GROWTH OF PINUS RADIATA ON RIPPED AND UNRIPPED TAUPO PUMICE SOIL

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ABSTRACT

Studies of **Pinus radiata** D. Don root systems in southern Kaingaroa State Forest showed clearly that the trees were making full use of the extra soil volume provided by ripping on both Kaingaroa gravelly sand and Kaingaroa loamy sand. These studies also demonstrated that root growth ceases when the soil resistance to penetration exceeds 3 MPa. The extra soil volume provided led to extra tree growth on Kaingaroa gravelly sand, but not on Kaingaroa loamy sand. Ripping also lessened the incidence of severe juvenile instability on Kaingaroa gravelly sand.

Keywords: cultivation; stability; root growth; soil compaction.

INTRODUCTION

Ripping has been employed as a site-preparation technique in New Zealand since the mid 1960s, when compacted gravels in Canterbury were ripped in order to improve tree root development and crop stability (Guild 1971; Potter & Lamb 1974). The operation was performed with unmodified rock rippers to a depth of 60 cm. Ripping with unmodified tines on Southland tussock country resulted in modest increases in survival and growth during the first 2 years (Hetherington & Balneaves 1973). The technique greatly improved the growth and survival of *Pinus radiata* on Northland podsols as well.

During the early 1970s, a ripping tine was modified by the addition of a steel plate at its base. This plate helped to lift and fracture heavy clay soils in preparation for planting (Berg 1975). On a clay site in Riverhead Forest, ripping improved initial survival of *P. radiata* seedlings by approximately 15%, and doubled height growth during the first 3 years.

Ripping has also been employed on compacted pumice soils in the central North Island. Page (1977) demonstrated that the addition of angled wings to the base of a ripper tine made the tool much more efficient on pumice sites. A larger area of soil was shattered after the addition of wings, often with lower or equal draught requirement.

The soils of southern Kaingaroa Forest are formed from ejecta of the Taupo eruption (1850 ± 100 years B.P.), in particular from a glowing avalanche or nuée ardente known as "Upper Taupo Pumice" (Pullar 1980) or "Taupo ignimbrite" (Walker & Wilson 1983).

The deposit or flow-tephra consists of angular coarse pumice with some charcoal fragments, and it compacted after cooling. Further away from the source in central and northern Kaingaroa Forest, the flow-tephra thinned out to less than 2 m thickness called a "smear" deposit.

The surface tephra may be divided into three general categories:

★ Flow-tephra formed from the main part of the glowing avalanche of the Taupo eruption. It generally occurs in southern Kaingaroa on flat surfaces and depressions. The material is compact, usually more than 10 m thick and often exceeds 20 m. The soil formed from this deposit is Kaingaroa gravelly sand (Rijkse in prep.).

★ "Smear" deposits are from the same eruption but further away from the source and generally on high ground. Professor G. P. L. Walker (pers. comm.) suggests that this deposit is a residue left by the main flow as it subsided into the low-lying areas, and it is variable in compactness. It overlies Taupo lapilli, Rotongaio Ash, Putty Ash, and Hatepe lapilli which were deposited by earlier airfall stages of the Taupo eruption. Beneath these tephra lies the Mapara paleosol, dated 2270 ± 100 years B.P. (Pullar *et al.* 1973). Soils derived from the "smear" deposit are named Kaingaroa loamy sand (Rijkse in prep.).

★ Water-sorted pumice covers smaller areas than the other two types. The deposits are alluvian or colluvian and the pumice is rounded and friable to a great depth.

The ripping trials described here were on Upper Taupo Pumice in Kaingaroa Forest, one on Kaingaroa gravelly sand (Fig. 1), the other on Kaingaroa loamy sand (Fig. 2).

METHOD

Kaingaroa Gravelly Sand

A flat area of gravelly sand in Cpt 558 at 650 m a.s.l. was uniform save for one small depression running through the centre, which contained at most a 15-cm-thick deposit of water-sorted pumice. The soil consisted of 15 cm of dark topsoil, overlying a blocky subsoil. An earlier crop of *Pinus ponderosa* C. Lawson had been processor-logged from the site, and the residues had been burnt.

The site was ripped with a Terex tractor pulling a tine to which small V-shaped wings were attached. The ripping depth varied considerably, but averaged 38.7 ± 2.3 cm.

Sixteen blocks of ripped and control (unripped) plots were established over the area. Control plots consisted of three planting lines, at 2.4 m spacing, of which only the centre line was assessed. The ripped plots consisted of four lines, and the middle two lines were assessed. In one of the assessed lines stock was planted in the middle of the ripped furrow, while in the other three lines the trees were planted 15 cm to one side of the rip, in a small mound of topsoil formed by the ripping operation.

FIG. 1—Kaingaroa gravelly sand. This layer is usually more than 10 m thick and very compact below 15 cm. The gravelly sand is underlain by Taupo lapilli.

Plots were 40 m long, with only the middle 10 trees of each assessment line actually measured. The ends of the lines were reserved for root assessment by destructive sampling.

The stock was 1/0 from the Forest Research Institute nursery, lifted 1 day prior to planting, and transported in cardboard boxes. Seedlings were planted in September. The soil was broken out in two directions, a wide slot was made for the roots, and the tree was pulled up slightly prior to firming of the displaced soil. Half of each block was planted by each planter, so that each of two planters planted the same amount of each line.

Kaingaroa Loamy Sand

Three groups of three levels of cultivation were laid out in Cpt 243, Kaingaroa Forest. The original crop of *P. ponderosa* had been shear-bladed, windrowed, and burnt. Ripping was carried out using the FRI experimental tine mounted on a C7 log skidder.

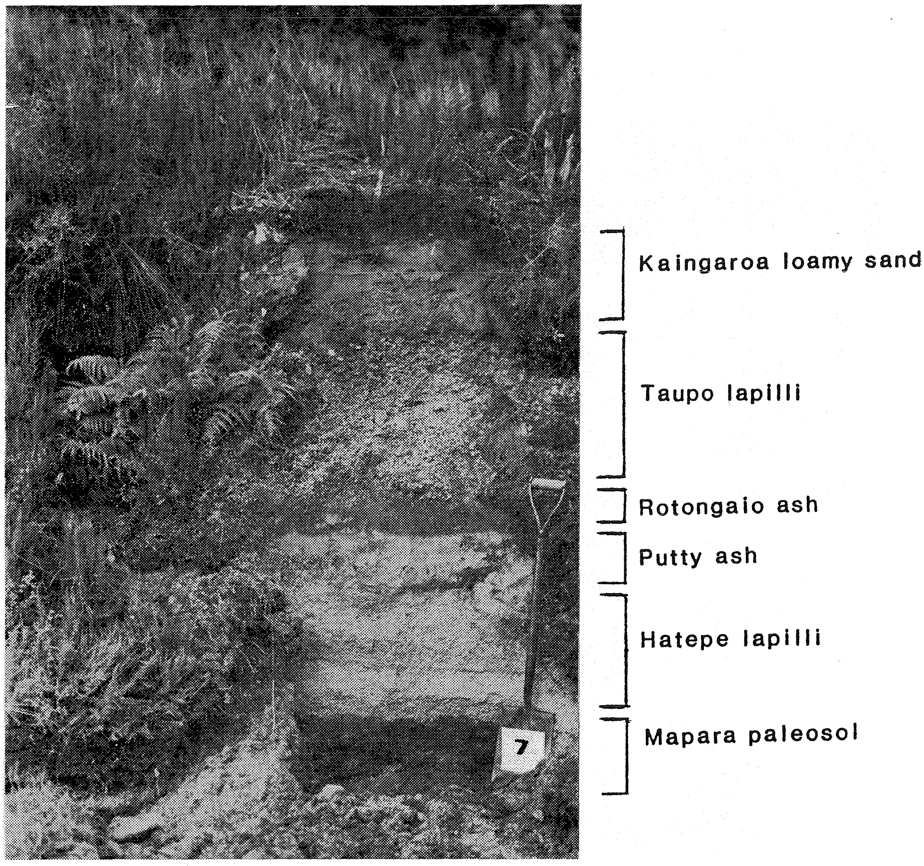

FIG. 2—Kaingaroa loamy sand. This is usually less than 2 m thick and very variable in compactness. Like Kaingaroa gravelly sand, it is underlain by Taupo lapilli and other tephra layers.

One of the treatments was ripped with a winged tine (Page 1977) to an average depth of 74 cm, one was ripped with a conventional tine (without wings) to an average depth of 47 cm, and the third treatment was left unripped as a control.

Six blocks of ripped and control plots were established over the area. In addition to the ripping treatments, three stock types were planted, giving nine treatments as a factorial. Two stocks, FRI 1/0 and FRI box-pruned, were planted in August by members of the Silvicultural Equipment Research Group without reference to the established blocks.

The third stock type consisted of direct-sown stock. The initial attempt at sowing, in October, was unsuccessful because of rodent predation, and a further broadcast sowing was conducted during December. Consequently the direct-sown stock was always a long way behind the planted stock, and only root measurements were taken in this treatment.

The plots were 70 m long, and contained at least 40 trees each. Every fourth tree was used for growth measurements.

Measurements Recorded

Similar measurements were recorded in each plot, but not always at the same times. The differences are denoted by "Kls" where the measurement was taken in the Kaingaroa loamy sand plot, and "Kgs" where it was taken in the Kaingaroa gravelly sand plot.

Survival, growth, and stem form

The height and basal diameter (5 cm above ground-level) were recorded for each tree in the measured plots immediately after planting and each September for the next 3 years. During these assessments any mortality, toppling, or malformation was noted.

Subsequent measurements were at age 5 (Kgs), and age 7 (Kls). The growth assessment at age 7 was expanded to include all remaining trees in each plot, since thinning at age 5 had reduced stocking to 600 stems/ha. Only the first three replications of Kls were assessed at this time, and the stem form of each tree was visually classified as either sinuous, buttswept, or straight.

By the middle of the third year after planting, many trees had toppled in the Kgs plot. The angle from vertical of each tree was assessed with a clinometer attached to a metre ruler. At age 5 the sinuosity of each tree was measured; the consequences of sinuosity have been analysed by Mason (1985).

Fine root analysis

An analysis of fine roots was performed on a tree from each treatment in the first three blocks at age 7, excluding the direct-sown plots (Kls). The same analysis was performed on a tree from each treatment in the first four blocks of Kgs at age 6.

The trees were randomly selected from those available for destructive sampling, and a 1.3-m-deep trench was dug with a clean face 1 m from the centre of the bole of each tree, across the planting/cultivation line. The face was then scraped with a garden fork, exposing 2 to 3 cm of each root. A wire frame grid 1.5 m wide and 0.9 m deep was placed over the face. It consisted of 15 × 15-cm squares. In each square the roots larger than 1 cm in diameter were measured; those between 1 cm and 0.3 cm, and those less than 0.3 cm were counted. In addition, the compaction of the soil in the centre of each square was measured with a hand-held, spring-loaded, indentation penetrometer. The penetrometer did not accurately measure compaction greater than 5 MPa.

Large root analysis

At ages 1 and 2 (Kgs), or at age 1.5 (Kls), one tree was excavated from each end of each plot, and their root forms were assessed using Menzies' Taproot Score which ranges from 0 for a good taproot system to 10 for a poor one (*see* Mason 1985, Fig. 3). In addition, the number of sinkers greater than 2 mm in diameter were counted. Sinkers were defined as roots oriented more than 45° from horizontal. These two parameters have been related to the likelihood of toppling (Mason 1985).

On Kls the general orientation of the lateral roots was also assessed as either along the line of the spade, along the line of planting, or in no single plane.

Four and a half years (Kls) or 6 years (Kgs) after planting, one root system was excavated from each plot (Kls), or from the plots in the first four replications (Kgs).

The following measurements were taken on each root system:

★ Menzies' Taproot Score (both Kgs and Kls).

★ Menzies' Lateral Score which ranges from 0 for a good lateral root system to 10 for a poor one (*see* Mason 1985, Fig. 4) (both Kgs and Kls).

★ The maximum depth of the root system (both Kgs and Kls).

★ The distance from ground-level to the first lateral root (Kgs only).

★ The number of lateral roots larger than 0.3 cm (Kls) or 0.5 cm (Kgs) at 10 cm from root origin.

★ The number of sinker roots larger than 0.3 cm (Kls) or 0.5 cm (Kgs) at 10 cm from root origin.

★ Mason's Core Distortion Score (Fig. 3) (Kgs only).

★ Mason's Lateral Orientation Score (Fig. 4) (Kgs only).

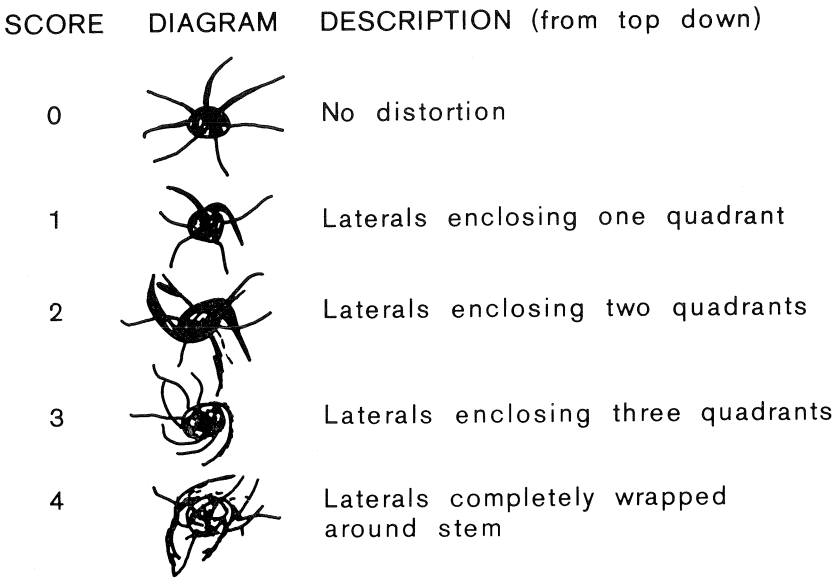

FIG. 3—Mason's Core Distortion Score. This score may be related to stem fracture (Mason 1985).

RESULTS

Kaingaroa Gravelly Sand

Survival

Survival in the control treatment was 78%, but ripping improved survival by approximately 10%. This difference was highly significant statistically ($p = 0.01$). Most of the mortality occurred during the first year after planting.

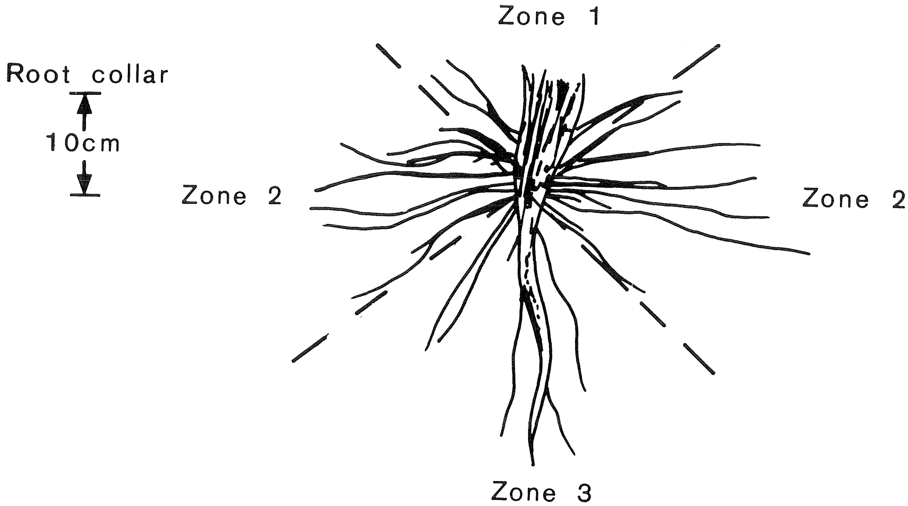

FIG. 4—Mason's Lateral Orientation Score consists of three numbers which must add up to four. Each number represents the number of quarters of lateral roots contained within each of three zones intersecting at 10 cm below the root collar. The root system shown would score 1–2–1 since one-quarter of the roots are in Zone 1, two-quarters in Zone 2, and one-quarter in Zone 3.

Growth

Trees planted on the edge of the ripline grew 3 cm higher than the other two treatments during the first year and by age 3 the difference between the best and worst treatments was 14 cm. The situation changed markedly between the third and fifth year assessments. By age 5, the trees planted on the edge of the rip were 466 cm high, those planted in the centre of the rip were 446 cm, and those in the control plots were 406 cm on average. Growth after ripping was statistically significantly different ($p = 0.05$) from that in the control at ages 1 and 5.

Trees in ripped plots were more uniform than those in the control plots. Coefficients of variation in height were 0.136 for the edge of the ripped plots, 0.116 for the centre of the ripped plots, and 0.169 for the control plots.

Average growth in diameter did not vary significantly between treatments, although diameters in the ripped plots were more uniform.

Stability

During the third year after planting, toppling was frequent throughout the experiment. Trees planted on the edge of the rip were most stable, while those in the centre of the rip tended to acquire a slight lean. Many trees in the control, however, toppled severely (Mason 1985, Fig. 9).

Measurements of sinuosity at age 5 were somewhat related to the angle of topple during year 3; however, it was clear that, especially in the control plots, trees had continued to topple throughout the intervening years.

An analysis of the potential consequences of sinuosity has been published previously (Mason 1985, Table 5). In brief, if thinning has been poorly done, trees next to the rip will incur a revenue reduction of NZ$4,876, those from the centre of the rip $5,339, and those from the control $7,170. Where thinning has been good, the figures will be $869, $1,759, and $2159 respectively. A "poor" thinning is defined as one during which tree selection is random with respect to stem form, while a "good" thinning would use stem form as the prime selection criterion. The projections are long term, and are based on the assumptions outlined by Mason (1985).

Root development

The average Menzies' Taproot Score and number of sinkers and laterals for the treatments at ages 1, 2, and 6 are presented in Table 1.

Trees in the control had significantly more lateral roots at age 6. Some of these would have been vertical roots, but were diverted by the hard soil.

TABLE 1—Menzies' Taproot Score and number of roots by treatments and years – Kaingaroa gravelly loam

Treatment	Menzies' Taproot Score			Number of sinkers			Number of laterals
	Years			Years			Year
	1	2	6	1	2	6	6
Next to rip	6	5	3	2	2	6	27
Centre of rip	5	3	2	2	3	6	21
Control	9	9	8	1	0	4	35

None of the other parameters varied significantly between treatments at age 6. One parameter, root depth, was too variable for such a small sample to pick up differences. The ripped treatments both had mean depths equal to 82 cm, while the control treatment had a mean root depth of 67 cm. Some root systems in the control treatment were able to exploit fissures in the soil profile, while others were confined to the top 20 cm of soil. All were to some extent horizontal "plates" with an occasional sinker exploring a weakness in the soil.

The profile wall analysis revealed stark differences between treatments. The outlines of the ripped zones were very clear because the small roots were largely confined within it (Fig. 5) and because the soil was noticeably darker where the ripper had shattered it. Comparison of the control treatment with the middle 60 cm of the ripped treatment profile (Fig. 6) shows clearly that average compaction had been reduced in this zone to a depth of at least 40 cm by ripping, and that the ripped profile had more roots at all depths measured. The 7.5-cm root count in the ripped profile was artificially depressed because the 15 × 15-cm squares at this level often included the depression formed by the ripper tine.

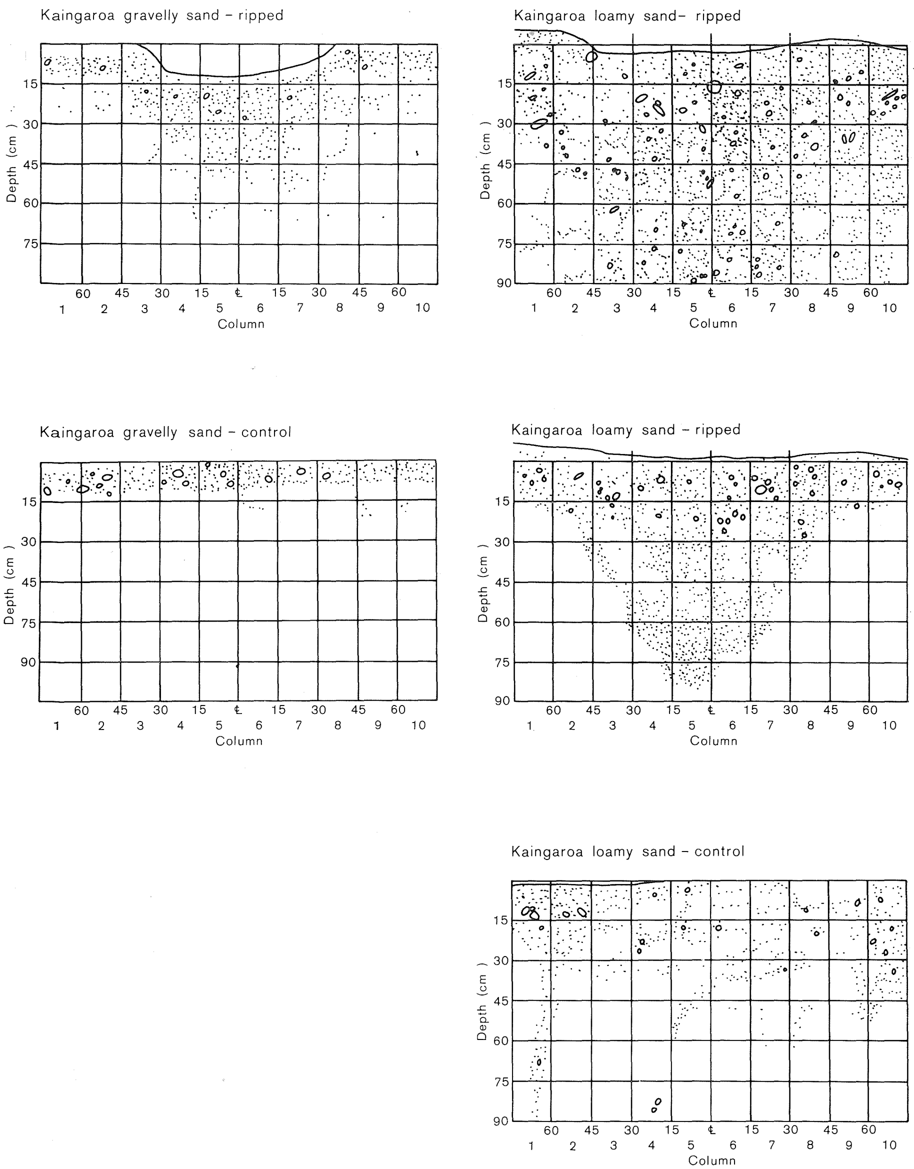

FIG. 5—Sketches of some of the profiles excavated in the two trial areas. In Kaingaroa gravelly sand the roots in the control treatment were largely confined to the top 15 cm, while in loamy sand root distribution was more variable. This is especially well-illustrated in the sketch at top right, where the soil was so soft that the rip outline cannot be determined. Roots larger than 1 cm diameter are outlined; smaller roots are indicated by dots.

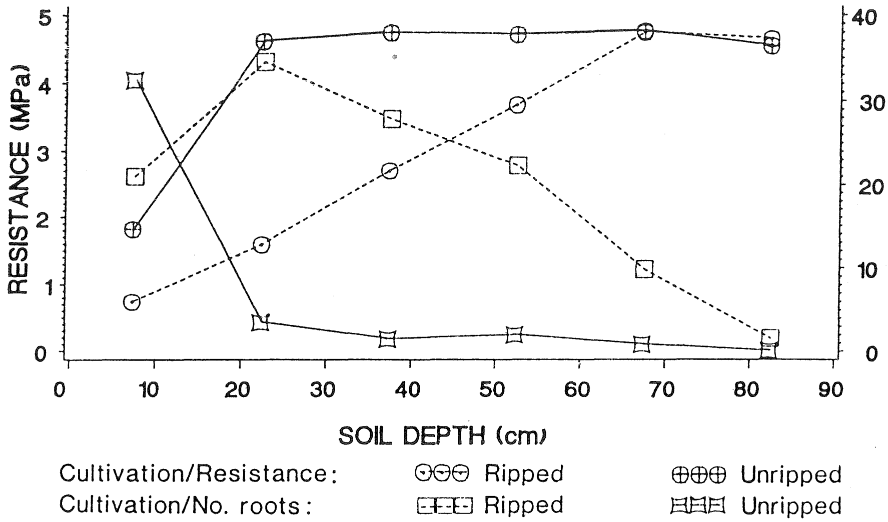

FIG. 6—Soil penetration resistance and numbers of roots per 15 × 15-cm square plotted against soil depth in Kaingaroa gravelly sand. Only data from the middle 60 cm of the ripped treatment are included (Columns 4–7 in Fig. 5). When average resistance rose above 3 MPa the number of roots dropped rapidly.

The number of roots per square varied with penetration resistance. Below a resistance of approximately 3 MPa, the number of roots was reduced only moderately with increasing resistance. Above this benchmark, the number of roots dropped markedly, and many of the squares had no roots at all (Fig. 7).

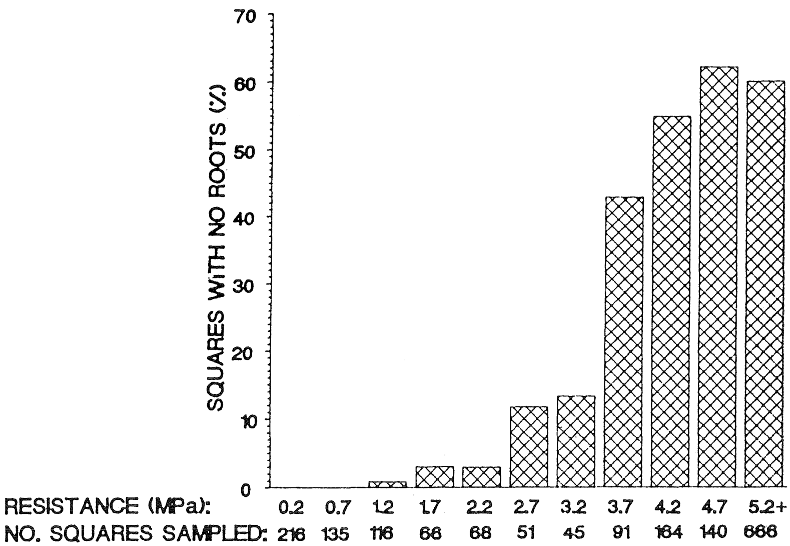

FIG. 7—Percentage of squares containing no roots within each soil penetration resistance class. Data from both sites are included.

Kaingaroa Loamy Sand

Survival

Survival did not vary between treatments on this relatively mild site and averaged 97%.

Growth

Up to age 3, the trees in the winged-rip treatment grew to 235 cm in height while the shallow-ripped and control treatments grew to 255 cm. This difference was statistically significant ($p = 0.05$). By age 7, after thinning, there were no statistically significant differences between treatments. This situation was mirrored by the diameter measurements; the trees in the winged-rip treatment grew 5 mm less during the first 3 years, and were not significantly different from the control or shallow-ripped treatments by age 7.

The two 1/0 stocks did not differ significantly in growth, and there were no significant differences in crop uniformity or stem form.

Root development

One and a half years after planting, the box-pruned stock had slightly better taproots than the conventional stock. The taproot scores were 4.8 and 4 respectively. This difference was significant statistically ($p = 0.05$). In addition, lateral roots of the conventional stock were more often oriented along the rip line, while those of the box-pruned stock were aligned with the spade slit or aligned in more than one vertical plane (Table 2).

TABLE 2—Orientation of the lateral roots at 1.5 years - Kaingaroa loamy sand

Stock	Along rip (%)	Across rip (%)	No. one alignment (%)
Box-pruned	4	57	39
Conventional 1/0	25	49	26

Ripping generally produced better taproots and allowed more sinker development than in the control (Table 3). These differences were highly significant statistically ($p = 0.01$). In addition, lateral roots in the control plots were more often aligned with the spade slit, less often aligned with the planting line, and more often in only one plane than those in the cultivated plots.

TABLE 3—Taproot scores at age 1.5 - Kaingaroa loamy sand

Cultivation	Menzies' Taproot Score	No. sinkers
Winged rip	3.3a	4.5a
Conventional rip	4.4b	4.3a
Control	5.4c	2.8b

Means followed by the same letter are not significantly different at the 95% confidence level.

The significant treatment means from the root assessment at age 4.5 are presented in Table 4. Direct-sown stock had fewer vertical and lateral roots than the planted stock, and the ripped treatments had better vertical root development than the control, in all aspects.

TABLE 4—Root parameters by treatments at age 4.5 - Kaingaroa loamy sand

Cultivation	Menzies' Taproot Score	Root depth (cm)	No. vertical roots >3 mm diameter
Winged rip	1.9a	59a	3.7a
Conventional rip	1.7a	53a	3.4a
Control	5.7b	41b	2.3b
Stock		**No. vertical roots >3 mm diameter**	**Total No. roots >3 mm diameter**
Box-pruned		4.6a	20a
Conventional 1/0		3.7b	20a
Direct seeded		1.2c	15b

Means followed by the same letter are not significantly different at the 95% confidence level.

The average compaction *v.* depth and the average number of roots *v.* depth for the three cultivation treatments at age 7 are shown in Fig. 8 for the middle two columns of the wire frame grid only. The winged rip was both deeper and wider than the conventional rip, and the trees exploited the extra available soil. The two ripped treatments in Columns 4 and 7 (Columns 5 and 6 were the two centre columns) are compared in Fig. 9.

The soil was noticeably variable in penetrability in all treatments (Fig. 6). Many trees had relatively large volumes of friable soil available to them even without ripping, while others were restricted to the top 30 cm of soil. Where the ripper had shattered compact soil, the soil in the profile was browner than the adjacent unshattered soil (Fig. 10).

The number of roots per square varied with penetration resistance (Fig. 8). Below a resistance of 3 MPa, the number of roots was reduced only moderately with increasing resistance, whilst above this benchmark the number of roots dropped markedly, just as in the plots on Kaingaroa gravelly sand.

DISCUSSION AND CONCLUSIONS

Kaingaroa Gravelly Sand

Ripping improved survival and growth markedly on this site. To achieve the same number of stems per hectare for selection as in the control plots, 10% fewer trees could have been planted in the ripped plots. In addition, trees in the ripped plots were more uniform, so that many trees of a size suitable for selection would be eliminated during thinning to a crop of 370 stems/ha.

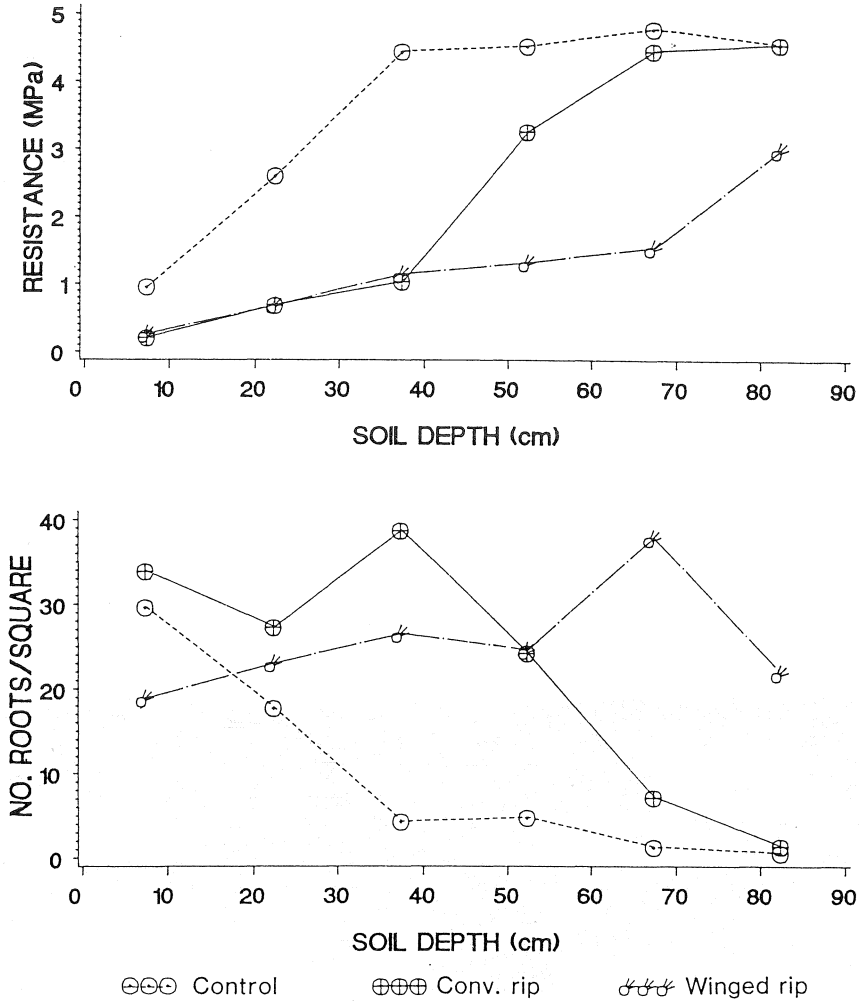

FIG. 8—Soil penetration resistance and number of roots per square **v.** soil depth in Kaingaroa loamy sand. Only the middle 30 cm are included for the ripped treatments (Columns 5 and 6 in Fig. 5). As in Kaingaroa gravelly sand, once the average resistance rose above 3 MPa the number of roots dropped rapidly.

The results to age 5 suggest that ripping has increased site quality. Fine root analysis showed that roots were exploiting the increased volume of soil provided, and the height growth of the trees in the control was beginning to slow. It is possible that the control trees were limited by available soil volume. To what extent this will be manifested as an increase in harvestable wood volume from the ripped area is unknown. In addition, now that the stocking has been reduced, perhaps soil volume will not be quite so limiting in the control plots. Somerville (1979) found that 11-year-old trees' root systems were still restricted to rip zones on Lismore gravels in Canterbury.

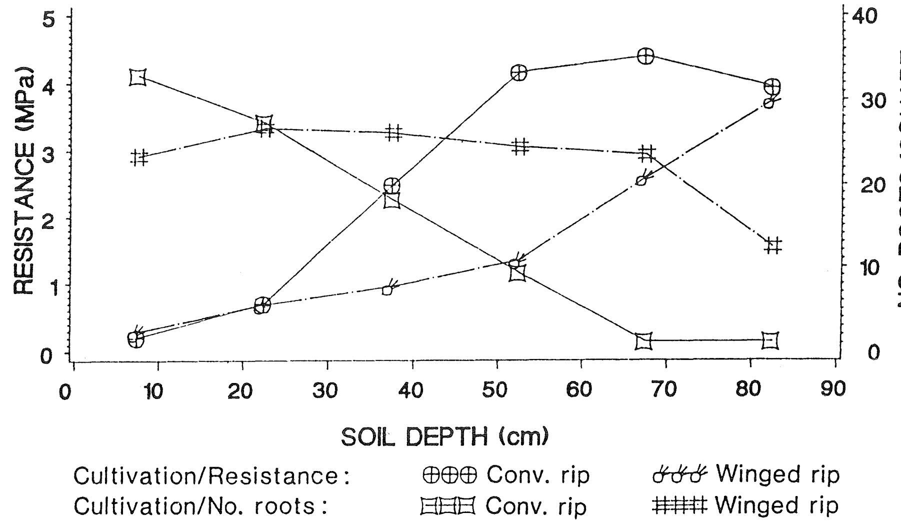

FIG. 9—Soil penetration resistance and numbers of roots per 15 × 15-cm square **v.** soil depth in the two ripped treatments on Kaingaroa loamy sand. Only Columns 4 and 7 (Fig. 5) are included. The roots have exploited the extra width of shattered soil provided by the winged ripper.

FIG. 10—Excavated profile in a winged rip treatment in Kaingaroa loamy sand showing the exploitation of the ripped zone by the roots and the darkening of the subsoil where it has been shattered by the ripper and the development of a B horizon has been accelerated. The wire frame grid was used for root assessment.

Growth of trees planted next to the ripline was slightly better than those planted in the ripline on this site. Ripper/mounder equipment (Page 1979) which pulls topsoil back over the ripline may be useful on this type of soil.

Kaingaroa Loamy Sand

Kaingaroa gravelly sand is uniformly compact below 15 cm, save for the occasional fissure, and ripping resulted in a great improvement in growth and stability. Kaingaroa loamy sand, however, is much more variable, and often friable to a depth of about 30 cm. While ripping did increase the volume of soil available to the trees, there was no correlated increase in tree growth, suggesting that soil volume was not limiting to the trees in the control plots on this site. Whether soil volume will become limited as the trees grow larger has not been determined.

Ripping accelerated the development of a B horizon in the soil profile, and improved the vertical rooting habit of some of the trees. These factors may have some significance as the trees grow older.

Differences between the two types of planted stock were slight, with perhaps a small tendency for box-pruned stock to initially have better taproots. The planted stocks had 35% more large roots than the direct-sown stock and, although there was also a physiological age difference, this is probably due in part to the manipulation of the planted stocks' root systems during their stay in the nursery.

General Discussion

On these sandy pumice sites, where the ignimbrite is partially welded, soil resistance measurements do not vary greatly with soil moisture. On other sites, such as clay sites north of Auckland, penetration resistance is more likely to vary with soil moisture, and only those measurements taken during periods of root growth will indicate the resistance actually encountered by the trees.

The fine root analysis provided some interesting insights into the limits of root growth on compact sites. The penetrometer measurements were taken in the centre of each 15 × 15-cm square. Sometimes other portions of the square contained soil with a different resistance to penetration. Because of this, in some squares with roots the penetration resistance exceeded 3 MPa (Fig. 7). In the centre of such squares, where the resistance measurement was taken, there were no roots. The reduction in root penetration at 3 MPa was sudden and absolute. This observation agrees with studies in Australia on *P. radiata* roots (Sands *et al.* 1979) and in the United States on *Gossypium hirsutum* L. roots (Taylor & Ratliff 1969).

On pumice sites, any volume of soil with a penetration resistance greater than 3 MPa is therefore unavailable to *P. radiata*. Whether such a soil should be ripped depends on its accessibility to the ripper, and on how limiting soil volume is to the trees' growth. Kaingaroa gravelly sand is uniformly above this benchmark at depths greater than 15–20 cm, and *P. radiata* responds positively to ripping at a depth of 40 cm. Whether the response would have been greater with wider and/or deeper ripping is a question which should be addressed in the near future. The available soil volume on

Kaingaroa loamy sand does not limit the growth of *P. radiata* up to age 7, and ripping does not result in any improvement in growth. However, soil volume may become limiting in an unripped area of Kaingaroa loamy sand as the trees' requirements increase with age.

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