INITIAL SPACING AND FINANCIAL RETURN OF PINUS RADIATA ON COASTAL SANDS

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SYNOPSIS

On the basis of measurements recorded in the Woodhill spacing trials (A35) and of the current Woodhill (piece-size dependent) stumpage rates, the financial returns for each of seven initial spacings (6 × 6, 8 × 8, 12 × 12, 16 × 16, 10 × 6, 12 × 6 and 10 × 8 ft) were determined for two tending regimes. Costs of establishment and early silviculture for each spacing were estimated, and these, together with the anticipated returns, were used to calculate the land expectation value (LEV) for several economic models at compound interest rates of 3%, 5% and 8%.

Of the models analysed, the 6 × 6 ft spacing was, without exception, the least profitable, giving LEVs, at 5% compound interest, of the order of $50–$60 an acre lower than those of the most profitable spacing. The 8 × 8 ft spacing, although more profitable than the 6 × 6, was never as profitable as any of the wider spacings. These wider spacings (12 × 12, 16 × 16, 10 × 6, 12 × 6, 10 × 8 and almost certainly the 10 × 10 ft had it been included) all showed remarkable similarity in their calculated net returns; but the values for the 16 × 16 ft and possibly the 12 × 12 ft were considered over-optimistic. It was concluded that, so long as the adopted initial spacing is within the range 10 × 6 to 12 × 12 ft, higher net returns can be anticipated. Aspects which need closer investigation are the effects of spacing on branch size and malformation; but, unless the effects are found to be more marked than present evidence suggests, there is no economic justification for close initial spacing on the coastal sands.

INTRODUCTION

Sand-dune forests are generally considered to produce some of the best quality *Pinus radiata* grown in New Zealand (Whiteside, 1964). Stands grown on the sand appear to have better form, lighter branching and a lower incidence of malformation than similar *P. radiata* stands grown on other sites. If this general observation is correct, then on these sites it should be possible to capitalize on the advantages of a wider spacing without the repercussions usually experienced when planting distances are extended beyond those currently practised.

In the Woodhill spacing trial, established in 1953, the planting includes spacings of 6 × 6, 8 × 8, 10 × 10, 12 × 12, 16 × 16, 10 × 6, 10 × 8 and 12 × 6 ft. Initially, sample plots were established in all spacings but, following a comparability test, only the 6 × 6, 10 × 10, 12 × 12 and 16 × 16 ft spacings were retained as permanent sample plots.

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As the initial tree stockings of this trial have been close to the theoretical figures, and as there are no other similar trials on sand-dune sites, it was considered wasteful not to make some evaluation of the effects of spacing on profitability. Such an evaluation, while not perhaps statistically perfect, could provide valuable information of immediate use to the forester.

The present study attempts, on the basis of measurements recorded in the Woodhill spacing trials at age 13 years, to evaluate the overall economics of stands grown at different spacing for a full rotation using two model thinning regimes.

Basis for an Economic Evaluation

The major obstacle in economic studies of New Zealand forestry is the general absence of a realistic stumpage rate for forest crops. The almost nation-wide acceptance of a uniform stumpage rate for all sizes of forest produce is one of the worst aspects of exotic sales practice in this country. A stumpage rate not related to log size or tree d.b.h. ignores the large differences that exist in the costs of both extraction and conversion (not to mention any differences in the value of the sawn outturn). A uniform stumpage tends to overvalue small logs and thinnings, and to undervalue the larger logs. An economic study based on one and the same stumpage irrespective of piece size must invariably favour regimes producing the highest volume. Only when the stumpage rate reflects true costs and realizations can a realistic economic evaluation be attempted.

Fortunately for this study, all outturn from Woodhill is now sold under a contract with a differential stumpage based on the size of the log outturn. Details of the contract rates (as given by Painter, 1965) are:

For clearfellings —

- logs 3–6 in. small end diameter (s.e.d.) (min. length 6 ft) 2.08c (2.5d) cu. ft
- logs 6–8 in. (s.e.d.) (min. length 10 ft) 3.75c (4.5d) cu. ft
- logs 8 in. (s.e.d.) and over (min. length 10 ft) 9.33c (11.2d) cu. ft

For thinnings the same stumpage rate applies except that logs of 8 in. s.e.d. and over are reduced to 6.83c (8.2d) cu. ft.

There is insufficient information to establish how accurately these contract rates reflect true differences in the cost of extraction and conversion but it is considered that the differential is of the right order and that economic studies based on these rates will give a valid comparison between alternative regimes. For these reasons all realizations in this study are based on the current contract stumpages.

For complete evaluation, both returns and costs are necessary. Returns from first thinning can be obtained from calculations based on measurements recorded in the spacing trials and those for later thinnings and clearfelling estimated from predictions of volume increment using the yield tables for thinned *P. radiata* (Beekhuis, 1966). Cost estimates can be obtained by adjustment of current costs for conventional planting.

METHODS OF ASSESSMENT

Four temporary plots were established in each spacing (except the 10 × 10 ft) and 32 trees, representative of the diameter range in each spacing, were measured as a basis for volume calculations. Measurements recorded were d.b.h. (o.b.), height, and diameters (i.b.) at ¼, ½ and ¾ height. Measurements of top height, basal area (B.A.), stocking and mean d.b.h. were also recorded in each plot to determine the extent of variation between spacings. Summarized results are given in Table 1.

TABLE 1: RESULTS OF INITIAL ASSESSMENT AT 13 YEARS

Spacing (ft)	*Top height (ft)*	*Mean basal area (sq. ft/acre)*	*s.p.a.*	*% of initial stocking*	*Mean d.b.h. (o.b.) (in.)*
6 × 6	63.6	200	975	80	6.2
8 × 8	63.2	197	675	99	7.3
12 × 12	64.1	148	300	100	9.5
16 × 16	60.2	127	175	102	11.5
10 × 6	67.0	205	660	91	7.6
12 × 6	65.7	188	550	91	7.9
10 × 8	72.7	201	470	86	8.9

Some discussion on the results of the initial assessment is desirable before the methods of volume calculation are elaborated.

The mean top height of the 10 × 8 ft spacing differed significantly from the mean of the other spacings. This and earlier evidence (J. Beekhuis, pers. comm.) indicate that site differences are involved. To avoid exclusion of this spacing, values were adjusted to the mean top height of the other spacings, 64 ft.

Differences in mean basal area were very highly significant but most of the difference was accounted for by the 12 × 12 and 16 × 16 ft spacings. Differences between the closer spacings were small — an indication that stagnation had probably already begun in the closer spacings.

Compared with the B.A. per acre top height curve given earlier (Levy and St. John, 1964) the measured B.A. appear high. For an unthinned stand of top height 65 ft, the earlier prediction of only 170 sq. ft B.A. compares with an actual B.A. maximum of about 200 sq. ft. Even so, these B.A. values are probably lower than those recorded on most New Zealand sites. Interpolating from Spurr (1962) the B.A. of an unthinned stand of top height 65 ft on pumice soil is 220 sq. ft/acre and for Golden Downs (Lewis, 1954) the B.A. expected is 225 sq. ft.

The reason for this discrepancy between the actual B.A. and those predicted earlier is not obvious but is possibly the result of full stocking in the spacing trials.

Method of Calculation of Merchantable Volumes

As volume tables with merchantable volumes to 3, 6 and 8 in. s.e.d. were not available for Woodhill, and as differences in spacing could affect form to the extent that general volume tables would not be applicable, a more direct method of volume calculation was required.

There is no generally accepted method for calculating merchantable volumes to any given s.e.d. A method that has proved useful for some species is based on the "taper-line" (Gray, 1956); but from a preliminary study it would appear that *P. radiata* grown in New Zealand conforms to the taper-line over only a limited portion of its total stem length (J. Beekhuis, pers. comm.). To overcome this limitation, a modified "taper-line" approach, based on the average reduction in cross-sectional area per foot of tree height, was developed. Regressions relating average taper to tree d.b.h. and height were calculated for each spacing and these were used for estimating the volume in the specified s.e.d. classes.

All supporting statistical analyses were carried out by Dr W. G. Warren and all calculations were handled by computer using programmes prepared by W. E. Drewitt.

Accuracy of Volume Estimates

The volumes as calculated were to a minimum s.e.d. of 3 in. These were converted to total stem volumes by the Auckland Taper and Volume Tables (Duff and Burstall, 1955) — see Fig. 1.

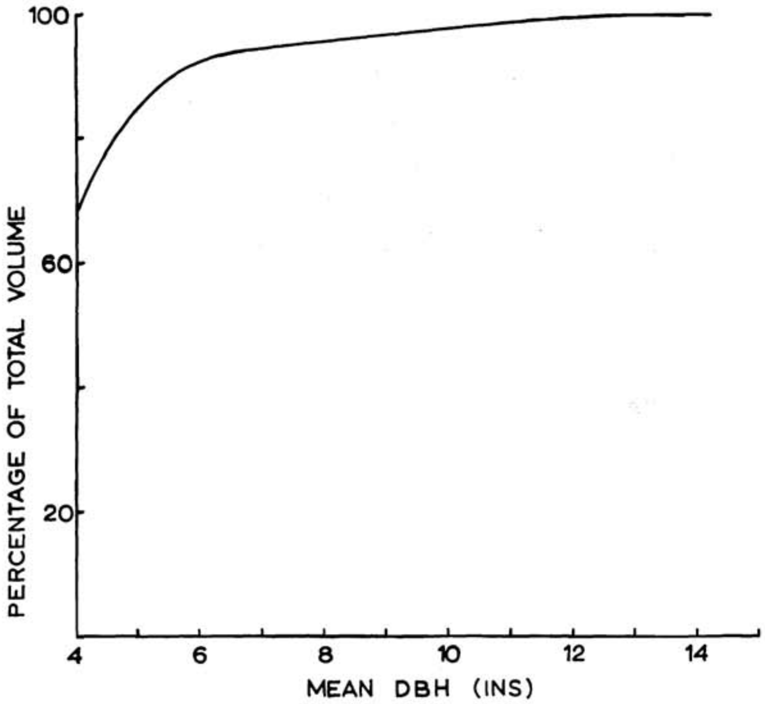

FIG. 1: *Volume to 3 inch s.e.d. as a percentage of total volume (based on Auckland Volume and Taper Tables — Duff and Burstall, 1955).*

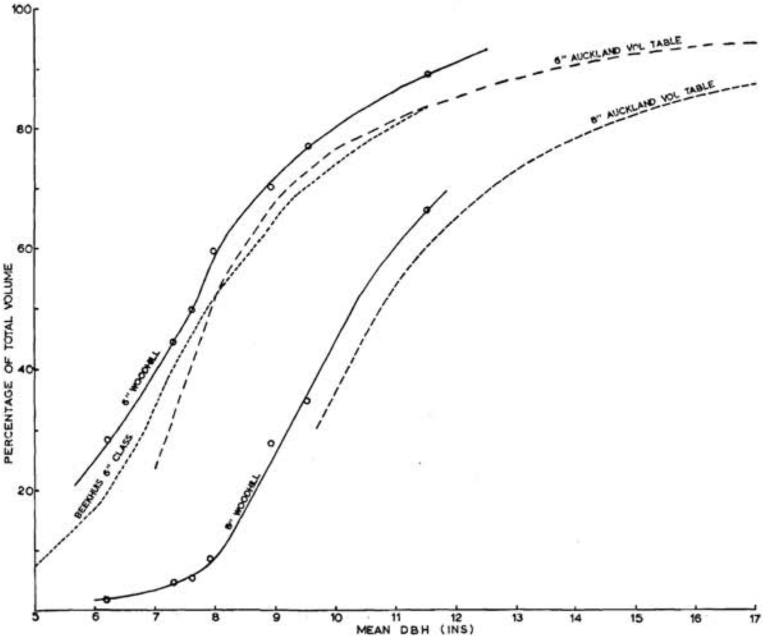

FIG. 2: *Comparison of volume estimates (percentage of total volumes to 6 and 8 inch s.e.d.).*

The percentages of total volume in the 6 and 8 in. s.e.d. classes for each spacing are given in Fig. 2 against their respective mean d.b.h. For comparison, the percentage volumes for the same s.e.d. from the Auckland Taper and Volume Table (Tables 16 and 17) and the percentage volume to a 6 in. s.e.d., as predicted by Beekhuis (1966), are given.

Comparisons indicate that the volume estimates for 6 and 8 in. s.e.d. are possibly overestimated by the method of calculation; the 6 in. by about 7% and the 8 in. by about 11%.

However, as the volume to 8 in. s.e.d. remains below 30% of the total volume in all spacings except the 12 × 12 and 16 × 16 ft, this overestimation in volume is not likely to have any significant effect on most of the results, except in the wider spacings where returns may be slightly overestimated.

The Volume and Value of Each Spacing

The total volume/acre, volumes to 3, 6 and 8 in. s.e.d., and the total value/acre for each spacing are given in Table 2. For the 10 × 8 ft spacing, values given are those for the adjusted measurements. Values were calculated by application of the Woodhill stumpage rates.

The total volumes exhibit the expected trend with the intermediate spacings having the highest volumes: mortality in the

TABLE 2: VOLUMES AND VALUE PER ACRE AT 13 YEARS

Spacing (ft)	*Volume (in cu. ft/ac) to s.e.d.* 8 in.	6 in.	3 in.	*Total volume (cu. ft/ac)*	*Total value ($/ac)*
6 × 6	50	1,150	3,800	4,040	100
8 × 8	190	1,850	3,960	4,170	120
12 × 12	1,130	2,490	3,140	3,240	142
16 × 16	1,600	2,160	2,390	2,410	136
10 × 6	240	2,390	4,580	4,800	142
12 × 6	370	2,670	4,240	4,440	144
10 × 8	600	2,580	3,910	4,070	144

close spacings and low stocking in the wide spacings have both had the effect of reducing volumes.

The total volumes of the close spacings compare well with those derived from Levy and St. John (1964); for a stand of top height 65 ft, the volume for an unthinned stand (presumably 8 × 6 ft) the estimated total volume, from their tables and figures, is 3,900 cu. ft per acre.

Volume per B.A./Height Relationship

The total volume per square foot of basal area, and the heights for each spacing are given in Table 3 and graphically in Fig. 3.

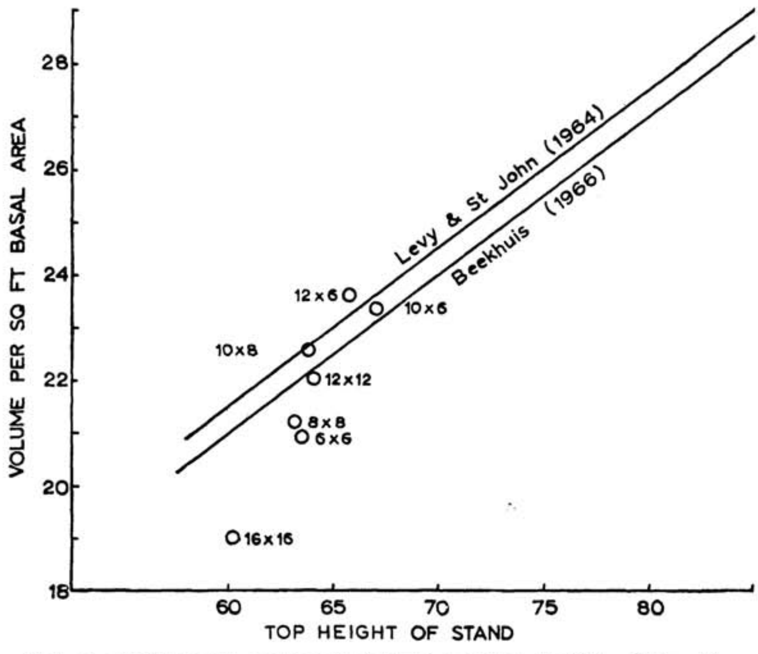

FIG. 3: *Volume per square foot basal area/top height relationships.*

TABLE 3: VOLUME PER B.A. — HEIGHT RELATIONSHIP AT 13 YEARS

Spacing (ft)	*Total vol. per sq. ft B.A.*	*Top height (ft)*
6 × 6	21.0*	63.6
8 × 8	21.2	63.2
12 × 12	22.1	64.1
16 × 16	19.0	60.2
10 × 6	23.4	67.0
12 × 6	23.6	65.7
10 × 8	22.6	64.0

* In the 6 × 6 ft living trees with no merchantable volume have been excluded.

Also given in Fig. 3 are the volume/B.A.-height relationships of Levy and St. John (1964), and Beekhuis (1966). These are derived from the equations:

Vol/B.A. = 3.5 + 0.3H (Levy and St. John)

Vol/B.A. = 3.0 + 0.3H (Beekhuis)

(H = height of the stand)

For spacings 12 × 12, 10 × 6, 12 × 6 and 10 × 8 ft, agreement with the two volume lines is good; in the 8 × 8 and 6 × 6 ft, agreement is not quite so good, while in the 16 × 16 ft the agreement is poor. The 16 × 16 ft exception is anticipated in previous work (Sutton and Drewitt, 1967) which showed that at a spacing of 16 × 16 ft trees tend to have more taper and lower volumes than would be expected in the closer spacings. It follows therefore that the volume/B.A. is also lower.

YIELD MODELS

Two thinning models are to be considered, using ages derived from height/age curves published by Levy and St. John (1964).

Model 1 — late thinning

1st thin at PMH* 65 ft (13 years) to 80 sq. ft/acre
2nd thin at PMH 95 ft (21 years) to 100 sq. ft/acre
Clearfell at PMH 125 ft (40 years)

Model 2 — early thinning

1st thin at PMH 50 ft (10 years) to 60 sq. ft
2nd thin at PMH 85 ft (18 years) to 90 sq. ft
3rd thin at PMH 105 ft (24 years) to 100 sq. ft
Clearfell at PMH 125 ft (40 years)

* PMH = Predominant mean height.

Realization from First Thinning

Model 1: The thinning model schedules a first thinning at PMH 65 ft to 80 sq. ft/acre.

To have accurately marked this thinning schedule in each plot would have been a major undertaking. Instead, the selection of thinnings was carried out in the office at the completion of the field work.

The first trees "selected" for thinnings were those which were the larger malforms or any tree which would normally be removed in a first thinning. These trees had been recorded separately at the time of plot measurement.

Additional trees to make up the necessary total were selected, taking the smallest first except in the case (by no means rare) of small diameter trees which had been high pruned but which were not malformed or in ill health.

To obtain the merchantable volumes by s.e.d. classes removed in each thinning the individual tree volumes (as calculated by computer) of the "selected" trees were totalled. A logging loss of 15% was assumed for all categories.

Values were obtained by applying the Woodhill stumpage rates. Calculated merchantable volumes of thinnings by s.e.d. classes and the total value for each spacing are given in Table 4.

TABLE 4: FIRST THINNING VOLUMES AND VALUES PER ACRE
(Late Thinning)

Spacing (ft)	*Thinning volumes in cu. ft* — *In log diameter class* 8 in.	6 in.	3 in.	Total merch. volume (cu. ft)	Value ($/acre)
6 × 6	—	170	1,650	1,820	40.8
8 × 8	50	570	1,230	1,850	50.6
12 × 12	210	670	360	1,240	46.8
16 × 16	370	240	100	710	34.6
10 × 6	40	870	1,390	2,300	64.2
12 × 6	60	960	970	1,990	60.2
10 × 8	80	880	800	1,760	55.4

Model 2: As early measurements in the spacing trial were limited to established F.R.I. plots in the 6 × 6, 10 × 10, 12 × 12 and 16 × 16 ft spacings, some other method of predicting basal areas and volumes at PMH 50 ft was necessary.

The method adopted for predicting basal areas at PMH 50 ft was based on the assumption that the basal area trends in all spacings would follow those of the unthinned control plots in the permanent FRI series. Growth curves for these plots were constructed and corresponding curves for each spacing, except the 16 × 16 ft, harmonized on these.

The volumes extracted in a thinning at PMH 50 ft to 60 sq. ft B.A. were calculated using the *P. radiata* yield tables (Beekhuis, 1966) except that the volume per sq. ft basal area/height relationship was that of Woodhill sands (Levy and St. John, 1964). A 15% logging loss was assumed.

Values were calculated by application of the Woodhill stumpage rates assuming the percentage log size class distribution as given in Figs 1 and 2. The mean d.b.h. of thinnings was derived by the prediction method.

Summarized results are given in Table 5. (Some minor adjustments in volumes and values were necessary to avoid anomalies in the results.)

TABLE 5: FIRST THINNING VOLUMES AND VALUES PER ACRE (Early Thinning)

Spacing (ft)	*Thinning volumes in cu. ft* — *In log diameter class* *8 in.*	*6 in.*	*3 in.*	*Total merch. volume (cu. ft)*	*Value ($/acre)*
6 × 6	—	98	886	984	28.2
8 × 8	12	298	930	1,240	34.6
12 × 12	34	276	364	674	21.6
10 × 6	25	373	1,022	1,420	39.0
12 × 6	12	312	876	1,200	33.4
10 × 8	20	350	750	1,120	32.4

Anticipated basal area increments, volumes of future thinnings and clearfelling, and mean d.b.h. for both models, were predicted from the yield table (Beekhuis, 1966). A 5% logging loss was assumed for all operations.

Realizations were obtained by application of the Woodhill stumpage rates assuming the percentage log size class distribution as given by the Auckland Taper and Volume Table (Duff and Burstall, 1955 — see Figs. 1 and 2.

Results are summarized in Table 6. (The realizations for the first thinnings are included for completeness.)

TABLE 6: REALIZATIONS IN $ PER ACRE OF THINNINGS AND CLEARFELLING

Model	*Spacing (ft)*	*Thinning realizations* *First*	*Second*	*Third*	*Clearfelling realizations*	*Total realizations*
Late thinning	6 × 6	40.8	94.2	—	574	709
	8 × 8	50.6	97.4	—	580	728
	12 × 12	46.8	120.4	—	604	771
	16 × 16	34.3	125.2	—	614	774
	10 × 6	64.2	103.0	—	586	753
	12 × 6	60.1	109.6	—	592	762
	10 × 8	55.4	112.6	—	598	766
Early thinning	6 × 6	28.2	89.6	78.8	482	678
	8 × 8	34.6	119.6	85.8	508	749
	12 × 12	21.6	134.4	89.2	518	763
	10 × 6	39.0	123.0	86.8	510	759
	12 × 6	33.4	127.0	86.8	512	758
	10 × 8	32.4	130.6	88.0	516	766

TABLE 7: SUMMARY OF ESTABLISHMENT COSTS

	Cost of operation in dollars per acre and year									
					Releasing					
Spacing	*Fence*	*Marram*	*Lupin*	*Planting*	*by machine*		*by hand*		*Total costs*	
(ft)	(—5)	(—4)	(—3)	*(0)*	*(1)*	*(2)*	*(1)*	*(2)*	*Machine releasing*	*Hand releasing*
6 × 6	0.5	10.6	2.0	24.8	3.8	1.6	18.8	9.4	43.3	66.1
8 × 8	0.5	10.6	2.0	17.8	3.8	1.6	14.0	7.0	36.3	51.9
12 × 12	0.5	10.6	2.0	12.0	3.8	1.6	9.2	4.6	30.5	38.9
16 × 16	0.5	10.6	2.0	9.6	3.8	1.6	7.2	3.6	28.1	33.5
10 × 6	0.5	10.6	2.0	17.0	3.8	1.6	11.2	5.6	35.5	46.9
12 × 6	0.5	10.6	2.0	15.0	3.8	1.6	9.2	4.6	33.5	41.9
10 × 8	0.5	10.6	2.0	15.2	3.8	1.6	11.2	5.6	33.7	45.1

Costs of Establishment per Acre

A comprehensive account of most of the costs incurred in the establishment of sand dune forests has been published (Restall, 1964). The estimates of costs for the various spacings are based on these except when stated otherwise.

Costs the Same for all Spacings

(a) Foredune fixation (year: −5):
Costs of foredune fencing per chain $12.60
To convert to cost per acre, assume the forest is 3 miles wide, then 3 × 640 acres require one mile (80 chains) of fence. So cost of fencing per acre is $0.52, say $0.50

(b) Cost of marram establishment (year: −4):
Cost of marram $3.35 to $4.35, say $4.0
Cost of planting $5.6
Cost of fertilizer — 1st application $1.0

Total per acre $10.6

(c) Cost of fertilizer and lupin sowing (year: —3):
Cost of fertilizer and application $1.0
Cost of lupin seed $1.0
Total per acre $2.0

Costs Different for Each Spacing

(a) Cost of trees (including distribution) (year: 0):
The cost of trees to Woodhill in 1963 and 1964 (from the Statements of Annual Accounts N.Z.F.S. 1963 and 1964) were $8,546 and $13,972, respectively. The areas planted in those years were 777 and 1,274 acres (N.Z.F.S. Annual Reports), so the costs of trees per acre were $11.2 and $11.0, respectively — say $11.00. If trees were planted at 900 per acre, then cost per 1,000 trees is $12.2 — say, $12.0.
On the basis of 20% of this cost being a fixed cost (*i.e.*, independent of the number of trees per acre) the cost of trees for the various spacings can be calculated:

Spacing	*s.p.a.*	*Total Cost*
6 × 6 ft	1,210	$14.0
8 × 8 ft	680	$ 9.0
12 × 12 ft	300	$ 5.2
16 × 16 ft	170	$ 4.0
10 × 6 ft	730	$ 9.4
12 × 6 ft	600	$ 8.2
10 × 8 ft	540	$ 7.6

(b) Cost of planting (year: 0):
Planting by Lowther machine costs $8.8 at 900 s.p.a.
If 30% of the costs are fixed and if the remainder of the planting cost is proportional to the distance travelled, then the costs of planting for the various spacings are:

Spacing	*Cost to plant each acre*
6 × 6 ft	$10.8
8 × 8 ft	$ 8.8
12 × 12 ft	$ 6.8
16 × 16 ft	$ 5.6
10 × 6 ft	$ 7.6
12 × 6 ft	$ 6.8
10 × 8 ft	$ 7.6

(c) Releasing costs (years: 1 and 2):

(i) Cost of releasing by discs and tractor:
Year one (two discings) $3.8
Year two (one discing) $1.6

(Note: Aerial spraying costs are similar to above. Theoretically the costs of releasing at wider spacings would be less than given above but the savings are negligible.)

(ii) Cost of releasing by hand:
Cost of a single hand-releasing at 8 × 6 ft spacing = $7.0 per acre. If costs of releasing other spacings are directly proportional to the number of rows and independent of the number of trees in the rows, then the cost of a single-releasing in the other spacings (assuming rows at wider spacing in the rectangular spacings) are as follows:

Spacing	*Cost of Single Hand-releasing*
6 × 6 ft	$9.4
8 × 8 ft	$7.0
12 × 12 ft	$4.6
16 × 16 ft	$3.6
10 × 6 ft	$5.6
12 × 6 ft	$4.6
10 × 8 ft	$5.6

So costs in year 1 are double the above and costs in year 2 are the same as above.

No pruning costs have been included as the stumpage rates are understood to be applicable to unpruned stands only. An allowance for annual maintenance is also excluded as it is assumed that this would be more or less independent of the actual spacing and would not therefore affect comparisons between spacings.

RESULTS AND DISCUSSION

Now that accurate estimates of all variable costs and all realizations for all spacings are available, it is possible to evaluate the overall economics of initial spacing by using Faustmann's land expectation value approach. The LEV for four models (late and early thinning with alternatives of hand- and machine-releasing) were calculated at 3, 5 and 8% compound interest. Results of the LEV calculations are given in Table 8.

TABLE 8: LAND EXPECTATION VALUES IN $/ACRE

Model	*Spacing (ft)*	*LEV for hand-releasing at*			*LEV for machine-releasing at*		
		3%	5%	8%	3%	5%	8%
Late thinning	6 × 6	240.8	75.2	12.4	300.2	104.2	11.2
	8 × 8	298.2	103.8	8.0	325.0	120.8	23.2
	12 × 12	346.4	129.6	26.0	358.0	138.8	33.8
	16 × 16	350.2	131.8	28.0	357.8	137.8	33.2
	10 × 6	330.8	121.0	20.0	346.6	133.4	30.8
	12 × 6	344.0	129.8	27.2	353.2	137.0	33.0
	10 × 8	339.8	125.6	23.2	353.2	136.2	32.0
Early thinning	6 × 6	277.0	91.6	0.2	308.4	116.4	21.6
	8 × 8	345.8	133.4	27.6	367.4	150.6	42.4
	12 × 12	369.4	148.8	39.2	381.2	158.0	47.0
	10 × 6	361.8	144.4	35.8	377.6	157.0	46.6
	12 × 6	367.2	148.4	39.2	378.8	157.6	47.0
	10 × 8	367.4	147.0	37.0	383.2	159.4	47.6

Before discussing the results in detail, it must be stressed that all the indirect forest costs have been deliberately excluded from the calculations. As these costs are constant for all spacings, their inclusion would only add to the amount of work involved without contributing anything to the overall objective of the analysis; their inclusion would considerably reduce the real LEVs for Woodhill.

In all economic models, the 6 × 6 ft spacing proved, without exception, to be the least profitable. Using late thinning models with hand-releasing the 6 × 6 ft spacing is worth (at 5% compound interest) $28.6 an acre less than the 8 × 8 ft, and $56.6 less than the most profitable spacings (16 × 16 ft). Using the same thinning model but with machine-releasing, the 8 × 8 ft and the most profitable spacing (12 × 12 ft) are worth, respectively, $16.6 and $34.6 more than the 6 × 6 ft. Within the early thinning models, the 6 × 6 ft proves to be an even less profitable alternative. With machine-releasing, the 6 × 6 ft is worth (again at 5% compound interest) $41.8 less than the 8 × 8 ft and $57.2 less than the 12 × 12 ft.

It could be argued that a thinning at age 10 in the 6 × 6 ft is late and that it should have been carried out earlier. However, such an early thinning would be of doubtful profitability for the merchantable volume (to 3 in. top) would be well under 1,000 cu. ft per acre and there would be very few logs over 6 in. diameter. A very early thinning must therefore be a thinning to waste. If an alternative yield model for the 6 × 6 ft spacing is developed with a tending schedule corresponding approximately to a 19% relative spacing regime with three thinnings (namely, a thinning to waste at PMH 35 ft leaving 300 s.p.a. and two commercial thinnings at PMHs 70 ft and 105 ft leaving 150 and 90 s.p.a., respectively—clearfelling at 125 ft) and yields and realizations calculated by the same methods as for the above hand-releasing models but with an additional charge of $16 an acre for a thinning to waste, then the LEV for the model is $115.0. This is an improvement of $23.8 over the delayed (but by no means late) thinning and this improvement is possible despite the fact that there are only two merchantable thinnings (as opposed to three) and an additional charge of $16 for the thinning to waste. This result suggests that it is poor economics to leave stands until a merchantable thinning is possible. The cost of thinning to waste will be more than cancelled out by the enhanced returns of the later thinnings. However, the increase is still not sufficient to make the 6 × 6 ft spacing anywhere near as profitable as the wider spacings.

The 8 × 8 ft spacing, although considerably more profitable than the 6 × 6 ft, is still not as profitable as any of the wider spacings. For most models the 8 × 8 ft is worth $16 to $20 per acre less than the least profitable of the wider spacings.

Within the wider spacings there is a remarkable similarity between the calculated LEVs. In all models the difference between the most profitable and least profitable of these wider spacings amounts to only a few dollars, though the order of profitability tends to change with each model. These observations suggest that among those wider spacings there is little difference in the overall profitability.

It must be stressed that the calculated returns depend on the basal area increments, after the first thinning, being the same in all spacings (a basic assumption in the yield table). In practice, it is very doubtful whether the same increment could be maintained initially in wide spacings such as the 16 × 16 ft and possibly the 12 × 12 ft, because of the relatively few stems per acre remaining after thinning. Also, as was stated earlier, the proportions of volumes in the larger log sizes are possibly overestimated and this could have resulted in some over-valuation in the 16 × 16 ft and 12 × 12 ft spacings. For these reasons the LEV for the 16 × 16 ft and possibly the 12 × 12 ft spacings are probably overestimated.

If so, this would leave the 10 × 6, 12 × 6, 10 × 8 and possibly the 12 × 12 ft as the most profitable spacings. To decide which of these spacings (or any other similar spacing for that matter) should be favoured, other factors must also be considered. Obviously such aspects as planting machine design, availability of labour, and the size and volume of the thinnings to be removed could be determining factors.

Early thinning (model 2) proved to be more profitable than late thinning (model 1) but the difference is attributable not so much to the earlier return from the first thinning as to the combined returns of three as opposed to two thinnings.

This improvement in returns from early thinning is more marked in the closer spacings, suggesting that the timing of thinnings is more critical with closer spacing. This assumes, of course, that the net price size gradient would hold for all differences in extraction costs over these operations — this may be unlikely, especially in the closer spacings where practically all outturn is in the smallest log size class.

Hand-releasing, as expected, lowered all returns but had least effect in the wider spacings.

The Advantages and Disadvantages of Wider Spacing

One aspect of major importance which has not been taken into consideration is the influence of spacing on branch size and hence log quality. Obviously, if the adoption of wider spacing results in a greatly increased branch size, then the sawmiller will expect compensation by way of a reduced stumpage. The effects of spacing, especially rectangular spacing, on branch size is not yet known and the economic comparison cannot be completed until this aspect has been properly investigated.

However, unless the increase in branch size within the wider spacings is a good deal more than existing evidence (admittedly subjective) suggests (Bunn and Brown, 1964) the log quality is unlikely to be degraded significantly. Indeed, the increase in planting distance could actually improve grade recovery if the more open stand conditions delay the death of the very small branches, which Whiteside (1964) found were a major degrading factor in timber from conventionally spaced Woodhill stands.

The most commonly accepted reason for not planting at wider distances is that the incidence of malformation is generally so high that there are insufficient good quality stems for the selection of a final crop. For most New Zealand sites the increase in malformation with wider spacing is so great as to nullify any possible advantages. However, this is not the case at Woodhill where the proportion of malforms, even in the widest spacings, is not great. In the 16 × 16 ft only three of the 35 trees measured were recorded as malformed. In the closer spacings the proportion was even lower. Thus the incidence of malformation is not likely to be a limiting consideration in wider planting on the sand-dunes at Woodhill.

The questions of branch size and the incidence, type and severity of malformation in relation to spacing are the subject of a separate investigation.

Another argument often advanced in favour of close spacing is that the volume production is greatest in the closest spacing. The total volume production over a rotation is probably greater in the closer spacing, but the merchantable volume, especially in the larger, more valuable sizes, is almost invariably lower. In this study the total thinning volumes at age 10, in the 6 × 6, 12 × 6 and 10 × 8 ft were practically the same (1,200-1,300 cu. ft/acre) but the proportion of this volume to a 6 in. top was only 10% in the 6 × 6 ft but was 28% and 35%, respectively, in the other two spacings. In terms of merchantable volumes, the claim of increased volume production for the closer spacings cannot be substantiated.

Following from this, obviously the wider spacings offer far greater silvicultural flexibility in timing the first thinning. In a stand of 6 × 6 ft spacing, the first thinning cannot be delayed without seriously affecting the financial returns since there will be both mortality and a reduced diameter increment resulting in a high proportion of small logs. With wider spacing, the first thinning can be delayed without such serious repercussions. In the present study the discounted worth (at 5% compound interest) of a first thinning at 13 years, compared with a first thinning at 10 years, represented an increase of $4.2 an acre in the 6 × 6 ft, of $9.4

in the 8 × 8 ft and of $11.6 in the 12 × 12 ft. The low monetary increase in the closer spacings is not the result of mortality, since this aspect has been ignored (had mortality been considered the increase in the returns would have been less in the closer spacings). Rather, it is simply the result of a preponderance of small diameter trees. In the wider spacing where the diameter increment was not so restricted, the proportion of larger sized logs, and hence the value of the outturn, is increased.

The 10 × 10 ft Spacing

It was originally intended that, since complete measurements in the 10 × 10 ft were not possible, appropriate values would have to be derived indirectly and used as input data for the calculation of LEVs, etc., but, in view of the similarity of returns from all spacings except the 6 × 6 and 8 × 8 ft, it is considered that the 10 × 10 ft spacing would almost certainly give the same result and the effort involved in determining the appropriate values would not be worth while. The 10 × 10 ft spacing should therefore be considered as being on a par with the rectangular spacings.

CONCLUSIONS

(1) Within the limitations of the two models used, the 6 × 6 ft and to a lesser extent the 8 × 8 ft spacing proved to be significantly less profitable than any of the wider initial spacings.

(2) The remaining spacings (12 × 12, 16 × 16, 10 × 6, 12 × 6 and 10 × 8 ft) were all calculated as having very similar net economic returns, although it is probable that for the 16 × 16 ft, and to some extent the 12 × 12 ft, the returns are over-optimistic.

(3) The 10 × 10 ft spacing, had it been included in the analysis, would probably have proved to be on a par with the most profitable alternatives.

(4) It follows, then, that so long as the adopted initial spacing is within the range 10 × 6 to 12 × 12 ft, the highest net returns can be anticipated.

(5) Radiata pine stands at Woodhill, and possibly at other forests on coastal sands, appear to benefit from wider initial planting without incurring those disadvantages generally expected on most other New Zealand sites. The only aspect on which there is any doubt is the exact relationship between spacing, branch size and malformation but, unless the effect on branch size is found to be more marked than present evidence suggests, there is no case for close initial spacing.

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