STAND REORGANISATION: RESULTS FROM THE TRIALS AT HAUTU FOREST, NEW ZEALAND

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ABSTRACT

Four layouts were tested in a stand reorganisation trial established in **Pinus radiata** D. Don at Hautu Forest in 1973 - groups of four trees at 800 stems/ha, and groups of five trees, short lines of five trees, and the more conventional rectangular spacing at 1000 stems/ha. The final-crop 200 stems/ha were pruned to 6 m in three lifts. A production thinning was carried out at age 10 years in 1983 with a yield of 100 m^3/ha and an estimated cost of NZ$12.50/$m^3$. The sale price on skid was $16.00/$m^3$.

The growth of the pruned final-crop stems was only marginally affected by the presence of the production thinning element and little mechanical damage was caused by thinning. The economics of production thinning were improved, although the load accumulation gains were not as clear as expected. Times for prebunching in the groups of four and five and in conventional rows were all less than the lines of five. In the groups of four an initial stocking of 800 stems/ha was sufficient to give an acceptable final-crop stocking of 200 stems/ha.

A second stand reorganisation trial established in 1975 investigated a paired row concept, i.e., pairs of final-crop rows alternating with pairs of rows for production thinning. Identification of the final-crop rows allowed them to receive seed orchard stock, cultivation, and fertiliser treatment to compensate for the green crown removal at pruning time. These advantages were sustained until the production thinning at age 10 years. Satisfactory levels of production were achieved using current machines and systems. However, more sophisticated harvesting systems would have benefited from the concentration of thinnings from adequate and well-defined corridors.

Keywords: production thinning; stand reorganisation; **Pinus radiata**.

INTRODUCTION

As described in an earlier paper (Terlesk *et al.* 1983), production thinning has generally been poorly executed from both the silvicultural and the financial points of view. Earlier research showed that to be viable the following conditions must apply:

(1) The selling price of thinnings must be sufficient to cover all direct and indirect costs of the operation;

(2) The final-crop trees must not be damaged or their growth unduly retarded by the presence of the trees being held for production thinning (Mackintosh & Bunn

1976). Economic justification for production thinning requires that the marginal revenue obtained by delaying thinning to produce greater piece size and volume per hectare should exceed the marginal cost of losing diameter increment on the final crop.

Other harvesting research has shown that load accumulation is of prime importance in small piece-size operations if a high level of production is to be achieved (Terlesk 1980). A trial was therefore established to test the feasibility of reorganising the stems at the time of establishment, instead of the more conventional approach of either modifying the silvicultural treatment at a later stage in the rotation or modifying or developing equipment to overcome the load-accumulation problem (Andersson 1969).

The objectives of the experiment were therefore to:

- Improve the load accumulation phase;
- Minimise the mechanical damage to the final crop;
- Protect the pruning investment;
- Cover the cost of production or show a direct profit on the operation.

FIRST HAUTU TRIAL, 1973

The terrain in the trial area was easy and covered in light vegetation which was hand cut and burnt prior to tree planting. The area was subdivided into four sub-plots in order to test the following layouts (Fig. 1):

(1) Rectangular line spacing, 3.7 m between rows × 2.9 m between trees, 1000 stems/ha initial stocking;

(2) Groups of five trees, 200 groups/ha, 1000 stems/ha initial stocking;

(3) Short lines of five trees, 200 lines/ha, 1000 stems/ha initial stocking;

(4) Groups of four trees, 200 groups/ha, 800 stems/ha initial stocking.

Standard tree stock from the Forest Research Institute nursery was planted by local labour. Spacing was controlled by the use of planting poles and measuring rods.

Pruning

All trees within the trial area were low pruned to 2.4 m; from these, 400 trees/ha were pruned to 4.3 m and subsequently c. 200 stems (one per group) were selected for the final crop and pruned to 6.0 m. More trees were low and medium pruned than considered necessary by current standards in New Zealand.

The three pruning lifts were carried out by unskilled labour but supervised in part by FRI personnel. A reasonable standard of treatment was achieved using large secateurs for the first lift and ladders and saws for the second and third.

Production Thinning

The trial area was production thinned in early 1983 at 10 years by a competent contract logging crew. Stand details prior to production thinning are summarised in

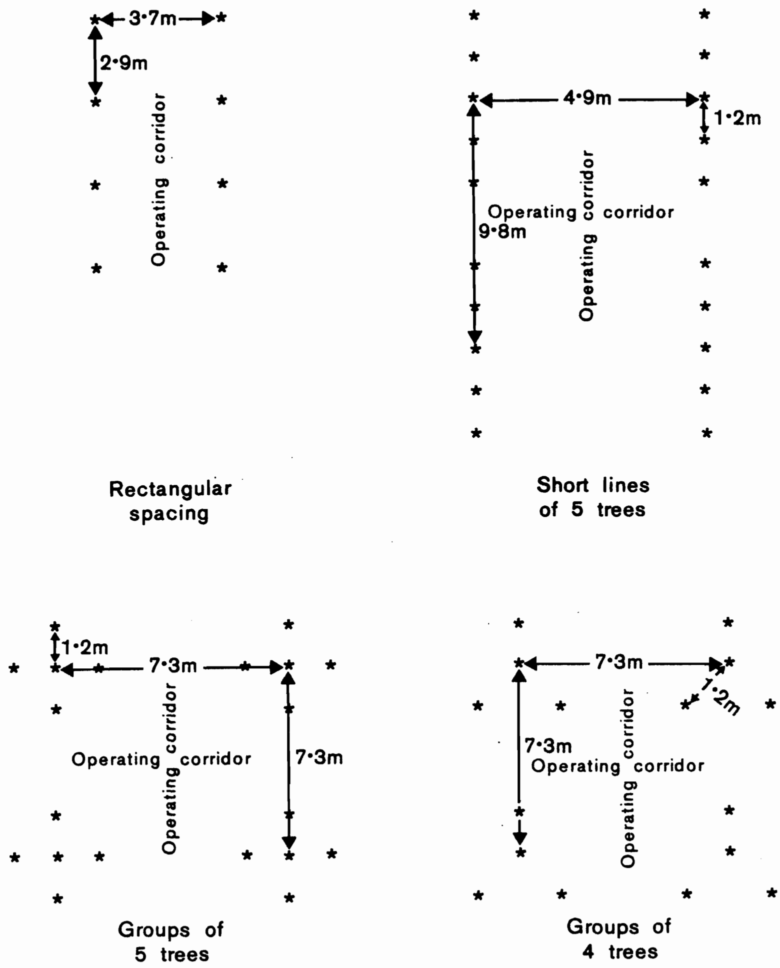


FIG. 1—Hautu trial, planting combinations.

Table 1. The stand yield averaged $100\,m^3/ha$, with a mean piece size of $0.17\,m^3$. Some loss of growth was evident for the centre trees in the groups of four and five, due mainly to competition and to green crown removal at pruning. As a result of these findings the central tree final-crop concept has been dropped in subsequent trial layouts.

Most (94–98%) of the groups and the short lines contained a suitable final-crop stem (Table 1). This indicates that a ratio of 1 : 4 or 1 : 5 for final crop selection was adequate in this particular series. Two operators felled and trimmed the stems using 90-cc power saws. Production per 8-hour day ranged from 21 to $25\,m^3$. A Bell Infield Logger bunched the prepared stems into a double pile of around 20, productivity ranging from 17 to $20\,m^3$/productive machine-hour over the four layouts.

TABLE 1–Hautu stand reorganisation trial 1973. Summary of stand details at 10 years, prior to production thinning

Groups of four		
Mean dbhob (cm)	- final crop	= 23.3 ± 2.7
	- thinnings	= 20.1 ± 3.6 (Merch. only*)
	- total	= 20.9 ± 3.6
Centre tree dbhob (cm)		= 19.0 ± 4.1
Mean height (m)		= 15.6
Centre trees selected for final crop (%)		= 28
No. of groups with no final-crop tree		= 2
Groups of five		
Mean dbhob (cm)	- final crop	= 21.9 ± 2.4
	- thinnings	= 18.9 ± 3.5 (Merch. only*)
	- total	= 19.5 ± 3.5
Centre tree dbhob (cm)		= 17.8 ± 3.8
Mean height (m)		= 15.8
Centre trees selected for final crop (%)		= 16
No. of groups with no final-crop tree		= 2
Short rows of five		
Mean dbhob (cm)	- final crop	= 22.3 ± 2.7
	- thinnings	= 19.3 ± 3.7 (Merch. only*)
	- total	= 20.0 ± 3.8
Centre tree dbhob (cm)		= 17.8 ± 3.8
Mean height (m)		= 16.3
Centre trees selected for final crop (%)		= 40
No. of groups with no final-crop tree		= 6
Rectangular spacing		
Mean dbhob (cm)	- final crop	= 21.6 ± 3.0
	- thinnings	= 20.6 ± 3.5 (Merch. only*)
	- total	= 20.8 ± 3.5
Mean height (m)		= 15.8

* Merchantable only = > 11 cm dbhob.

A cable skidder was used to extract the bunches to the landing using two long (5.5-m) strops attached to the main winch rope. This method proved very effective at both the load accumulation point and the landing. The productivity of the skidder using a 150-m average haul distance was c. 35 m^3/productive machine-hour. Fewer than 2% of the logs were dropped during extraction despite the large number of pieces per bunch.

Production was stockpiled at the landing for later loading-out and transport to the pulp mill. Cost of production to the landing was estimated at \$12.50/m^3 (1983 NZ\$).

Silvicultural Considerations

The silvicultural objectives of sustained growth and minimal stem damage were met in this trial, as indicated by a comparison between the final-crop stems in the trial and the growth of the crop from four control plots (Table 2). Waste thinned to 300 stems/ha at age 4 years, to 250 stems/ha at age 7 years, and to 200 stems/ha at

TABLE 2–Hautu trial 1973, summary and comparison of growth

	Mean dbhob (cm)	Mean height (m)	Mean tree total stem volume (m^3)
Groups of four	23.3 + 2.7	15.6	0.22
Groups of five	21.9 + 2.4	15.8	0.20
Short rows of five	22.3 + 2.7	16.3	0.21
Rectangular spacing (rows)	21.6 + 3.0	15.8	0.19
Mean control plots	25.2 + 3.05	14.1	0.23

age 8 after pruning to 6.0 m, these control plots are referred to as the "free-grown" controls.

Mean tree size in the four trial layouts compared favourably with the control plot data, indicating little loss of growth.

Branch size in the log immediately above the pruned zone is of economic importance as it affects the value of the sawn outturn. Holding a stocking of 800–1000 stems/ha to 16 m (9–10 years Site Index 30+) achieved a measure of branch control. Sampling of final-crop trees in which all branches were measured with calipers 6 months after the production thinning showed that in the groups there were no branches greater than 5 cm in diameter and that branch sizes were smaller in the quadrants facing towards the centre. Branches were largest in the out-facing quadrants, but only marginally, and on average a centre tree had smaller branches than an outside tree. This result is supported by earlier results (R. Fenton, unpubl. data) in which relatively high stockings were held to stand top height of 15 m.

Branch measurements in the rectangular spacing layout showed a few branches greater than 5 cm diameter; however, most (99%) of the branches were < 5 cm.

Mechanical damage from the harvesting operation was low. A damage assessment throughout the four layouts indicated that at maximum only 5% of the final-crop stems (10 stems/ha) had received major damage, i.e., greater than 100 cm^2 per stem. Damage to the pruned butt section is considered a serious fault as it degrades the value of the log, particularly in the veneer-peeling process (Park 1987). Butt damage is not so important if the logs are sawn, although some degrade of the outturn results. Because of the general vigour of *P. radiata* and a copious gum flow, a secondary pathogen infection is not common in New Zealand.

Advantages and Disadvantages

Stand reorganisation using group planting at establishment brought some productivity gains at the time of the production thinning operation although the gain from the grouping of stems (a 7% reduction in load accumulation time) was not as great as expected.

At the time of establishment (1973) it was envisaged that a skidder with double-drum winches operating from the well-defined extraction corridors would carry out the harvesting operation. This was overtaken by the development of the very manoeuvrable Bell Infield Logger as an effective and efficient bunching or load-accumulation machine, thus reducing expected gains from the group effect using winch and strop technology.

Some of the advantages and disadvantages claimed for the group layout are:

Advantages

(1) Tree growth was maintained at a satisfactory rate for both the thinning and the final-crop elements.
(2) A measure of branch control was achieved in the first log above the pruned zone.
(3) An initial stocking of 800 stems/ha was sufficient to ensure a final-crop stocking of 200 well-formed stems/ha.
(4) The final-crop was well distributed in the groups but created gaps were obvious in the plot with rectangular spacing.
(5) Mechanical damage was kept to an acceptable level.
(6) Machinery movement within the stand was improved.
(7) The location and presentation of thinned stems for extraction were enhanced.
(8) The tree selection task for silvicultural work was made easier by the group concept.
(9) A well-defined initial layout and the reduction to a relatively low final-crop stocking improved the likelihood of a highly mechanised system operating economically within the stand (Terlesk *et al.* 1983).
(10) The layout lends itself to a second production-thinning option for small sawlogs and pulpwood.

Disadvantages

(1) Establishment may be more costly because of the measurement methodology.
(2) It is difficult to mechanise the establishment phase with the group layouts.
(3) Suppression of competing ground vegetation in all layouts tested was not as rapid or as complete because of the relatively low initial stockings. This could be an advantage in an agroforestry situation.

SECOND HAUTU TRIAL, 1975–76

Experience gained with the first Hautu trial and earlier research (Terlesk *et al.* 1983) led to the establishment of a second trial in the Hautu area in 1975–76. In this large-scale trial further options for the group and paired row concepts were established.

The objectives of this second trial were similar to those of the first trial with the addition of a further two:

(1) To further test the feasibility of establishing stands of *P. radiata* in groups to reduce the number of stems per hectare, and to concentrate potential production-thinning stems to improve load accumulation and to ensure that the final-crop stems came from the group centre – this should ensure greater branch control in the logs above the pruned zone (Anderson 1951).
(2) To test the feasibility of giving the centre final-crop stems added growth advantages by:
    (a) Using superior seed orchard stock;

(b) Employing cultivation techniques at the time of planting;
(c) Using fertiliser at the time of planting;
(d) Planting the crop stems 1 year earlier than the production-thinning element;
(e) Using 1/0 standard stock for the production-thinning element.

These added advantages for the final-crop element were considered necessary to compensate for the loss of growth and vigour induced by pruning with green crown removal.

Group Trial Centre Crop Stem

Although the initial establishment of the groups at 300 stems/ha was successful they quickly merged and lost their identity after 5–6 years.

Some growth advantage arose from planting the final-crop stems 1 year in advance of the thinning element. The thinning component, however, was badly affected by *Dothistroma pini* Hulbary (needle-cast fungus) and was never in a position to compete with the final-crop element or achieve an "economic production thinning yield"; also, it suffered from crown damage because of its subordinate position. Crown damage was particularly severe in periods of high winds – this led to extensive malformation, in addition to the poor growth performance.

A tree quality malformation assessment immediately after "green" pruning to 4.3 m showed that it was not possible to select a final crop of 250 stems/ha of good trees from group centres, and that where the surround trees had not been pruned (to reduce costs) only 30% of the centre trees were suitable for the final crop – largely through loss of dominance.

The advantages expected from larger seed orchard stock, cultivation, and fertiliser application to the centre final-crop stems did not materialise. In general, the green pruning of the crop stem resulted in a loss of vigour when compared with the unpruned stems. In the group trial the cultivating was done with the planting spade and as such it was not as extensive or as thorough as other mechanical methods. It was then decided to largely abandon the group trial concept which included a central tree.

Selective pruning had such an effect on vigour that dominance was lost and with the loss of growth, the pruning investment. Three hundred groups per hectare led to a rapid loss of identity and a loss of many of the expected advantages listed for the first Hautu experiment.

The current approach to group stand reorganisation establishment is outlined in Fig. 2 – 200–250 groups/ha, four trees/group, no centre tree, 800–1000 stems/ha.

Paired Row Concept

The results from an earlier attempt to impose the paired row concept on an existing stand have been reported by Terlesk *et al.* (1983). It was observed that there were inherent problems in imposing a row pattern on an existing stand. Variations in spacing precision at the time of establishment led to stocking differences; subsequent tending operations (or lack of them), coupled with an arbitrary allocation into crop and thinning rows, magnified the variation.

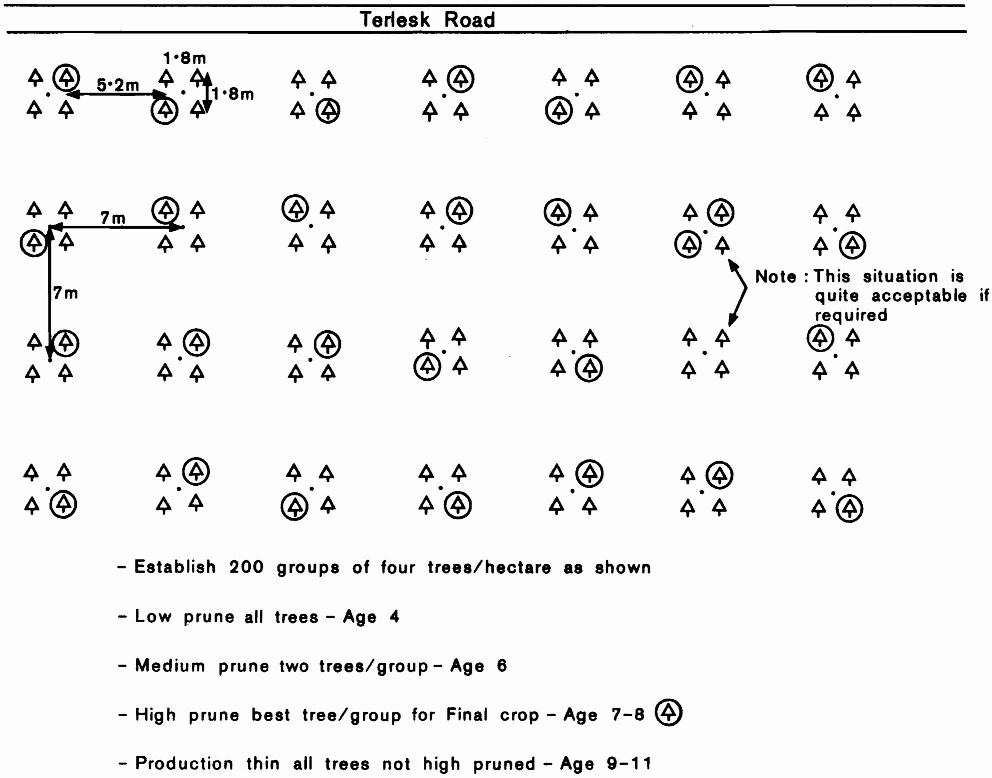


FIG. 2—Current group layout.

In an effort to overcome these problems, a paired row trial was included in the later layout established in 1975–76 (Fig. 3 and Appendix 1). Here the objectives were to concentrate the production-thinning element to improve load accumulation and thus the harvesting economics. Similar techniques to those in the group trials were employed to compensate for green crown removal at pruning. More extensive cultivation was possible in the line trial where a large tractor and a set of giant discs were used.

Annual Measurement Results

1981

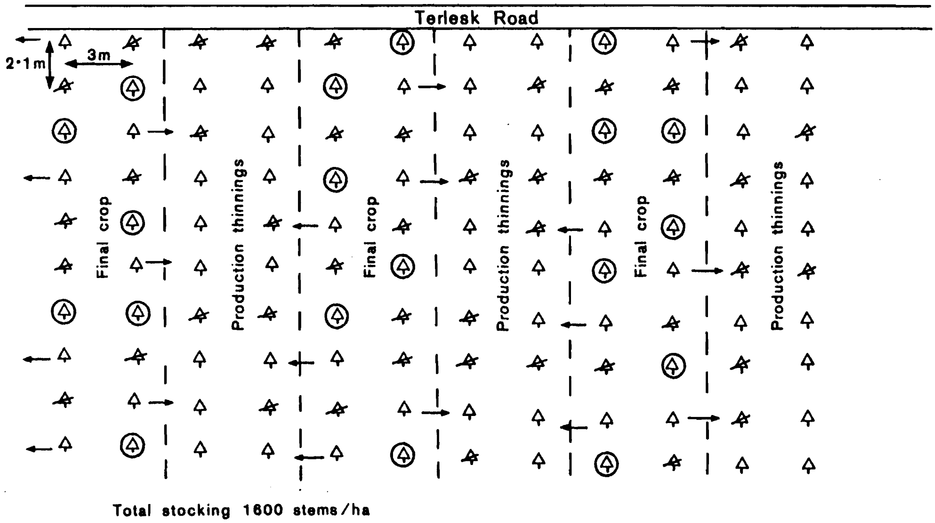
Measurement in the winter of 1981 showed the following:

(1) Cultivation and fertiliser application at planting in the row blocks had led to an increase in final-crop basal area of between 11% and 18%.

(2) Basal area of the thinnings planted in 1976 (1 year after the final crop) ranged from 24% to 39% lower than the thinnings planted at the same time as the final crop in 1975.

1982

(1) There was a fall-off in increment of the medium-pruned (4.3 m) final-crop stems compared to the low-pruned thinning element.



Age	
4	Low prune 500 stems/ha final crop + 500 stems/ha production thinnings. Waste thin remaining trees
6	Medium prune 350 stems/ha final crop only
7–8	High prune 250 stems/ha final crop only. Waste thin remaining final-crop trees OR Retain as additional production thinnings
9–11	"Clearfell" production thinning row pairs

FIG. 3—Current paired row layout.

(2) Some beneficial influence from the fertiliser application and cultivation at planting continued.

(3) Basal area increment in the thinnings planted in 1976 (1 year after the final crop) was very low, averaging 1.5 m^2/ha/annum. The thinnings planted at the same time as the final crop averaged 2.5 m^2/ha/annum.

1985

Variation to the initial silvicultural proposals occurred over the early life of the trial. These changes were brought about by wind damage, and a desire to test additional options. The thinning element in two plots was reduced from c. 1000 stems/ha to c. 450–500 stems/ha, while in the other four plots they were left at 1000 stems/ha. The greater piece-size of the thinnings at the reduced stocking is significant and this information had a bearing on the stocking levels adopted in subsequent stand re-organisation trials. The plots in this trial were not replicated, hence the differences between treatments should be viewed as indicative and treated with some caution.

The effects shown up in the 1985 remeasurement (Table 3) included:

(1) The beneficial effects of the fertiliser and cultivation treatments continued to age 10 years – Plot 2 and the "free grown" control (Plot 5) had similar basal areas at age 10 years, 12.55 and 12.47 m^2/ha respectively.

TABLE 3–Annual measurement summary of paired row trial at June 1985 (age 10)

Plot		Final crop				Production thinnings			
		PMH (m)	Mean dbhob ± s.d. (cm)	Basal area/ha (m^2)	Stems/ha	PMH (m)	Mean dbhob ± s.d. (cm)	Basal area/ha (m^2)	Stems/ha
1	A	17.2	23.2 ± 3.6	10.57	250	16.6	22.5 ± 3.6	19.88	500
	B	16.7	20.6 ± 3.4	8.07	242	17.0	18.2 ± 3.7	25.58	983
	C	15.3	25.8 ± 3.5	13.07	250				
2	A	17.5	25.7 ± 3.1	12.55	242	17.0	22.0 ± 3.3	17.10	450
	B	17.9	25.8 ± 2.8	13.49	258	16.5	18.0 ± 4.3	24.18	950
3		16.8	24.7 ± 3.0	12.99	271	14.6	13.4 ± 4.3	13.86	983 (age 9)
4		16.9	28.2 ± 2.5	15.37	246	12.5	11.0 ± 4.3	8.79	925 (age 9)
		16.4	28.2 ± 3.0	15.99	256				
5	Control	15.4	25.2 ± 2.9	12.47	250				

(2) Where the thinnings were planted 1 year later they had no effect on the growth of the final crop (Table 3, Plots 3 and 5, 15.37 and 12.47 m^2 basal area respectively). Comparison between Plots 1 and 3, 2 and 4 shows the effect of a delay of 1 year in planting the thinning element – for Plots 1 and 3 respectively, 25.58 and 13.86 m^2 basal area/ha, and 24.18 and 8.79 m^2 basal area/ha for Plots 2 and 4 respectively.

(3) Branch sizes above the pruned zone in the final-crop stems were not measured at the time of the production thinning. However, the planting layout, particularly where the thinnings were planted at the same time, ensured a mean branch size of less than 2.5 cm.

(4) In order to quantify branch characteristics in the production-thinning element, 61 trees were felled and all branches measured (Table 4). The force required to mechanically delimb is a function of branch area and, as branches are found in whorls in *P. radiata,* the force required to delimb may be a function of the total branch area in the whorl (M. McConchie, unpubl. data). Branch area/whorl/diameter class is indicated in Table 4, but it is important to note the big differences between the mean and the maximum area.

TABLE 4–Whorl size

	Branch area/whorl (cm^2)			
	Thinnings @ 1000 stems/ha		Thinnings @ 500 stems/ha	
	Mean	Maximum	Mean	Maximum
(a) dbh class (cm)				
10.0–14.9	20.6 ± 18.8	82	12.4 ± 7.0	28
15.0–19.9	18.6 ± 13.7	76	19.2 ± 11.7	62
20.0–24.9	28.3 ± 16.8	88	30.2 ± 21.4	95
25.0–29.9	25.3 ± 16.9	71	40.0 ± 28.0	188
Total	23.2 ± 16.4	88	30.4 ± 23.6	188
(b) Branch area/whorl (cm^2)				
0– 25		66.6%		50.2%
26– 50		25.9%		33.8%
51– 75		6.2%		10.6%
76–100		1.3%		4.2%
>100		–		1.2%

Production Thinning

Unfortunately, as in earlier stand reorganisation trials, the trials were ready for thinning before the more sophisticated equipment (such as the harvester, mechanised feller-skidder, delimber bucker, and self loading trucks) was readily available to test for performance and cost effectiveness in the various layouts.

A motor manual system (power-saw felling and delimbing, a Bell Infield Logger for bunching with extraction to the roadside by a winch-equipped skidder) was employed for part of the trial. A Waratah Delimber feller/buncher was also tested for delimbing, felling, and bunching with extraction of bunches to the roadside by grapple skidder.

The Waratah machine was virtually a prototype recommissioned for this study and although it performed creditably (Table 5) it suffered from mechanical unreliability and design faults. The major design fault was its inability to process a tree length (in one pass) greater than 10.0 m; an average length of 7.7 m was achieved (Table 5). This led to a loss of merchantable material amounting to 16% in the 1000 stems/ha and 20% in the 500 stems/ha thinnings.

Production performance was also reduced in Plot 1 (Table 5). This was ascribed mainly to operator performance, Plot 1 being the start-up plot. Disregarding this, there was a decrease in move time per stem in the higher stocking, although this gain is not as significant as the gain from the increased piece-size in the lower stocked plots.

During these extensive work measurement exercises, relatively large machines were able to move through the stand without causing damage to the final-crop stems; only two trees out of several hundred were damaged.

GENERAL CONCLUSIONS

Group Planting

Stand organisation at the time of establishment is a feasible option in the management of *P. radiata* in New Zealand where production thinnings are required by the industry. The orderly layout of the stand facilitates machinery movement within the stand and assists in reducing stem damage.

If groups are to retain their identity until production thinning (age 10 years) no more than 200–250 groups/ha should be established. With better quality tree stock available, four trees/group to give an initial stocking rate of 800–1000 stems/ha is now recommended. A final-crop selection of 1 : 4 was sufficient to ensure a final-crop stocking of 200–250 well-formed stems/ha.

Stocking rates of between 800 and 1000 stems/ha are sufficient to initially restrict branch diameter growth in the second log above the pruned zone when production thinning is delayed to c. 16 m tree height. Stocking rates of between 800 and 1000 stems/ha also ensure a thinning yield of approximately 90–120 m^3/ha at age 10 years. Growth rates are acceptable, the pruning investment is largely protected, and the costs of production thinning can be held to a reasonable level.

Experience has shown that there is no benefit from planting a central tree in a group formation and the practice has been discontinued in more recent trials. Trees planted in square formation at 1.5 m has now been adopted as the standard layout (Fig. 2) for FRI trial purposes.

The group planting technique provides an opportunity to carry out multiple thinnings – a first thinning from 1000 to 400 stems/ha at age 10 followed by a second to 200 stems/ha at age 16–18 years.

Paired Row Concept

A suitable final crop in terms of tree size, form, and spacing was obtained by using the paired row concept. Identification of final-crop rows prior to establishment

TABLE 5–Waratah machine productivity summaries

Element	Time/tree (minutes)			
	Plot 2 500 stems/ha (without bunching)	Plot 2B 1000 stems/ha (without bunching)	Plot 2A 500 stems/ha (bunched)	Plot 1B 1000 stems/ha (bunched)
1. Select tree	0.216 ± 0.05	0.198 ± 0.04	0.240 ± 0.05	0.208 ± 0.06
2. Delimb and head off	0.332 ± 0.10	0.305 ± 0.09	0.346 ± 0.11	0.391 ± 0.13
3. Drop top	0.078 ± 0.06	0.074 ± 0.03	0.088 ± 0.05	0.090 ± 0.06
4. Reselect tree	0.056 ± 0.03	0.053 ± 0.02	0.053 ± 0.03	0.069 ± 0.04
5. Lower boom	0.100 ± 0.06	0.084 ± 0.06	0.072 ± 0.06	0.068 ± 0.05
6. Shear	0.065 ± 0.04	0.052 ± 0.01	0.071 ± 0.05	0.067 ± 0.02
7. Place log	0.074 ± 0.03	0.084 ± 0.05	0.216 ± 0.07	0.229 ± 0.07
8. Other	0.035	0.028	0.043	0.104
9. Move	0.071	0.041	0.073	0.071
Total	1.027	0.919	1.202	1.297
Sample size	88	108	277	309
Actual stocking (stems/ha)	489	947	–	–
Mean dbhob (cm)	20.6	17.5	21.0	18.2
Range (cm)	12.0–28.5	10.5–28.0	11.5–31.4	10.0–28.5
Av. log volume (m^3)	0.17	0.13	0.18	0.14
Av. merch. log length (m)	7.7	7.5	7.7	7.5
Lineal metres/min.	7.5	8.2	6.4	5.8
No. of bunches timed	–	–	44	43
Logs/bunch	–	–	6.3 ± 1.3	7.2 ± 1.6
Av. vol/bunch (m^3)	–	–	1.14	0.98
Time/m^3 (minutes)	5.90	7.24	6.64	9.47
m^3/day @ 5 prod. m-h*	61.0	49.7	54.2	38.0
6.5 prod. m-h	66.1	53.9	58.7	41.2
7 prod. m-h	71.2	58.0	63.3	44.4

* prod. m-h = productive machine-hour.

Regressions: Total process time/tree (with average time for "other" and "move") *v.* dbhob (cm).

	Plot 2	Plot 2B	Plot 2A	Plot 1B
Time (minutes) =	0.0127 dbhob + 0.770	0.0083 dbhob + 0.773	0.0184 dbhob + 0.823	0.0201 dbhob + 0.959
r^2	0.07	0.07	0.15	0.16

can allow this element of the stand to receive superior stock, cultivation, and fertiliser treatment. It also ensures that money invested in pruning is not lost at the time of production thinning, as happens in most outrow or geometric thinning approaches.

In these trials a thinning stocking of c. 500 stems/ha resulted in a piece size of c. 0.24 m^3 and a yield of over 100 m^3/ha at age 10 years. An initial stocking rate of 600–700 stems/ha in the thinning rows should be sufficient to ensure this result (Fig. 3).

The concentration of production thinnings into easily identifiable rows enhances the prospect of improving the productivity of current harvesting equipment and should enable more highly mechanised harvest systems in the future to achieve and maintain high productivity rates with a minimum of final-crop damage (Verheij 1970).

The growth performance of the final-crop stems in both stand reorganisation approaches was acceptable, pruning investments were largely protected, "economic" early production thinnings were possible, and the layout ensured easy access within the stand with minimal stem damage.

The ability to accumulate large loads from a concentration of available stems must improve the economics of the production thinning operation in the stump-to-dump phase. Larger, more "economic" payloads should also ensure reduced tracking and landing densities through the adoption of greater average haul distances than were possible in operations prior to the development of harvesting systems around the stand reorganisation principle.

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APPENDIX 1

PLOT DETAILS, SECOND HAUTU TRIAL

PLOT 1: Area: 1.5 ha
Spacing: 3.0 × 1.5 m
Stocking: 2150 stems/ha
Final crop: Seed orchard stock 1/0
Thinnings: Select stock 1/0
This plot was planted July–August 1975 using standard planting techniques, the only difference between crop and thinnings was quality and age of stock. Crop rows and thinning rows in pairs, as in Plots 2, 3, and 4.

PLOT 2: Area, stocking, tree type/age as in Plot 1. This plot was planted July–August 1975 but the crop rows received cultivation and fertiliser.

PLOT 3: Final-crop rows were planted July–August 1975 in pairs at spacing 3.0 × 1.5 m within rows. A distance of 9.1 m was left unplanted between pairs of final-crop rows. Normal establishment practices were used. Seed orchard stock 1/0. Thinning rows were planted July–August 1976 at 3.0 × 1.5 m within rows. Select stock 1/0.

PLOT 4: Final-crop rows were planted July–August 1975 in pairs at spacing 3.0 × 1.5 m within rows. A distance of 9.1 m was left unplanted between pairs of final-crop rows. Trees to receive cultivation and fertiliser. Seed orchard stock 1/0. Thinning rows were planted July–August 1976 at 3.0 × 1.5 m within rows. Select stock 1/0.

PLOT 5: Control. An area of 0.75 ha was planted with *P. radiata* 1/0 select stock at 3.0 × 1.5 m (2150 stems/ha). This area received the same silvicultural treatment as shown under "Proposed Silvicultural Treatment – Crop Lines Only". Measurement plots were established and these will serve as a yard-stick for growth performance throughout the *P. radiata* trial area and will indicate the timing of production thinning if growth loss on final-crop stems is to be avoided.

Note: Silvicultural prescriptions were modified as further research data became available.

Demarcation: Plot boundaries were marked by painted orange pegs 5 × 5 cm at each corner.

SILVICULTURAL TREATMENT – CROP LINES ONLY

Pruning Predominant mean height (PMH) 6.0 m, 450 stems/ha to 2.0 m
PMH 10.0 m, 300 stems/ha to 4.3 m
PMH 14.0 m, 250 stems/ha to 6.0 m

Thinning to waste Crop rows reduced to 450 stems/ha at PMH 6 m and to 250 stems/ha at PMH 10 m. Thinning rows reduced to c. 740 stems/ha, gross malforms and subdominants removed.

Production thinning	Carried out when final-crop stem growth became affected by the competition of the followers as indicated by a control plot reduced to 250 stems/ha at 10 m PMH. The control plot received similar silvicultural treatment to that set out above.
Measurement	Four growth plots of 0.0606 ha were established in each plot. Annual measurements were commenced 4 years after establishment.
Data required	(a) Diameter at breast height (b) Predominant mean height (c) Number of trees at breast height (d) Record branch sizes in second log when appropriate.
Fertiliser recommendations	200 g diammonium phosphate (DAP) per tree applied in two spade slits 15 cm from trees in September.