bedding approximately doubled the rooting depth (limited to the topsoil layers) in the bedding zone at the Utakura trial (Wharekohe soil, trial AK622). Only slight changes in topsoil physical properties, caused by cultivation, were found. Ripping did not improve root penetration into the impeding pan (an Erd densipan horizon).

- Ripping and bedding marginally increased wood production (+36 m^3/ ha) on the Wharekohe soil. Although the ripping was not effective in loosening the Erd horizon pan to increase rooting depth, bedding approximately doubled the rooting soil volume along tree rows (but decreased it between rows). This suggests combined mounding and ripping may be more beneficial for tree production on these Ultisols (but not Podzols)[3].

[3] Bedding in these trials formed continuous topsoil mounds using discs then rotary-hoeing. Mounding and ripping in one operation, with hydraulic excavators, creates isolated mounds of soil.

- The cultivation techniques used in these studies over 20 years ago were not as advanced as those available now. Modern forest cultivation machinery and techniques are likely to be more effective in loosening impeding subsoil pans than the machinery used in these trials. Rooting volume and tree production should be significantly improved from modern cultivation of North Island soils with impeding subsoils or pans.

7. Acknowledgements

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Appendix 1 – Moisture release data

Table of soil physics data from Forestry Trial Revival sites at Kaiangaroa, Karioi, and Northland forests.

Means, standard deviations and standard errors for four replicate samples per treatment depth.

Forest	Site	Treatment	Plot	Horiz	Depth	Bulk Dens.	Porosity	Macro-porosity	Air Capacity	Field Capacity	TAW		Gravimetric water content				Volumetric water content				
											(10-1500)	Field	@ Sat (calc)	@ -5 kPa	@ -10 kPa	@ -1500 kPa	@ Sat (calc)	@ -5 kPa	@ -10 kPa	@ -1500 kPa	Field
					(cm)	(g/cm^3)	(%)	(%)	(%)	(%)	(%)		(g/100g)				(m^3/100m^3)				
Kaiangaroa	cpt 1031	Control	1	Ah	1-9	0.54	76.2	33.6	43.6	32.7	23.0	44	142	79.3	60.7	17.9	76	42.7	32.7	9.6	24
						0.03	1.2	1.9	2.3	2.0	2.1	4	9	5.5	4.8		1	1.7	2.0		2
						0.02	0.8	1.3	1.5		1.4										
Kaiangaroa	cpt 1031	Control	1	BwA	25-33	0.72	68.7	23.3	28.3	40.4	30.7	53	95	63.0	56.0	13.4	69	45.4	40.4	9.7	38
						0.04	1.8	1.2	1.0	2.4	2.9	6	8	6.9	6.2		2	2.6	2.4		3
						0.03	1.2	0.8	0.7		2.0										
Kaiangaroa	cpt 1031	Shearblade & bed	2	Ah	1-9	0.57	75.3	34.1	42.4	32.9	21.4	49	133	72.7	58.1	20.3	75	41.2	32.9	11.5	28
						0.02	0.9	3.2	2.8	2.5	2.4	4	6	5.8	4.3		1	3.0	2.5		2
						0.01	0.6	2.1	1.9		1.6										
Kaiangaroa	cpt 1031	Shearblade & bed	2	Bw	25-33	0.65	72.5	25.4	30.4	42.1	31.5	61	113	72.9	65.1	16.4	72	47.1	42.1	10.6	39
						0.04	1.9	4.1	5.1	3.5	3.0	4	11	2.9	3.6		2	2.4	3.5		4
						0.03	1.3	2.7	3.4		2.0										
Kaiangaroa	cpt 1031	Shearblade & bed	8	Ah	1-9	0.68	73.4	21.7	33.6	39.8	28.4	44	109	76.4	58.8	16.9	73	51.7	39.8	11.4	30
						0.07	2.9	7.4	7.2	4.7	3.5	3	14	3.6	2.1		3	4.8	4.7		6
						0.05	1.9	5.0	4.8		2.3										
Kaiangaroa	cpt 1031	Shearblade & bed	8	Bw	25-33	0.63	72.2	23.4	31.4	40.8	32.6	53	115	77.3	64.7	13.0	72	48.8	40.8	8.2	33
						0.03	1.4	3.1	2.9	1.7	1.3	2	8	2.0	1.8		1	1.8	1.7		1
						0.02	0.9	2.1	1.9		0.9										

Kaiangaroa	cpt 558	Control		Ah	1-9	0.53	77.4	41.7	47.8	29.7	19.5	55	146	67.1	55.7	19.1	77	35.7	29.7	10.2	29
						0.04	1.7	4.1	3.7	2.2	1.6	3	13	2.3	2.0		2	2.5	2.2		2
						0.03	1.1	2.7	2.5		1.0										
Kaiangaroa	cpt 558	Control		Bw	19-27	0.89	61.2	16.2	21.0	40.3	36.1	41	69	50.6	45.3	4.7	61	45.1	40.3	4.1	37
						0.03	1.2	1.0	1.2	0.9	1.0	2	4	2.2	2.0		1	0.9	0.9		1
						0.02	0.8	0.7	0.8		0.7										
Kaiangaroa	cpt 558	Rip	Pit 1	Ah	1-9	0.56	75.8	44.7	49.5	26.3	17.5	45	137	56.0	47.2	15.6	76	31.2	26.3	8.8	25
						0.07	3.0	4.3	3.8	2.0	2.2	4	25	8.6	6.6		3	2.9	2.0		2
						0.05	2.0	2.8	2.5		1.4										
Kaiangaroa	cpt 558	Rip	Pit 1	Bw	30-38	0.79	66.1	27.7	34.4	31.7	28.0	34	84	49.0	40.4	4.7	66	38.5	31.7	3.7	27
						0.04	1.6	2.1	1.9	0.6	0.5	2	6	2.1	1.6		2	0.9	0.6		1
						0.02	1.0	1.4	1.3		0.3										
Kaiangaroa	cpt 558	Rip	Pit 2	Ah/Bw	1-9	0.48	79.4	46.5	52.2	27.2	18.0	57	168	69.4	57.2	19.3	79	33.0	27.2	9.2	27
						0.04	1.8	2.9	3.1	1.3	0.7	5	19	5.1	2.8		2	1.4	1.3		1
						0.03	1.2	1.9	2.1		0.4										
Kaiangaroa	cpt 558	Rip	Pit 2	Bw	25-33	0.52	77.1	38.5	46.5	30.6	27.1	50	147	73.4	58.3	6.6	77	38.5	30.6	3.4	26
						0.02	0.7	3.1	2.0	1.3	1.2	1	6	2.6	1.2		1	2.4	1.3		1
						0.01	0.5	2.1	1.3		0.8	44									
Karioi	cpt 16	Ripped	R2	Ah	1-9	0.77	69.5	18.6	22.0	47.5	35.2	63	90	66.2	61.8	15.9	69	51	47	12.2	49
						0.02	0.8	2.6	3.1	2.8	2.7	4	3	2.9	3.4		1	2	3		3
						0.01	0.5	1.8	2.1		1.8										
Karioi	cpt 16	Ripped	R2	Bw1	30-38	0.55	77.7	38.3	44.9	32.8	21.8	64	142	71.9	59.8	19.9	78	39	33	10.9	35
						0.04	1.7	1.9	2.7	1.0	0.4	4	15	5.5	3.1		2	0	1		1
						0.03	1.2	1.3	1.8		0.3										
Karioi	cpt 16	Ripped	R3	Ah	1-9	0.84	66.4	27.5	32.1	34.4	17.3	41	80	46.5	41.1	20.4	66	39	34	17.1	34
						0.02	0.9	1.3	1.3	1.0	1.1	2	3	1.8	1.6		1	1	1		1

						0.01	0.6	0.9	0.9		0.8										
Karioi	cpt 16	Ripped	R3	AB	34-42	0.69	71.9	26.6	31.3	40.5	23.3	57	104	65.4	58.5	24.9	72	45	41	17.2	40
						0.02	0.7	1.5	2.0	1.3	0.9	1	4	0.7	0.6		1	1	1		2
						0.01	0.5	1.0	1.3		0.6										
Karioi	cpt 16	Control	U3	Ah	1-9	0.82	67.3	18.1	21.3	46.0	28.7	58	83	60.4	56.4	21.2	67	49	46	17.3	48
						0.03	1.2	1.2	1.4	1.9	2.4	4	4	3.8	4.0		1	2	2		2
						0.02	0.8	0.8	1.0		1.6										
Karioi	cpt 16	Control	U3	Bw1	35-43	0.81	67.3	17.6	21.2	46.1	24.1	58	83	61.1	56.7	27.0	67	50	46	22.0	47
						0.03	1.2	1.2	1.8	0.7	0.6	2	4	2.3	1.5		1	0	1		0
						0.02	0.8	0.8	1.2		0.4										
Rangiuru		Ripped	1	AB	0-8	0.83	68.8	28.6	29.9	39.0	14.1	36	83	48.2	46.8	29.9	69	40	39	24.9	30
						0.07	2.5	6.6	6.6	4.3	2.8	2	10	2.8	2.8		2	4	4		4
						0.04	1.7	4.4	4.4		1.8										
Rangiuru		Ripped	1	Bw1	20-28	1.04	61.8	7.2	8.2	53.5	16.5	44	59	52.3	51.3	35.5	62	55	54	37.0	46
						0.02	0.8	1.8	1.6	0.8	0.3	0	2	0.3	0.5		1	1	1		1
						0.02	0.6	1.2	1.0		0.2										
Rangiuru		Control	2	AB	0-8	0.83	68.9	30.1	31.5	37.4	14.4	33	84	47.1	45.5	27.9	69	39	37	23.1	27
						0.06	2.1	1.8	1.6	0.7	2.2	1	8	3.7	3.8		2	1	1		1
						0.04	1.4	1.2	1.1		1.4										
Rangiuru		Control	2	Bw1	20-28	1.03	62.6	8.1	9.0	53.6	15.2	46	61	53.1	52.1	37.4	63	55	54	38.4	48
						0.03	0.9	2.2	2.2	1.3	0.5	0	2	0.5	0.4		1	1	1		2
						0.02	0.6	1.4	1.5		0.3										
Rangiuru		Ripped	7	AB	0-8	0.87	67.3	22.8	23.9	43.5	16.4	42	80	52.2	51.0	31.3	67	45	43	27.1	35
						0.14	5.3	8.3	8.2	3.9	3.8	7	20	7.3	7.2		5	4	4		3
						0.09	3.5	5.5	5.5		2.5										
Rangiuru		Ripped	7	Bw1	20-28	1.00	63.7	7.0	7.5	56.2	17.8	55	64	56.9	56.4	38.5	64	57	56	38.4	54
						0.04	1.4	2.3	2.5	1.2	0.8	1	4	1.6	1.3		1	1	1		1

					0.02	0.9	1.6	1.6		0.6										
Te Kopuru	Ripped	1	Ah1	0-10	1.08	56.1	20.4	29.4	26.7	20.9	20	52	33.2	24.8	5.4	56	36	27	5.9	22
					0.09	3.6	3.9	3.5	1.4	1.6	3	8	4.0	2.9		4	2	1		2
					0.06	2.4	2.6	2.3		1.1										
Te Kopuru	Ripped	1	Ah2	20-30	1.48	42.0	14.3	20.2	21.8	18.3	13	28	18.8	14.8	2.4	42	28	22	3.5	19
					0.01	0.6	1.0	0.4	0.6	0.6	0	1	0.8	0.5		1	1	1		1
					0.01	0.4	0.6	0.3		0.4										
Te Kopuru	Control	4	Ah1	0-10	1.31	47.1	12.5	20.1	27.0	21.9	19	36	26.5	20.7	3.9	47	35	27	5.1	25
					0.03	1.2	1.1	0.9	0.8	0.9	1	2	0.7	1.0		1	0	1		1
					0.02	0.8	0.7	0.6		0.6										
Te Kopuru	Control	4	Ah2	20-30	1.47	42.3	15.3	20.5	21.8	18.2	15	29	18.4	14.9	2.5	42	27	22	3.7	22
					0.04	1.7	2.2	2.1	0.6	0.6	0	2	0.5	0.4		2	1	1		1
					0.03	1.1	1.4	1.4		0.4										
Te Kopuru	Ripped	3		0-10	0.99	59.3	22.7	25.9	33.5	25.9	31	60	37.1	33.9	7.7	59	37	33	7.6	31
					0.03	1.4	2.2	2.1	0.7	0.4	1	4	0.6	0.6		1	1	1		1
					0.02	1.0	1.4	1.4		0.3										
Te Kopuru	Ripped	3		20-30	1.43	42.6	12.4	14.3	28.3	21.4	19	31	21.5	20.1	4.8	43	30	28	6.9	27
					0.17	6.8	5.5	5.8	2.6	3.1	4	9	4.2	3.7		7	3	3		2
					0.11	4.6	3.7	3.9		2.1										
Utakura	Ripped & Bedded	8		0-10	1.04	57.2	15.1	16.8	40.4	32.8	36	60	42.8	41.0	7.3	57	42	40	7.6	36
					0.24	9.9	8.5	8.9	1.9	3.2	9	28	13.1	12.2		10	2	2		1
					0.16	6.6	5.7	5.9		2.2										
Utakura	Ripped & Bedded	8		20-30	1.43	42.7	8.1	9.1	33.6	26.4	21	30	24.1	23.5	5.0	43	35	34	7.2	31
					0.03	1.3	1.1	1.1	2.1	2.2	2	2	2.0	1.9		1	2	2		3
					0.02	0.9	0.7	0.8		1.5										
Utakura	Control	1	Ah1	0-10	0.82	65.2	18.6	23.1	42.1	30.2	38	80	57.4	51.8	14.6	65	47	42	11.9	31
					0.06	2.5	2.4	2.4	1.2	1.6	5	9	5.3	4.5		2	2	1		2

					0.04	1.6	1.6	1.6		1.1										
Utakura	Control	1	Ah2	20-30	1.47	41.7	11.1	12.5	29.2	24.5	16	28	20.8	19.8	3.2	42	31	29	4.7	24
					0.02	0.7	0.8	0.8	0.6	0.6	0	1	0.6	0.5		1	1	1		0
					0.01	0.5	0.5	0.6		0.4										
Utakura	Ripped & Bedded	2		0-10	0.99	58.4	21.1	23.7	34.7	24.3	28	68	40.8	37.8	10.7	58	37	35	10.4	26
					0.29	11.8	13.2	14.0	2.3	1.9	9	43	14.5	12.2		12	2	2		2
					0.19	7.9	8.8	9.3		1.2										
Utakura	Ripped & Bedded	2		20-30	1.40	44.0	12.0	13.4	30.6	24.3	18	31	22.9	21.9	4.5	44	32	31	6.3	25
					0.03	1.0	3.4	3.4	2.9	2.8	2	1	2.0	2.0		1	3	3		3
					0.02	0.7	2.3	2.3		1.9										

Appendix 2 – Summary of cultivation effects on rooting patterns and wood production for 6 North Island trial sites.

+ = slight increase or effect restricted to topsoil
++ marked increase
n.s. = not significant

Trial no	Soil (NZ classification) &	Effect of cultivation on potential rooting volume	Effect of cultivation on observed root volume	Effect on tree volume
Central Plateau Trials				
RO1063	Pumice Soil	+	+	Nil
RO1964	Pumice Soil	++	++	Nil
W261/2	Allophanic Soil	++	+	+ n.s.
North Island Trials				
AK578/2	Ultic Soil	+	n.s.	Nil
AK578/1	Podzol	++	n.s.	- n.s.
AK662	Ultic Soil	+	+?	+ n.s.

Trial no	Soil (NZ classification) &	Depth to root-limiting layer in uncultivated soil (cm)	Depth to root-limiting layer in cultivated soil (cm)	Notes on probable limiting factor
Central Plateau Trials				
RO1063	Pumice Soil	1 m +	1 m +	Coarse pumice
RO1964	Pumice Soil	30	70	Welded pumice
W261/2	Allophanic Soil	1 m +	1 m +	Silt loam subsoil
North Island Trials				
AK578/2	Ultic Soil	40 cm	40 cm	Clay subsoil
AK578/1	Podzol	30–40 cm	30–40 cm	E / Bhm pans
AK662	Ultic Soil	15	30	Erd densipan