STAND REORGANISATION TO FACILITATE LOAD ACCUMULATION IN PRODUCTION THINNING

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ABSTRACT

In harvesting operations such as production thinning where the piece size is small, the time involved in accumulating scattered felled stems into a sufficiently large load to match the capacity of the extraction machine can limit system productivity. Trials in which the stand was organised with a view to aiding harvesting were established in the early 1970s in **Pinus radiata** D. Don stands on a range of sites and terrain at Rotoehu, Turangi, and Woodhill Forests. Stockings were over the range 400–850 stems/ha, and the thinnings rows and final-crop rows were nominated early in the trial establishment.

The results of these trials showed that, with a 200 stems/ha final-crop prescription, small gains in productivity were achievable on flat country using a conventional skidder system, and larger ones on steeper country using a small skyline hauler. The increase in productivity obtained using a prebunching machine on flat terrain was not closely related to the reorganisation of the crop.

INTRODUCTION

Historically in New Zealand production thinning has been indifferently executed from both the silvicultural and the economic points of view. Delaying thinning to achieve increased piece-size and acceptable costs of production has resulted in reduced diameter increment in the final crop and some loss of pruning investment. Extraction has also caused mechanical damage to the final crop by bark removal and branch breakage. The economic and pathological significance of this damage has not been quantified, but stem damage in the potentially high-value pruned zone must result in some downgrade of the end product.

For production thinning to be economically viable to the forest grower the following conditions should apply:

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

(2) The growth of the final-crop trees must not be unduly retarded by the presence of the trees being held for production thinning, nor must they be damaged during the operation (Mackintosh & Bunn 1976).

Early FRI studies (unpubl. data) showed that efficient load accumulation in operations with small piece-sizes is of prime importance if high production rates and reasonable costs are to be achieved. Overseas research (Ager 1969; Maki 1969; Anderson 1969; Bradley 1969; Nelson 1969) has also shown that production gains could be obtained from row or geometric thinning. As a result of these observations, it was decided in the early 1970s to establish three trials on a range of sites and terrain in the North Island of New Zealand.

MATERIALS AND METHODS

The row concept was superimposed on existing forest stands, thus speeding up establishment of the trials. The thinning rows were separated from the final-crop rows in trial areas of sufficient size to allow for future harvesting work-measurement exercises. In addition, some stands contained in immediate proximity to the row arrangement the traditional selection thinning option over a range of stockings. The timing of the production thinning was dictated by a number of "free-grown" control plots established throughout the trial area to final-crop stocking (200 stems/ha). When annual remeasurement and comparison between final-crop growth and the growth in the controls indicated a fall-off in the former, the production thinning operation was scheduled. The layout adopted, although not allowing for replication, allowed for comprehensive measurement and analysis.

The Rotoehu Trial

The Rotoehu trial area was the first established on terrain broadly classed as cable country. The history of the stand and the trial area is summarised in Table 1, and the layout in Fig. 1. There was no selection thinning option included in this trial. Crop details immediately prior to production thinning are given in Table 2.

The skyline hauler used for the thinning was a "Wilhaul" model 1347. It is a mobile unit mounted on a Mercedes Benz truck base, and has been used in both uphill and downhill production thinning and also in some clearfelling. An experienced three-man crew carried out the hauler extraction phase of the operation.

Extraction was downhill over relatively even concave slopes with an occasional across-slope spur. The average slope was easy (7–10°) at the foot rising to steep (25–30°) up to the "back blocks". Each pair of thinnings rows was felled directly down the slope and the thinnings from the final-crop rows were directionally felled towards the thinnings rows (Fig. 1). Three fellers were used for this phase of the operation, which included felling, trimming, and topping the tree length at about 10 cm s.e.d.

"Breaking out" was done by one crew member, and three 2-m chain strops were used for securing the haul. Communication was maintained with the hauler operator through a signalling device which transmitted both coded and verbal instructions. The extracted stems were stockpiled in front of the hauler for subsequent removal to the landing by a small rubber-tyred skidder (65 kW).

At the landing a final trim was carried out and the stems were cut into random lengths of between 3.8 and 11.0 m. A rubber-tyred loader sorted and stacked the produce and also undertook truck-loading at irregular intervals.

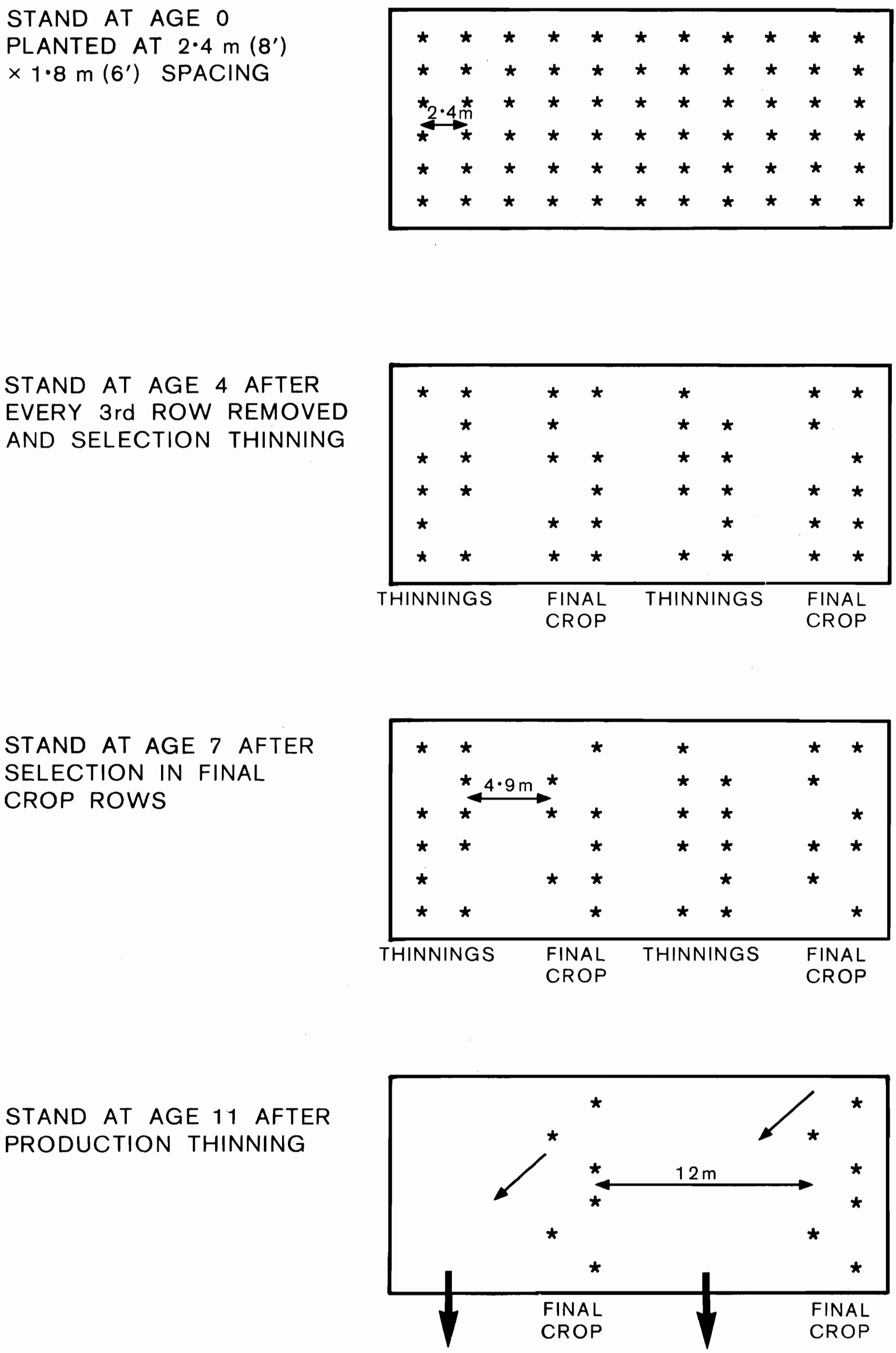

FIG. 1—Diagrammatic representation of crop layout at Rotoehu.

TABLE 1—Stand treatment in the trials at Rotoehu and Turangi

Crop age (yr)	Trial*	Year and treatment		Final crop	Thinning element	Treatment total
0	**R**	1968 Plant ***P. radiata*** 2.4 × 1.8 m		–	–	2300
	T	Plant ***P. radiata*** 2.1 × 2.1		–	–	2220
3	**T**	1971 Prune to 1 m				1750
4	**R**	1972 Thin-to-waste every third row†		–	–	1530
		Low prune 750 stems/ha to 1.8 m		–	–	1530
		Thin-to-waste unpruned stems				
	T	Thin-to-waste every third row in row thinning block. Equal number removed from selection thinning blocks		–	–	750
		Final-crop rows thinned to waste to 300 stems/ha in row blocks. Equal number removed from selection thinning blocks	R1	300	500	800
			R2	300	310	610
			R3	300	200	500
			S1			840
			S2			680
			S3			500
		Controls thinned to waste		300		300
		All trees pruned to 2.4 m				
7	**R**	1975 Nominate alternate pairs of rows as future final-crop and thinning		370	380	750
		Medium prune (in final-crop rows only) 300 stems/ha to 4.3 m		370	380	750
		Thin-to-waste unpruned stems in final-crop rows		300	380	680

	T	250 stems/ha final crop pruned to 4.2 m and 50 stems/ha final crop thinned to waste	R1	250	500	750
			R2	250	310	560
			R3	250	200	450
			Controls	250	–	250
		250 stems/ha selected for final crop pruned to 4.2 m and 50 stems/ha thinned to waste	S1	250	540	790
			S2	250	380	630
			S3	250	200	450
8	R	1976 High prune (in final-crop rows) 200 stems/ha to 6.0 m		300	380	680
	T	200 stems/ha final crop pruned to 6.0 m and 50 stems/ha final crop thinned to waste	R1	200	500	700
			R2	200	310	510
			R3	200	200	400
			Controls	200	–	200
		200 stems/ha final crop pruned to 6.0 m and 50 stems/ha thinned to waste	S1	200	540	740
			S2	200	380	580
			S3	200	200	400
11	R	1979 Production thin				
		(a) In final-crop rows all trees not pruned – 100 stems/ha				
		(b) Thinning rows – 380 stems/ha		200	–	200
12	T	1980 All blocks production thinned to 200 stems/ha		200	–	200

* **R** = Rotoehu; **T** = Turangi.

† This was a stocking adjustment at the commencement of the trial proper. Too many trees were planted initially and this mechanical thinning was made to adjust numbers without imposing a selection bias.

TABLE 2—Crop details at time of production thinning - Rotoehu trial

Species/Cpt	*P. radiata*/128 Rotoehu S.F.
Age/Origin	11 years/planted
Stocking	680 stems/ha
Mean d.b.h.o.b.	24.3 cm
Mean top height	20 m
Average tree volume	0.32 m^3

All elements of the operation were timed by stopwatch for 10 consecutive working days. Ground distances were measured by tape for extraction distance estimates for each recorded cycle time. A volume table was constructed from the harvested stand for the estimate of haul volume. Individual haul volumes could not be measured because of the stockpiling nature of the operation, but were derived from the subsequent measurement of stems on the landing.

The Turangi Trial

This was the first trial area where the paired-row and the selection thinning options were established at similar stockings back to back (Fig. 2) with the the prime objective of comparing productivity. The three row blocks R1, R2, and R3 had stockings of 700, 510, and 400 stems/ha respectively, and the selection blocks S1, S2, and S3 had 740, 580, and 400 stems/ha respectively. All were thinned to 200 stems/ha. The terrain was predominantly easy, suitable for ground extraction or for highly mechanised harvesting.

The history of the stand up to the production thinning operation in early 1980 is summarised in Table 1, and the crop layout in Fig. 3.

Diameter at breast height over bark (d.b.h.o.b.) and predominant mean height (PMH) were measured annually in plots in each block, and in the four "free-grown" control plots (Fig. 2). Basal area increment of the final-crop trees in each block was compared with that of the trees in the "free-grown" control plots to indicate when the removal of the production thinning element was necessary to minimise the loss of increment on the final-crop trees. All three row blocks (R1, R2, and R3) and the high-stocking selection block (S1) were overdue for thinning, hence some loss of potential increment had already occurred. Table 3 summarises the stand data for all plots immediately prior to production thinning.

The harvesting operation was carried out by a three-man crew operating a 52-kW skidder fitted with a winch, a 20-m main rope, and seven ring-mounted wire strops. Two men felled and trimmed the tree lengths in the bush; the third man operated the skidder, doing his own "breaking out" and unstropping at the road edge. This harvesting system is generally recognised in New Zealand as a suitable one for selection thinning.

Tree lengths were extracted to the road edge and unstropped by the skidder operator. After 10–12 hauls the machine was used to pile the stems along the road edge for later transport to the utilisation plant. There was a light-to-moderate ground cover of manuka scrub throughout the trial area, especially in the plots with lower tree stockings.

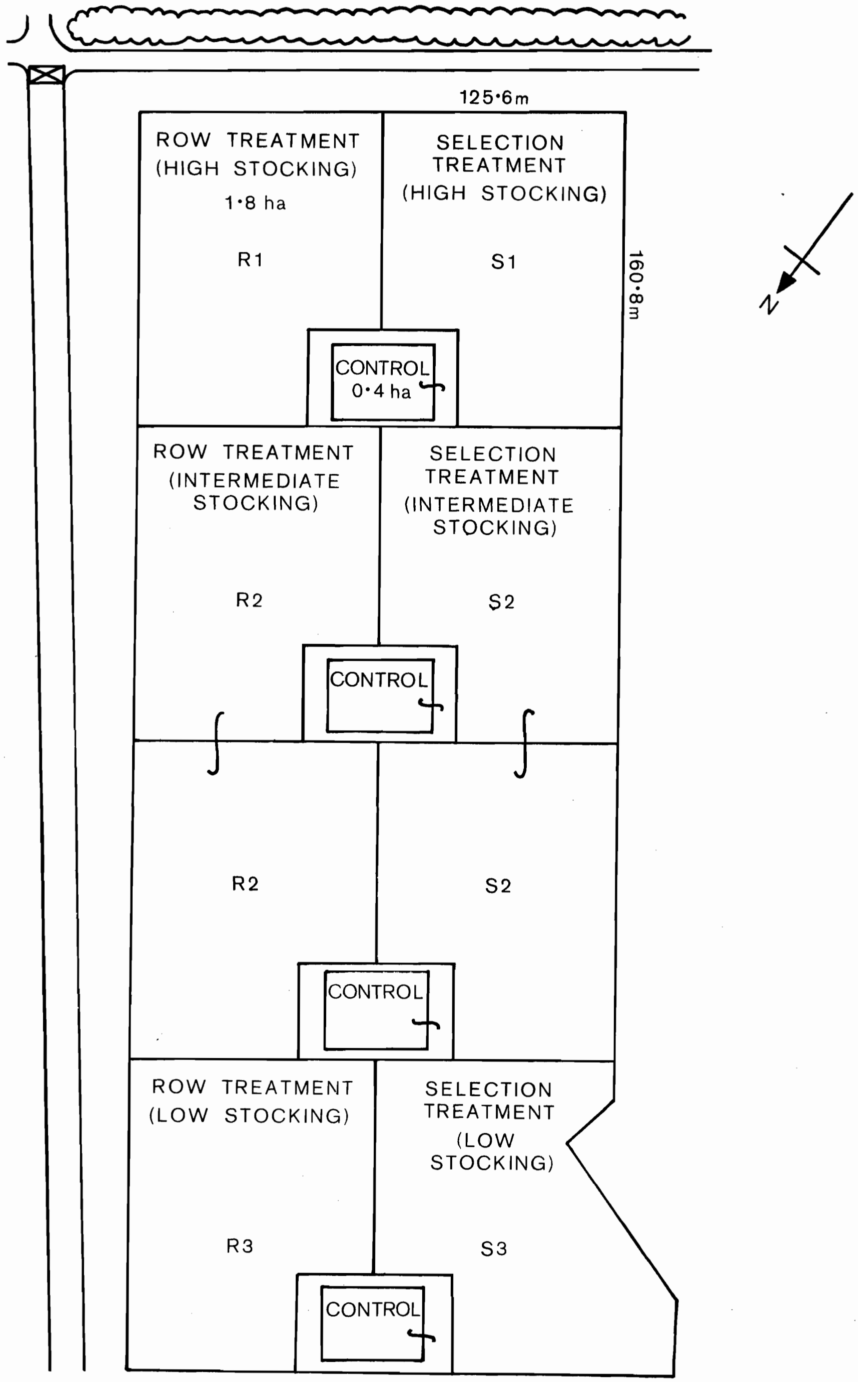

FIG. 2—Turangi trial layout.

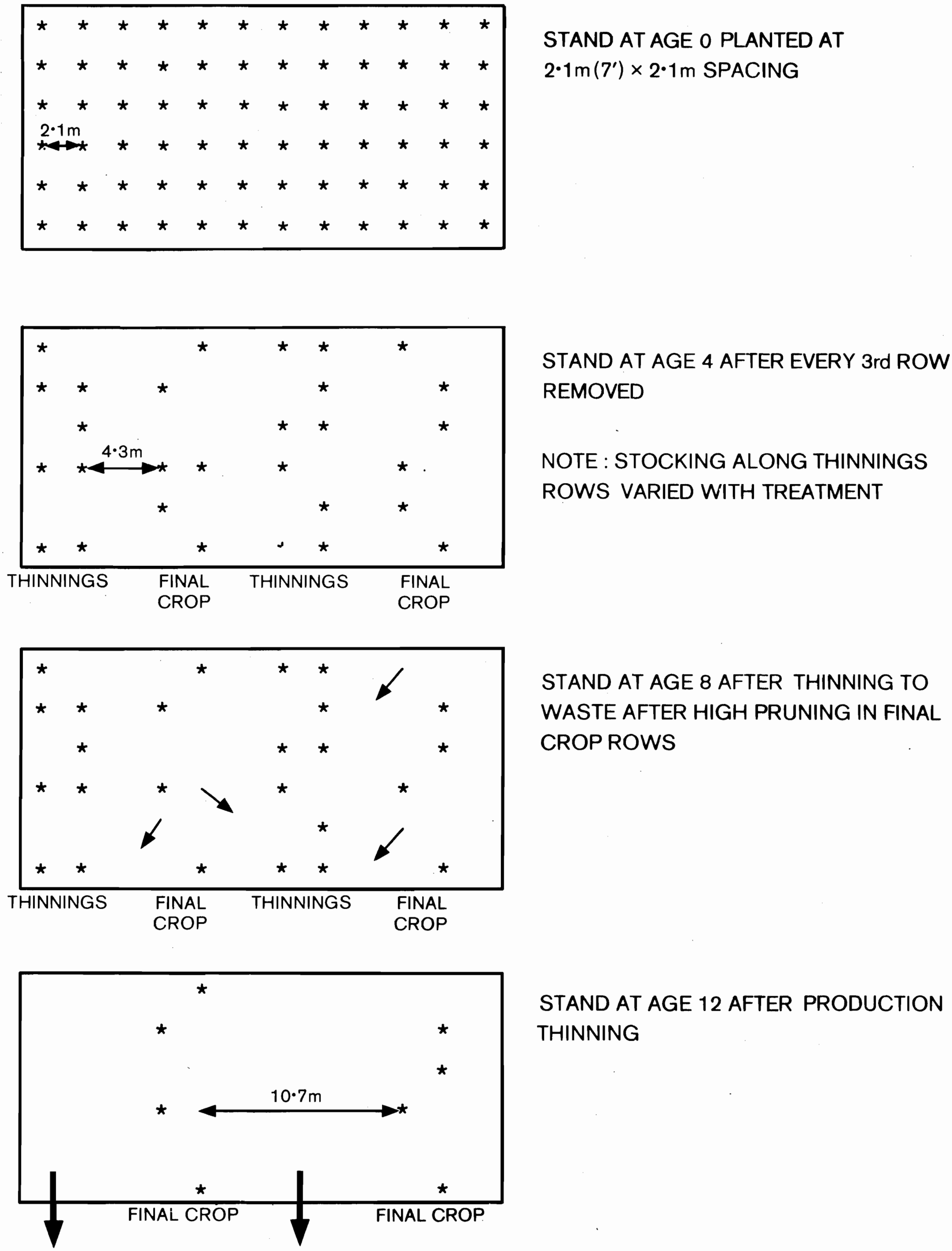

FIG. 3—Diagrammatic representation of crop layout at Turangi.

TABLE 3—Crop details at time of production thinning - Turangi trial

	Row treatments		Selection treatments	
	Final crop	Thinnings	Final crop	Thinnings
High stocking				
Block number	R1	R1	S1	S1
Stocking (stems/ha)	194	502	194	544
Mean d.b.h. (cm)	24.8	23.1	25.0	23.5
Basal area (m^2/ha)	9.29	21.08	9.48	23.55
Predominant mean height (m)	17.5	16.9	17.9	17.4
Mean piece size extracted (m^3)*		0.22		0.23
Merch. volume (m^3/ha)		108		122
Intermediate stocking				
Block number	R2	R2	S2	S2
Stocking (stems/ha)	196	311	198	387
Mean d.b.h. (cm)	25.2	27.7	27.3	26.0
Basal area (m^2/ha)	9.84	18.55	11.57	20.49
Predominant mean height (m)	17.5	17.5	18.1	17.6
Mean piece size extracted (m^3)*		0.29		0.29
Merch. volume (m^3/ha)		90		112
Low stocking				
Block number	R3	R3	S3	S3
Stocking (stems/ha)	198	206	198	198
Mean d.b.h. (cm)	26.0	29.2	28.2	28.0
Basal area (m^2/ha)	10.48	13.87	12.34	12.21
Predominant mean height (m)	17.5	17.2	18.0	17.2
Mean piece size extracted (m^3)*		0.36		0.30
Merch. volume (m^3/ha)		74		58
Control plots				
Stocking (stems/ha)	198			
Mean d.b.h. (cm)	29.5			
Basal area (m^2/ha)	13.58			
Predominant mean height (m)	17.3			

* Volume = $0.006 + 0.726\,D^2L$ ($r^2 = 0.94$)
where D = mid-point diameter
L = log length

The Woodhill Trial

The third trial area was laid out in 1974 in a 4-year-old stand of *P. radiata.* Woodhill Forest was initially established to control sand dune movement and was chosen as a trial area because of its easy topography and its proximity to a suitable market for production thinnings. Plot layout was basically the same as for the Turangi trial – row and selection thinning options in close proximity, with a series of "free-grown" controls. The main variation in this trial was that the production thinnings and final crop were in single rows.

Both the row and selection plots were reduced to a similar stocking and received identical pruning treatment – three lifts to 6 m. Annual remeasurement in 1980 indicated that growth of the final-crop element was being restricted and therefore a production thinning was scheduled for early 1981. Stand details prior to this thinning are given in Table 4.

A local contract crew was hired for the 10 days required to production thin the area. As a result of the Turangi study, completed 12 months earlier, it was decided to incorporate a bunching machine (Bell Infield Logger, 28 kW) into the system to improve load accumulation. Trees were felled with their butts facing the direction of extraction and trimmed to a 10 cm s.e.d. The pre-bunching machine then formed bunches of approximately 12 stems, usually in pairs, with one bunch lying across the other to

TABLE 4—Crop details at time of production thinning – Woodhill trial

	Block and treatment				
	Control Select.	1 Row	2 Row	3 Select.	4 Select.
Stocking (stems/ha)					
Final crop	200	200	200	200	200
Production thinning	170	440	650	440	650
	370	640	850	640	850
Predominant mean height (m)	13.2	13.8	13.9	14.2	14.7
Mean d.b.h. (cm)					
Final crop	22.0	19.6	17.6	19.6	20.6
Production thinning	20.2	17.9	16.6	16.3	16.9
Basal area (m²/ha)					
Final crop	7.69	6.25	4.84	6.22	7.00
Production thinning	5.43	11.04	14.20	9.23	14.83
Total	13.12	17.29	19.04	15.45	21.83

facilitate stropping of both from the same position. The paired bunches were extracted to the landing by a 97-kW rubber-tyred skidder. A skidworker was required to cut-to-length and assist in releasing the load from behind the skidder at the landing. Samples of the three main activities (felling and trimming, bunching, and extraction) were stop-watch timed in each of the blocks.

RESULTS AND DISCUSSION

Rotoehu Trial

Daily production for the study period ranged from a high of 49.7 m^3 to a low of 16.7 ^{3}, the latter being the result of a major mechanical breakdown. Over the period machine availability was recorded as 90% and utilisation 48%. From the basic work measurement data a production figure of 43 m^3/day was derived, based on a mean haul distance of 100 m and an average piece-size of 0.27 m^3.

One of the main objectives of this trial was to determine if the paired-row arrangement of the crop would improve load accumulation and lead to an increase in average haul volume, and hence in productivity. The size of the average haul volume is a critical factor in determining daily production. If the average piece-size is determined by silvicultural requirements such as the timing of thinning, then one method by which the average haul volume can be increased is by raising the average number of pieces stropped per haul. Analysis of the frequency of the number of pieces stropped per haul in this trial produced the relatively high average of three (80% of the recorded hauls had three or more pieces). This compares with two pieces per haul in an unpublished FRI study of a similar-sized hauler, with similar rigging, downhill strip thinning, and removing a similar number of stems per hectare (approximately 470) but utilising the narrow corridors (4–6 m) of the common crop layout. If this difference is sustained, then an appreciable increase in production should accrue from a crop layout which enhances haul size. Assuming that the average piece-size of the thinnings extracted from the stand will not vary significantly between stands grown on these two systems, then the increase in production would be of the order of 30–40%. This is a significant production gain and represents a reduction in cost per cubic metre.

Turangi Trial

Piece size is one of the most important parameters affecting productivity with the harvesting system used in this trial. Piece size of thinnings can be controlled to a degree by varying the intensity of thinning-to-waste at low pruning. Work measurement data showed that production was greater in the blocks with lower stocking, reflecting an increase in piece size. There was also an increase in production in row blocks compared with selection blocks at the same stockings (Table 5). A consistent time saving was achieved in the load accumulation phase in the row operation (Table 6). Concentration of stems to be extracted reduced the time to accumulate a full load behind the skidder by 14–25%. However, as this phase occupies only approximately 30% of the total cycle (including allowances) these gains were diluted by the elements unaffected by stand organisation. The high gains in productivity that were anticipated from concentrating the production thinnings into rows are not reflected in the collected

TABLE 5—Skidder productivity estimate at Turangi, based on an 8-hour (480-minute) working day

	Row 1	Row 2	Row 3
Basic cycle time for 100-m av. haul (min)	7.29	7.43	7.74
Add skidwork interference			
(a) Operator using skidder	1.33	1.33	1.33
(b) Operator using saw	1.95	1.95	1.95
	10.57	10.71	11.02
Add process allowance @ 9.8%	1.04	1.05	1.08
	11.61	11.76	12.10
Add rest allowance @ 15.5%	1.80	1.82	1.89
	13.41	13.58	13.99
Add minor contingency allowance @ 5% of basic cycle	0.53	0.54	0.55
TOTAL = X =	13.94	14.12	14.54
No. of hauls/day = $\frac{480}{X}$ = Y =	34.4	34.0	33.0
Av. volume/haul (m^3) = Z =	1.50 ±0.227	1.95 ± 0.405	2.30 ± 0.397
Daily production (m^3) = Y × Z =	51.4	66.2	75.9
Productivity in minutes/m^3	9.3	7.3	6.3

	Select. 1	Select. 2	Select. 3
Basic cycle time for 100-m av. haul (min)	7.99	8.83	8.75
Add skidwork interference			
(a) Operator using skidder	1.33	1.33	1.33
(b) Operator using saw	1.95	1.95	1.95
	11.27	12.11	12.03
Add process allowance @ 9.8%	1.10	1.19	1.18
	12.37	13.30	13.21
Add rest allowance @ 15.5%	1.92	2.06	2.05
	14.29	15.36	15.26
Add minor contingency allowance @ 5% of basic cycle	0.56	0.61	0.60
TOTAL = X =	14.85	15.97	15.86
No. of hauls/day = $\frac{480}{X}$ = Y =	32.3	30.0	30.3
Av. volume/haul (m^3) = Z =	1.51 ± 0.34	1.99 ± 0.35	2.06 ± 0.37
Daily production (m^3) = Y × Z =	48.8	59.7	62.4
Productivity in minutes/m^3	9.8	8.0	7.7

TABLE 6—Load accumulation time - Turangi trial

Treatment block	No. cycles measured	Element (min)			Total load accumulation time (min)	Av. No. logs per cycle	Av. load accumulation productivity (min/m^3)
		Position	Strop	Winch			
Row 1	36	0.48	2.65	0.54	3.67	6.9	2.5
Row 2	46	0.73	2.54	0.59	3.68	6.8	2.0
Row 3	43	0.95	2.56	0.74	4.25	6.3	1.8
Select. 1	46	0.99	2.68	0.64	4.31	6.9	2.9
Select. 2	25	1.46	2.85	0.80	5.11	6.8	2.6
Select. 3	41	1.41	2.84	0.80	5.04	6.8	2.4

data. This is due in part to using a fixed number of ring-mounted strops on the main winch rope as this configuration limits the number of stems that can be "broken out" at any one time, even if the stems are readily available.

Although bark and butt damage was lower in the row thinning than in the selection thinning blocks, it was higher than had been expected because of the felling procedure. A lean towards the gap created by earlier thinning operations precluded the thinnings from being felled directly into the thinning strips. Felling outwards into final-crop rows caused branch damage, and extraction caused stem damage to the pruned final-crop.

A better quality (size and straightness) final-crop remained after thinning in the selection blocks. Basal area of the final-crop trees in the selection blocks was higher than in the corresponding row blocks, especially at the low and intermediate stockings. This is mainly a consequence of imposing the row pattern on the crop. The "free-grown" controls have consistently maintained the highest basal area increment. However, with better-designed row thinning, especially where there is a low incidence of malformation, there should be little difference in final-crop tree quality.

Woodhill Trial

The results from this trial showed no discernible production gains from row thinning, either in rate of production or in the average time taken to form bunches and to extract them to the landing. The low residual stocking (200 stems/ha) allowed the bunching machine to maintain a high rate of production in both the row and selection thinning plots. However, the introduction of the bunching machine into the harvesting system had a significant effect on the productivity of the extraction machine. Load accumulation time for the skidder was reduced to 0.9 min/m^3 compared with 1.9 to 2.9 min/m^3 in the Turangi trial. The skidder was able to extract approximately 230 m^3/day (8-hour working day, 100-m average haul distance) which is well in excess of the bunching machine's daily production of approximately 60 m^3. A balanced system would therefore comprise:

★ 13–14 bushworkers felling and trimming;
★ Four Bell Infield Loggers prebunching stems;
★ One 97-kW cable skidder;
★ One rubber-tyred loader;
★ One skidworker.

An alternative would be a smaller skidder working with fewer bunching machines and bushworkers. The production costs generated by such systems harvesting small piece-size material and reducing stocking to a relatively low number of stems per hectare are lower than those normally associated with more conventional harvesting approaches.

The stocking range (640–850 stems/ha) had no appreciable effect on piece size, which ranged from only 0.11 to 0.13 m^3. Damage in both the row and the selection plots was considered excessive, one in four residual trees exhibiting bark or cambium damage, but it could be greatly reduced with more care and experience.

CONCLUSIONS

There are inherent problems in imposing a row pattern on an existing stand. Variations in precision of spacing at establishment lead to stocking differences; subsequent tending operations (or lack of them), coupled with an arbitrary allocation into crop and thinning rows, can magnify the variation. Changes in trial layout to compensate for these factors can also reduce the clarity of subsequent results. This happened in the Turangi and Woodhill trials – some gains were indicated in the row arrangement but their magnitude could not be clearly measured. To minimise the effect of variation, another series of trials was established at Turangi in 1975 on bare ground. Production thinning of this area is scheduled from 1985–86 onwards and measurement will allow a more accurate gauging of the production gains indicated in the earlier studies.

Some loss of final-crop growth was evident in all three trials, and it is apparent that if this is to be minimised the production thinning must take place soon after the 6.0 m pruning lift, or at around 9–10 years of age. At Turangi, crown depth and vigour had deteriorated in the rows and the selection blocks when compared with the "free-grown" controls and it is likely that increment loss will continue for some time; crown recovery will occur but the increment loss is permanent over the rotation.

Concentration of the stems in a row arrangement increases productivity in a cable operation as shown by the Rotoehu trial data. This results from the ability of the cable system to maintain a greater number of stems per extraction cycle.

A significant conclusion from the three trials is that a reduction to between 200 and 250 stems/ha removes some of the problems usually associated with a first production thinning. Movement within the stand is much easier, allowing prebunching of material and extraction to the landing with minimum interference. Many of the harvesting systems developed both in New Zealand and overseas have been aimed at overcoming the restrictive effect of high residual stocking on machinery movement within the stand. The row arrangement improves the chances of successfully introducing further mechanisation of the production thinning of small piece-size stems. The concentration of the stems reduces ineffective movement time, removes the selection decisions and the frequency of "hang ups", and also provides a suitable path to lay out the produce for subsequent operations with less risk of damage to the final crop.

If the forest industry is determined to production thin, stand reorganisation has the potential to improve productivity and to reduce the high costs associated with small piece-size harvesting. This applies particularly where cable-thinning operations are contemplated.

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