Thinning and Spacing Research in Sitka Spruce and Lodgepole Pine

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ABSTRACT

Thinning and spacing experimentation began in Ireland in the late 1950's. Some meaningful results are now available from these experiments. If spacing at planting is increased from 1.8 to 2.4m square in Sitka spruce a loss in production of about 4% is incurred. A loss of the same magnitude results from a thinning intensity which removes 80% of volume increment. Wider initial spacings or heavier thinning intensities than those conventionally practised give greater quantities of sawlog timber. A first thinning in spruce which removes alternate lines of trees does not depress increment. Rethinning after line thinning comprises a certain amount of unattractive material. There are implications for timber quality where wide spacing and heavy thinning are employed.

1. INTRODUCTION

The paper outlines the principle results from thinning and spacing experimentation in the Republic of Ireland. The question of spacing is dealt with first followed by that of thinning, subdivided into selective and systematic thinning types.

The first replicated spacing experiment was established in 1958; thinning research was initiated in 1962. Altogether, a total of 15 thinning and 17 spacing trials has been established in Sitka spruce (SS) and the various provenances of lodgepole pine (LP). Windblow has eliminated two of the thinning trials and caused varying degrees of damage to five others. One of the spacing trials in which the Lulu Island provenance of lodgepole pine was being studied failed to develop satisfactorily and yielded no meaningful results.

Scattered throughout the country are 59 permanent sample plots (44 in spruce, 15 in pine). These provide growth data for the production of yield models.

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2. SPACING

Originally, spacing experiments were established at time of planting. A major disadvantage of this procedure was the time-lag involved before any meaningful results were forthcoming. More recently, the emphasis has changed to one of respacing in a crop which has successfully established itself. A necessary requirement for respacing is that competition between trees is not too advanced before the stocking is reduced.

Many of the earlier spacing experiments suffered various misfortunes. Three experiments contain either the Lulu Island or inland provenances of lodgepole pine; these had been initiated before only the Coastal provenance of this species became accepted for general planting. Other trials received a "spot" fertiliser treatment at planting in accordance with the management practice of the time. Consequently, plots with closer spaced plants received a higher concentration of nutrient. Some confusing and seemingly contradictory growth patterns have since been attributed to this practice. The imbalance in nutrient input was later corrected. Injudicious blocking, attacks of sawfly and aphid, frost and wind-damage have all influenced growth to a greater or lesser degree in some other experiments.

The concept of respacing adopted in recent years may eliminate many of the above draw-backs.

Spacing results discussed here come from two of the most informative older type experiments at Ballyhoura (SS) and Cloosh Valley (LPC) forests. The former is a high productive gleyed site, 130m above sea level fertilised with phosphate and potash nine years after planting. The pine experiment is on a western blanket peat site and 90m above sea level. "Spot" fertilisation at planting was equalised two years later with a broadcast application of phosphate. Planting in both trials is on a ploughed ribbon.

Both the pine and the spruce studied have a high production rating — Yield Class 16 and 24 respectively (Hamilton and Christie, 1971).

2.1. *Results of Different Spacings*

2.1.1. *Survival*

Percentage survival up to canopy closure is not affected by spacing. From then on, it can be expected that competition between stems in the closer spacings will lead to a higher mortality rate at these espacements.

2.1.2. *Height*

Both mean height and top height are greater at closer spacings at least in the early stages (Fig. 1). Differences in pine may, in part be due to the greater concentration of fertiliser in closely spaced plots due to spot application at planting. Mean height differences are statistically significant for both species. Differences in top height are significant for pine only.

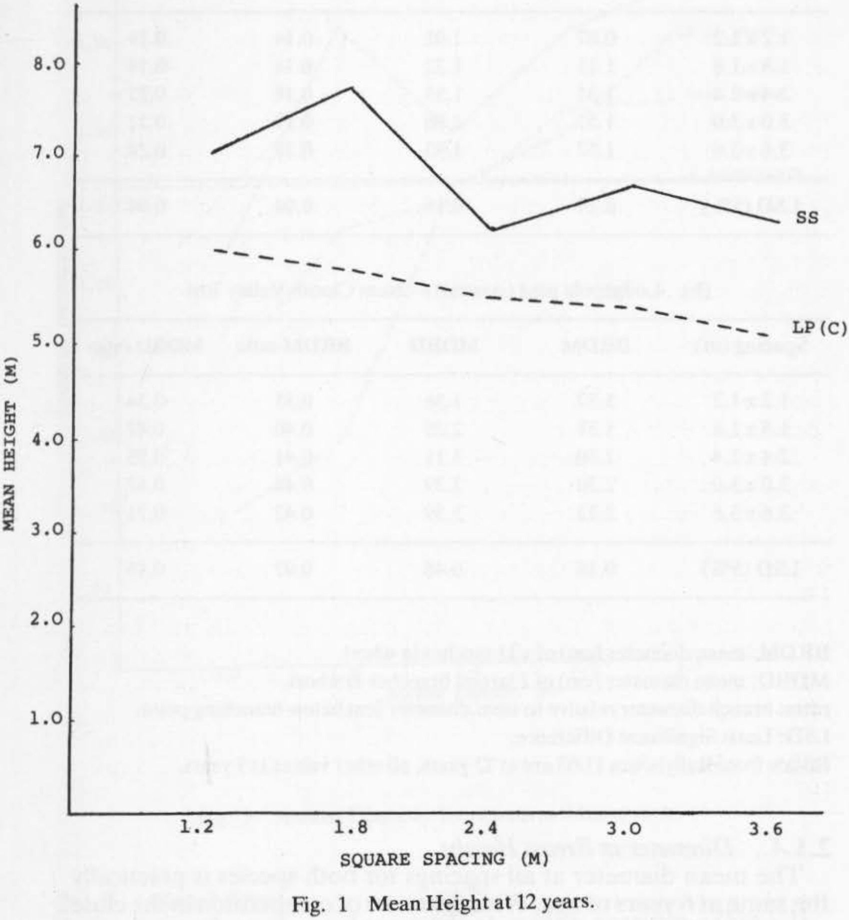

Fig. 1 Mean Height at 12 years.

2.1.3. *Branch Size*

Measured on the lowest live whorl, mean branch diameter increases with wider spacing for both spruce and pine. When the ratio of branch to stem diameter (measured 5cm beneath point of branching) is studied, an increase with wider spacing is also detected. (Table 1).

Table 1 Branch Diameter and Relative Branch Size.

(a) Sitka spruce — from Ballyhoura 11/63

Spacing (m)	BRDM	MDBD	BRDM ratio	MDBD ratio
1.2 x 1.2	0.87	1.01	0.14	0.19
1.8 x 1.8	1.15	1.32	0.14	0.18
2.4 x 2.4	1.31	1.55	0.18	0.22
3.0 x 3.0	1.51	1.86	0.17	0.22
3.6 x 3.6	1.57	1.93	0.18	0.24
LSD (5%)	0.19	0.16	0.04	0.04

(b) Lodgepole pine (coastal) — from Cloosh Valley 7/64

Spacing (m)	BRDM	MDBD	BRDM ratio	MDBD ratio
1.2 x 1.2	1.57	1.56	0.35	0.34
1.8 x 1.8	1.87	2.26	0.40	0.47
2.4 x 2.4	2.30	3.11	0.41	0.55
3.0 x 3.0	2.30	3.39	0.44	0.67
3.6 x 3.6	2.12	3.59	0.42	0.71
LSD (5%)	0.18	0.48	0.07	0.16

BRDM: mean diameter (cm) of all branches in whorl.
MDBD: mean diameter (cm) of 2 largest branches in whorl.
ratio: branch diameter relative to stem diameter 5cm below branching point.
LSD: Least Significant Difference.
Ratios from Ballyhoura 11/63 are at 12 years, all other values at 9 years.

2.1.4. *Diameter at Breast Height*

The mean diameter at all spacings for both species is practically the same at 6 years of age. With the onset of competition in the close spacings, differences become evident at 9 years so that by 15 years a difference of 5.4cm separates the widest from the narrowest spacing in LP (C) — the equivalent figure for SS is 8.2cm.

Annual diameter increments of 1.27cm result in exactly four rings per inch at the breast height point. Spacings wider than 2.3m square for high yield class spruce will give timber containing less than four rings per inch during the age 6 to 15 years. The equivalent spacing in high yield class pine is 2.8m square.

The pattern of diameter increment in spruce is shown in Fig. 2.

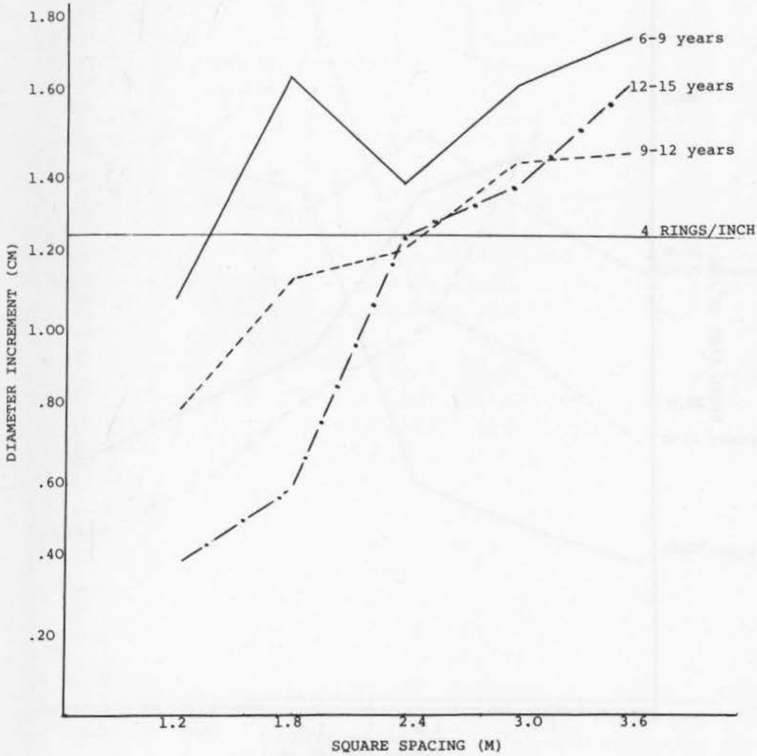

Fig. 2 Annual Diameter Increment in Sitka spruce.

2.1.5. *Basal Area*

Total production is depressed at wider spacings. (Fig. 3). Differences between 1.2 and 3.6m spacings at 15 years stand at $20m^2$/ha in SS and $27m^2$/ha in LP (C).

The graphs in Fig. 4 show a levelling off in basal area increment by the fifteenth year over all spacings. Presuming this equalisation in increment to be maintained, maximum production loss in basal area over the rotation should be in the region of 20 and $30m^2$/ha respectively for spruce and pine.

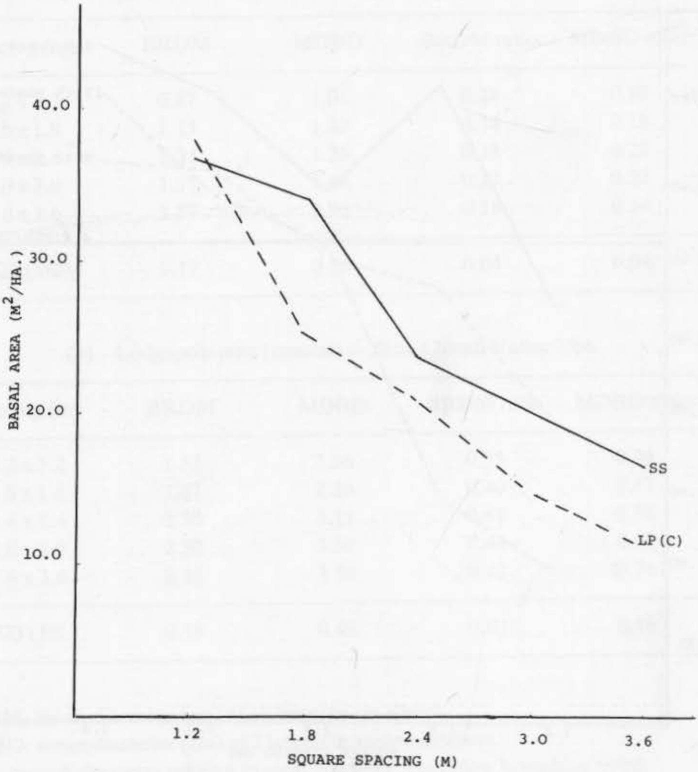

Fig 3. Basal Area at 15 years.

2.1.6. *Volume*

Data are scarce through similar trends as with basal area are evident. Losses in production of about $60m^3$/ha in spruce are suggested as spacing increases from 1.2m to 3.6m square.

2.1.7. *Tree Form*

Wide spacings greatly affect the shape of the individual stem. When expressed as millimetres diameter for each metre length of stem, rate of taper in SS at 3.6m spacing is more than three times that at 1.2m at 15 years. (Table 2).

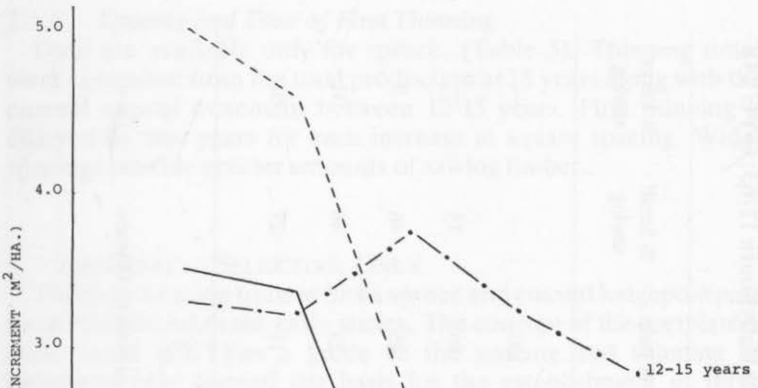

Fig. 4 Annual Basal Area Increment in Sitka spruce.

Table 2 Taper in Sitka spruce at 15 years (Ballyhoura 11/63).

	Spacing (m)					
Factor	1.2 x 1.2	1.8 x 1.8	2.4 x 2.4	3.0 x 3.0	3.6 x 3.6	LSD (5%)
Length to 7cm top diameter	4.2	6.1	5.5	5.8	6.1	1.9
mm/m to 7cm	7.3	10.3	15.4	19.6	24.2	2.9
cm diam/cm length	1:137	1:97	1:65	1:51	1:41	

Table 3. Pre-thinning Details of SS at Various Spacings. (Based on experiment Ballyhoura 11/63, GYC 24).

Spacing (m)	Thin at (years)	Stems/ha	Top Ht. (m)	BA (m^2/ha)	DBH (cm)	Vol. 7 (m^3/ha)	% Pulp	% Small sawlog	% Large sawlog
1.2x1.2	15	6911	10.0	36.8	8.3	129.7	100	—	—
1.8x1.8	17	3045	11.5	35.6	12.2	181.0	86	14	—
2.4x2.4	19	1714	13.5	38.6	16.9	198.4	45	46	9
3.0x3.0	21	1104	15.5	39.2	21.3	209.0	23	46	31
3.6x3.6	23	762	17.0	39.0	25.5	203.5	11	27	62

Top height figures are taken from Management Tables. (BFC Booklet 34).
Volume and basal area figures are derived from actual values at 15 years and current annual increment from 12-15 years.
Volume assortments are derived from Management Tables.
Pulp: 7 – <14cm top diameter.
Small sawlog: 14 – <20cm top diameter, minimum length 3m.
Large sawlog: >20cm top diameter, minimum length 3m.

2.1.8. *Spacing and Time of First Thinning*

Data are available only for spruce. (Table 3). Thinning times were computed from the total production at 15 years along with the current annual increment between 12-15 years. First thinning is delayed by two years for each increase in square spacing. Wider spacings provide greater amounts of sawlog timber.

3. Thinning — Selective Only

The first thinning trials in Sitka spruce and coastal lodgepole pine were established in the early sixties. The concept of the correlated-curve-trend (CCT)[1] as a guide to the spacing and thinning of lodgepole pine formed the basis for the establishment of three experiments in 1962. Two of these trials are now windblown and only a portion of the third remains.

An LP (C) thinning trial set down in the mid-1960's to study various intensities of selective thinning has also been severely damaged by wind. There remains today only one full experiment in this species as yet undamaged and in which different forms of line thinning are compared.

Early thinning experimentation in Sitka spruce was almost entirely concerned with studies of low, selective thinning though some less common treatments like eclectic and selection types were also included. Windblow has caused less damage to spruce trials. From a total of ten Sitka trials established, only three have suffered appreciable damage.

Many of the earlier thinning experiments suffered from insufficient replication in their design. Consequently, significance levels are low in variance analysis. More recently established trials contain up to four replications of each treatment.

Our most important experiment studying low, selective thinning is that at Avoca forest. (Table 4). It was laid down in 1963 to study a range of thinning intensities and to see at what intensity increment was lost. (Intensity of thinning refers to the quantity of timber removed per annum). To date, the crop has been thinned four times at 21, 25, 29 and 34 years of age. Light thinning has constituted little more than the removal of dead and suppressed trees, moderate thinning is closest to the normal management practice in this country

1 O'Connor and Craib developed the correlated-curve-trend guide to thinning in South Africa, based on experiments which consisted of a series of plots subjected to progressive reduction in number of stems before onset of competition over a period of years. One plot is left unthinned at each reduction. This gives a wide range of stocking at final crop, from free-grown to fully competing stems.

while the heavy intensity may be regarded as being more severe than would otherwise be accepted.

Some relevant details of the thinnings as well as of the present main crop are given in Table 5.

Table 4. Avoca 1/64.

Description:	Thinning intensity experiment in Sitka spruce.
Location:	Compartmant 81032G.
Elevation:	Between 150-180m above sea level.
Aspect:	Sloping gently southward.
Exposure:	Unexposed.
Site:	Brown earth, formerly cultivated.
Species:	Sitka spruce, provenance 6/R/39, Washington (Manning). Age 2 + 2 years.
Planted:	1943, pit-planted.
Initial Stocking:	3,964 stems/ha. Spaced at 1.5 x 1.5m.
Treatment:	Three levels of intensity described as light, moderate and heavy. First thinning to a pre-determined basal area after thinning.
Thinning type:	Low, selective.
Experimental design:	Randomised block; 3 treatments, 2 replications.
Plot size:	.04 ha, with 5 metre surround.

3.1. *Results of selective thinning*

3.1.1. *Stems*

The average initial stocking for all plots was 3,964 stems/ha. After fourth thinning at 34 years, heavy thinning had reduced stocking to 543 stems/ha. the equivalent figures for moderate and light treatments were 1,074 and 2,136 stems/ha respectively.

3.1.2. *Height*

The removal of more smaller stems with heavy thinning increases mean height. In 1979, sixteen years after first thinning mean height is greater by 1.8m with heavy thinning.

Top height is only slightly greater after heavy thinning (Table 5).

Table 5. Avoca 1/64: All thinnings and present main crop.

Factor	Treatment Light	Moderate	Heavy
Four thinnings, vol. to 7cm (m^3/ha)	66	200	308
Percentage total volume removed	9.3	26.4	42.3
Percentage total basal area removed	19.4	39.2	53.8
Percentage yield class removed	18.8	56.8	87.5
Percentage stems removed	51.9	73.9	83.6
Main crop in 1979, standing			
volume (m^3/ha)	647	558	421
top height (m)	21.8	22.0	22.4
mean height (m)	19.3	20.8	21.1
mean diam. (cm)	19.9	25.4	31.3

Table 6. Avoca 1/64: Basal Area.

Treatment	Increment since first thinning (m^2/ha)					Cumlative BA in 1979
	Yrs. 1-4	Yrs. 5-8	Yrs. 9-13	Yrs. 13-16	Yrs. 1-16	(m^2/ha)
Light	10.6(100)	9.6(98)	6.5(80)	4.2(89)	30.9(93)	82.8(93)
Moderate	10.6(100)	9.8(100)	8.1(100)	4.7(100)	33.2(100)	89.1(100)
Heavy	9.5(90)	11.0(112)	7.5(92)	4.9(104)	32.9(99)	90.5(102)

Differences are not statistically significant.
Brackets denote data as a percentage of moderate thinning.

3.1.3. *Diameter at Breast Height*

Heavier thinning intensities produce significantly greater diameter increment. The trend is more or less consistent over a 16 year period. (Fig. 5). All stems in the heavily thinned plots have a mean diameter of 20cm or greater with an overall mean of 31.3cm. (Fig. 6).

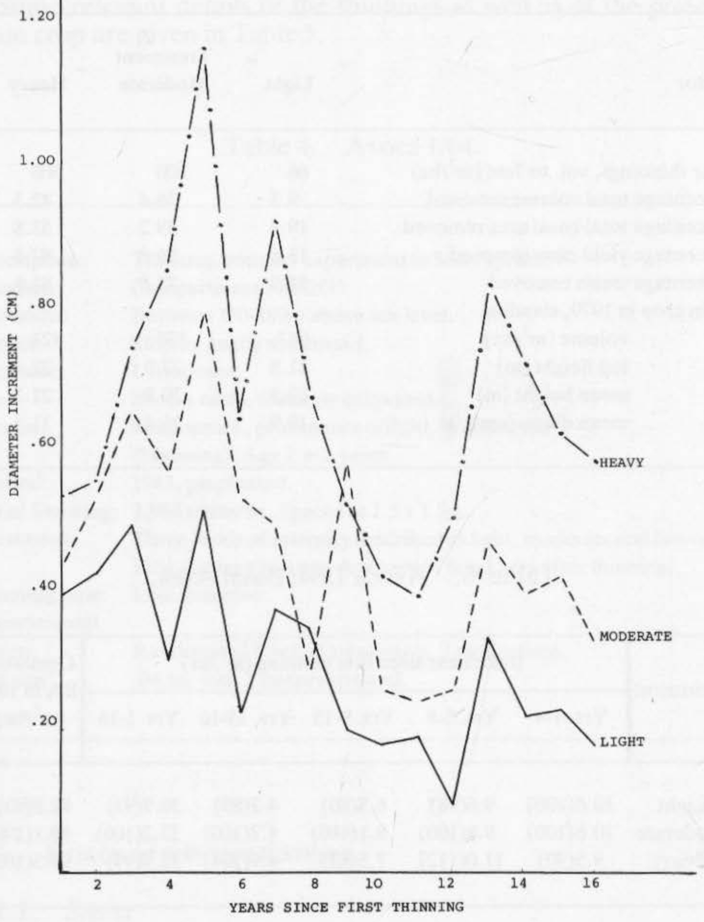

Fig. 5. Avoca 1/64: Mean Diameter Increment over 16 years.

3.1.4. *Basal Area*

During each of the three years after first thinning, increment was depressed with heavy thinning. Increment recovered in the fourth year, the recovery was maintained and initial losses were made up. (Gallagher 1969). Cumulative production — present main crop and all thinnings — at 37 years has fallen behind by nearly 10% in the lightly thinned plots (Table 6).

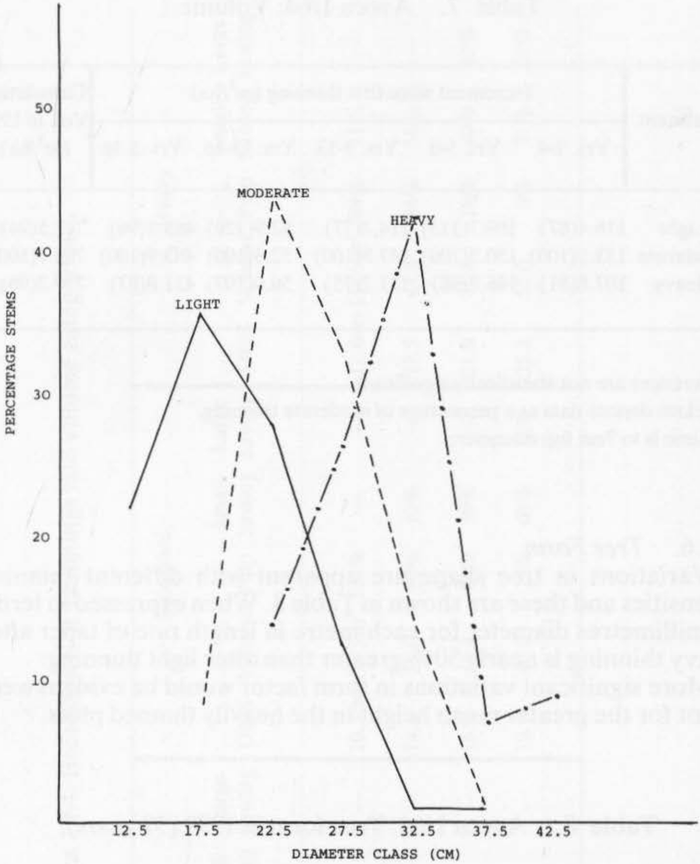

Fig. 6. Avoca 1/64: Diameter Distributions at 37 years.

3.1.5. *Volume*

The heavy thinning at Avoca removed 83% volume increment in four thinnings. The equivalent figure for the moderate treatment — and comparable with accepted practice — is 46%.

Increment trends differ somewhat from those of basal area. (Volume is to 7cm top diameter, basal area includes all stems). Heavy thinning depresses volume increment somewhat. A reduction in the region of 13% is incurred during the 16-year period after thinning commences when the heavy treatment is compared to the moderate. Cumulative production is down by about 4% or 30m^3/ha. (Table 7).

Table 7. Avoca 1/64: Volume.

Treatment	Increment since first thinning (m^3/ha)					Cumulative Vol. in 1979 (m^3/ha)
	Yrs. 1-4	Yrs. 5-8	Yrs. 9-13	Yrs. 13-16	Yrs. 1-16	
Light	116.4(87)	169.7(113)	114.3(77)	62.9(120)	463.3(96)	713.5(94)
Moderate	133.5(100)	150.3(100)	147.8(100)	52.3(100)	483.9(100)	758.7(100)
Heavy	107.8(81)	146.8(98)	111.2(75)	56.0(107)	421.8(87)	729.2(96)

Differences are not statistically significant.
Brackets denote data as a percentage of moderate thinning.
Volume is to 7cm top diameter.

3.1.6. *Tree Form*

Variations in tree shape are apparent with different thinning intensities and these are shown in Table 8. When expressed in terms of millimetres diameter for each metre in length rate of taper after heavy thinning is nearly 50% greater than after light thinning.

More significant variations in form factor would be evident were it not for the greater mean height in the heavily thinned plots.

Table 8. Avoca 1/64: Tree form in 1979 (37 years).

Factor	Treatment Light	Moderate	Heavy	LSD (5%)
Form factor	.496	.494	.474	—
mm/m to 14cm top diam.	10.7	12.2	15.6	3.6
cm diam/cm length to 14cm	1:93	1:82	1:64	—
length to 14cm top diam (m)	10.0	13.6	15.4	—

$$\text{Form factor} = \frac{\text{Vol. to 7cm top diameter}}{\text{basal area x mean height}}$$

Table 9. Avoca 1/64: Breakdown of Thinnings into volume categories.

Treatment	Light					Moderate					Heavy				
Thinning	DBH	Volume	Pulp	Small Sawlog	Large Sawlog	DBH	Volume	Pulp	Small Sawlog	Large Sawlog	DBH	Volume	Pulp	Small Sawlog	Large Sawlog
First	8.1cm	23.1m³	100%	—	—	10.3cm	77.9m³	100%	—	—	12.8cm	136.9m³	89%	11%	—
Second	10.9	13.8	100%	—	—	14.4	33.0	90%	10%	—	17.5	43.5	44%	56%	—
Third	12.1	17.0	100%	—	—	16.9	48.4	61%	39%	—	21.8	75.8	18%	40%	42%
Fourth	13.3	12.2	100%	—	—	19.1	40.9	25%	68%	7%	25.3	52.0	8%	31%	61%

3.1.7. *Volume Assortments*

The effects of increased thinning intensity and a greater diameter growth are reflected in the distribution of timber into different volume categories. Categories included here are large and small sawlog and pulpwood. Large sawlog is that portion of the stem from butt to 20cm top diameter (3m minimum length), small sawlog is from 20cm or butt to 14cm top diameter (3m minimum length) and pulpwood from 14cm or butt to 7cm top diameter.

At Avoca all the yield from the light treatment was pulpwood. Third and fourth heavy thinnings, on the other hand gave over 80% volume in the sawlog categories (Table 9).

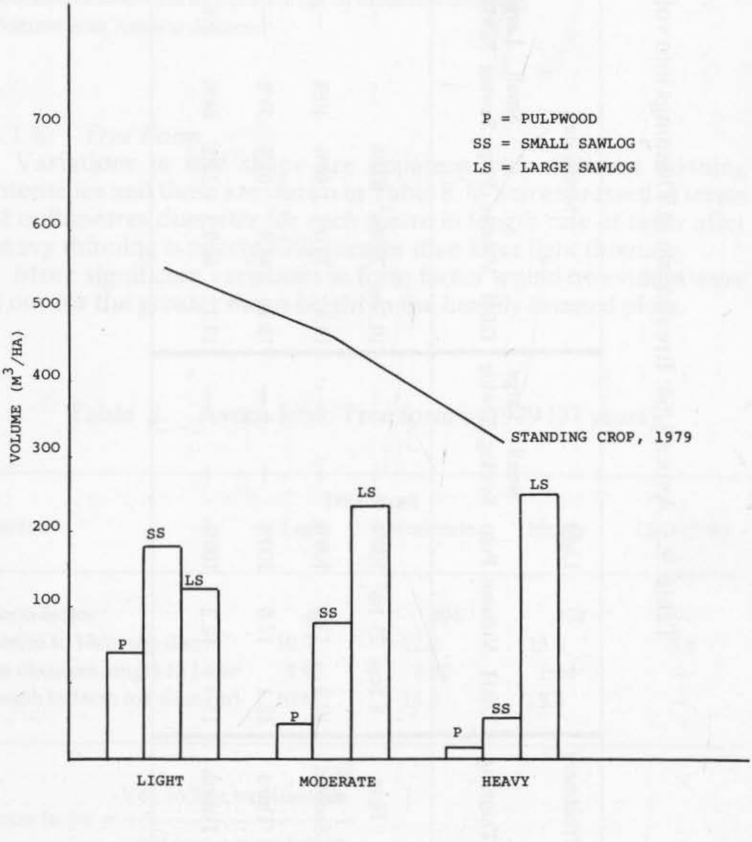

Fig. 7. Avoca 1/64: Volume Categories of Main Crop, 37 years.

In 1979, three years after fourth thinning the standing crop in the heavily thinned plots comprised more than 80% large sawlog. The total crop, including thinnings has produced more than half its volume as large sawlog under the heavy thinning regime and less than one-third with light thinning. (Fig. 7, 8).

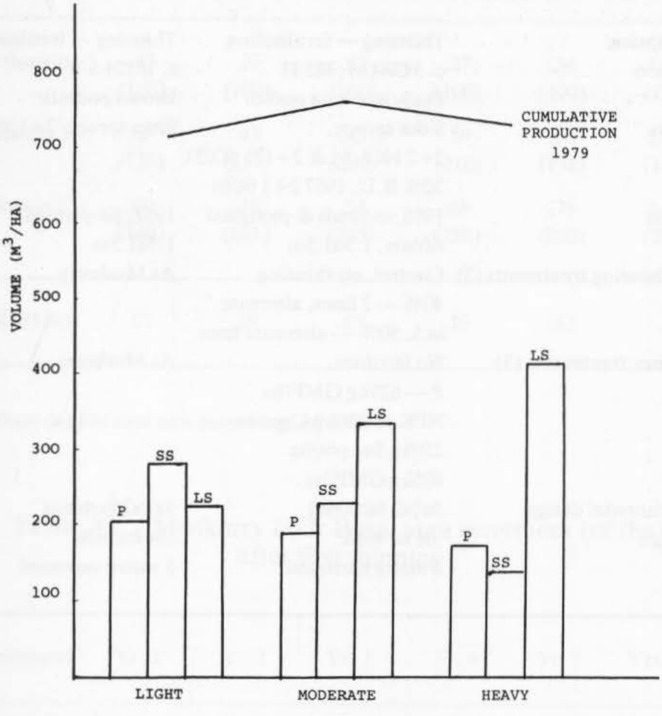

Fig. 8. Avoca 1/64: Volume Categories of Total Production, 37 years.

4. Thinning — Systematic or Line

Experimentation in line-thinning is relatively new to Ireland. One trial in Sitka spruce established in 1968 in Avoca forest (Gallagher 1970, 1976) has been extensively damaged by wind. In 1972, two thinning fertilisation trials were established in spruce. (Table 10). Since their experimental designs were identical, initial results from both trials were combined for analysis purposes. (O'Brien, Phillips, Lynch 1977). No effect of fertiliser was detected nor was there any interaction between fertiliser and thinning or fertiliser and site. Thinning alone was responsible for differences in growth rate.

Table 10. Two line — thinning experiments.

	Muskerry 1/73	Shillelagh 2/73
Description	Thinning — fertilisation	Thinning — fertilisation
Location	c. 34384 M, 385 H	c. 16124 S
Soil	Peaty iron-pan podsol	Brown podsolic
Species	Sitka spruce, 2+2 HC6/51 & 2+1?1 6Q/51 20% B.U. 1957 2+1 6t/64	Sitka spruce, 2+1, 6t/47
Planted	1956, mounds & ploughed ribbon, 1.5x1.5m	1951, pit-planted 1.5x1.5m
First thinning treatments (3)	Control, no thinning 40% — 2 lines, alternate, in 5, 50% — alternate lines	As Muskerry
Fertiliser treatments (3)	No fertiliser, P — 625kg GMP/ha NPK — 250kg Urea/ha 250kg Sul.pot/ha 605kg GMP/ha	As Muskerry
Experimental design	3x3x2 factorial	3x3x2 factorial
Plot size	.04 ha with 5 metre surround	.04 ha with 5 metre surround

For the purpose of this paper both experiments were re-analysed separately on the basis of three thinning treatments and six replications. Both trials have since been rethinned selectively. the site at Muskerry has a higher yield class than that at Shillelagh — 26 compared to 18.

4.1. *Results of line thinning*

4.1.1. *Diameter at Breast Height*

There is an immediate and positive response to line thinning (Table 11). Significance levels are high. Using the Least Significant Difference (LSD) technique, all three treatments are significantly different from each other when the five-year period is taken as a whole.

Table 11. Muskerry 1/73: Mean diameter increment (cm) after first thinning.

Treatment	Yr. 1	Yr. 2	Yr. 3	Yr. 4	Yr. 5	Yrs. 1-5
No thinning	.43	.27	.22	.27	.34	1.53
	(100)	(100)	(100)	(100)	(100)	(100)
2 lines in 5	.55	.43	.45	.59	.66	2.68
	(128)	(159)	(204)	(218)	(194)	(175)
1 line in 2	.60	.49	.54	.69	.75	3.07
	(140)	(181)	(245)	(256)	(220)	(201)
LSD (5%)	.07	.09	.07	.10	.12	.30

Brackets denote data as a percentage of control.

Table 12. Muskerry 1/73: Basal area increment (m^2/ha) after first thinning

Treatment	Yr. 1	Yr. 2	Yr. 3	Yr. 4	Yr. 5	Yrs. 1-5
No thinning	3.91	2.47	2.08	2.56	3.36	14.38
	(100)	(100)	(100)	(100)	(100)	(100)
2 lines in 5	2.99	2.44	2.63	3.56	4.16	15.78
	(76)	(99)	(126)	(139)	(124)	(110)
1 line in 2	2.70	2.27	2.60	3.48	3.99	15.04
	(69)	(92)	(125)	(136)	(119)	(104)
LSD (5%)	.48	—	.41	.66	—	—

Brackets denote data as a percentage of control.

4.1.2. *Basal Area*

Details of basal area increment are given in Table 12. Increment is less in the first two years relative to the no-thinning regime. A recovery is subsequently effected and during the overall five-year period, initial losses are made up.

Results are similar for the experiment at Shillelagh except that increment does not recover until the fourth year.

4.1.3. *Re-thinning after line-thinning*

A first line-thinning usually means the retention of some dead, suppressed and small stems in the main crop which are removed at second thinning. Some consequences of this are shown in Table 13. The mean tree from second thinning has hardly changed after a cycle of five years. Furthermore second thinning contains a sizeable number of small, dead stems which would most likely have been already removed had first thinning been selective.

Table 13. Shillelagh 2/73: Details of first and second thinnings (data per hectare).

Thinning	Treatment	All Stems	Mean DBH	Stems <7cm	Stems Dead	Vol. to 7	Mean Vol.
First	1 line in 2	2,010	12.2cm	110	30	119.8m^3	.063m^3
Second	33% volume	1,075	12.4cm	70	75	75.6m^3	.075m^3

5. THINNING OF LODGEPOLE PINE (COASTAL)

No specific details of thinning research in LP (C) are presented because of the paucity of data. Indications from a thinning experiment at Killavullen forest are that increasing intensities of thinning in pine have very similar effects on diameter growth as already reported for spruce. Basal area increment appears to be stimulated by thinning, a fact which is also borne out in the CCT trials.

CONCLUSIONS AND DISCUSSION

In The Forest and Wildlife Service at present recommended spacing at planting for Sitka spruce and coastal lodgepole pine is 2 meters square or 2,500 stems per hectare. Thinning policy follows the "marginal intensity" concept as described in Forest Management Tables (Hamilton and Christie 1971). First thinning, for the most part, removes every third line of trees. These practices have evolved from what were originally narrower spacings and lighter intensities. Experimental results presented here put the emphasis on the effects of even wider spacings and heavier thinnings than those presently practised.

The forest manager about to embark on a planting programme may enquire: "What happens if I plant at wider spacing, say 2.5m square?" Should he decide to do so he can expect a drop in cumulative production in the region of 4% where the species is Sitka spruce. A drop of somewhat greater magnitude will be incurred with coastal lodgepole pine. First thinning will be delayed by about two years, thereby reducing the number of thinnings and giving somewhat less thinning volume than at 2m spacing (a figure of about 7% less thinning volume in high yield class spruce might be expected). On the other hand, the extended spacing will give larger diameter trees at any given time.

Wider spacing gives the forest manager more flexibility when deciding on exactly when to thin. This is especially true with spruce. Because of the larger diameters obtainable, thinning may be earlier than normal in response to a specific demand. Such is the resilience of the species that the effects of early reduction in stocking should soon be overcome. Alternatively, should thinning be delayed by a number of years, competition between individual stems will not be as detrimental as in conventional spacing.

The possibility of a shorter rotation at wider spacing is feasible. As long as a normal thinning programme is carried out and having regard to the larger than average tree diameters, the attainment of an acceptable final crop containing appreciable amounts of sawlog should be possible some years earlier than otherwise.

Thinning to a marginal intensity as described in Management Tables will remove, on average about 45% volume increment during the thinning rotation. The recommended age of first thinning for Sitka spruce, Yield Class 22 is 18 years after which thinnings will be felled periodically for a further 18 years. this presumes a rotation of 38 years — maximum mean annual increment less 20% — and that final thinning takes place two years before the end of the rotation.

The heavy thinning treatment at Avoca has removed 308m^3 of merchantable volume or 83% of increment in four thinnings over a 13 year period. Stocking is now reduced to 540 stems per hectare with a mean diameter three years after fourth thinning of 31.3cm. On a shortened rotation this may be regarded as a final crop. This heavy thinning has reduced total production by 4% — a reduction similar to that which follows a widening of initial spacing by half a metre.

There are indications from the experiment at Avoca that volume increment begins to be irretrievably lost when more than 80% volume increment is removed in thinning though basal area production remains unaffected. Diameter increment is greatly stimulated by heavier thinning intensities, something which is reflected in the greater amounts of sawlog timber contained in the thinnings and in the final crop.

The precise nature of first thinning requires some comment. At Avoca, first thinning was low and selective, removing 45% of the standing volume or 65% of the stems. In the Forest and Wildlife Service, at present, the general practice at first thinning is to remove one-third of the crop in lines. Recent research evidence indicates that, in spruce at least this intensity may be increased so that alternate lines of trees are removed. There is no reason to believe that a thinning intensity of 80% volume increment over a similar period to that at Avoca and where first thinning removed every second or every third line would have anymore significant effect on crop growth than if all thinnings were purely selective.

An undesirable consequence of line thinning is the amount of "rubbish" which remains to be cut out at re-thinning. Such a situation may be relieved somewhat by removing all dead and badly suppressed trees as one operation in a first line thinning. Delaying first thinning further aggravates the situation as more trees will have died by the time thinning is felled.

This paper does not attempt to answer all questions relating to spacing and thinning of forest crops. The forest manager will need to consider other important questions before embarking on a particular spacing and/or thinning regime. He will need to be conscious of the threat of windblow following thinning. If he decides to increase spacing at planting will he be able to satisfactorily control weed growth? Wide spacing and heavy thinning will yield bigger timber but this must be extracted, transported and sold. What are the economic advantages of one silvicultural system relative to another? The whole question of timber quality is becoming more relevant. To what extent will the financial gains accruing from more sawlog timber be offset due to deterioration in quality? Results show that coarser branching, wider rings and more acute slope of grain are all "part and parcel" of wider spacings and heavier thinnings?

One silvicultural practice not dealt with in great detail is that of respacing or precommercial thinning. A forest manager may decide to play safe at planting and stick with conventional spacing. Then, when the crop is about ten years old and having decided on a course which will yield the greatest amount of sawlog timber he may either:

(a) respace to a pre-determined stocking which will require either none or at most one or two thinnings during the remainder of the rotation.

or

(b) maintain present stocking, first-thin early and heavily, every second line of trees say, remove three or four further thinnings to an intensity which does not exceed 80% volume increment down to a final crop of about 500 stems per hectare.

The ten-year period after planting provides a breathing space during which the forest manager can make up his mind what his long-term strategy should be. The second alternative may not be feasible if windblow is a definite threat. But it does give a supply of small as well as large timber which can be advantageous.

Close initial spacing may be the only realistic option for coastal lodgepole pine considering the poor form of the species. Indeed, respacing in pine should prove a very desirable silvicultural treatment if it removes the worst looking stems at an early age. Line thinning in lodgepole pine does nothing to improve the appearance of the stand so respacing in a closely spaced crop may be the most acceptable practice.

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