SELECTIVE PRUNING OF RADIATA PINE

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ABSTRACT

To evaluate selective butt log (6 m) pruning 14 treatments (most combinations of 1-, 2-, 3- and 4-lift pruning removing a nominal 20, 35, 50 and 60% of the green crown at each lift) were applied in unthinned (initial spacing 2.4 × 1.8 m) radiata pine stands. Selected trees were dominants in all treatments, except one. In application, the nominal pruning intensities were substantially exceeded.

The size of the knotty core decreased with an increase in both the severity and the frequency of pruning. For a given severity, pruning to 6 m in three, instead of two, lifts decreased the knotty core by 2.5 cm. For a given pruning lift the size of the knotty core was related to the tree height at the time of pruning. An increase of 1 m in tree height was equivalent to an increase of 1.5 cm in the diameter of the knotty core—indicating the importance of timely pruning.

The size of the largest branch and total basal area of branches removed decreased with an increase in both the intensity and frequency of pruning.

Loss of dominance became important if over 40% of the length of the green crown was pruned. For those schedules considered most practical only 25-50% of the pruned dominants remained dominant. At these pruning intensities the proportion of good form stems increased.

Some loss of height increment occurred in all pruning treatments. Losses increased with the increase in both pruning severity and frequency: basal area increment trends were similar but more marked. For the more practical pruning schedules height and basal area increments were respectively, 11-25%, and 38-57% lower than the controls. In the absence of thinning, restoration of normal increments was observed only in the least severe pruning treatments. Measurements of form at the end of the trial failed to reveal any trends between treatments.

Adventitious ("epicormic") shoots became more prevalent when either pruning severity or frequency increased. For the practical schedules at least 45% of stems can be expected to produce some adventitious shoots. Thinning of pruned stems favoured their development.

Twenty percent of pruned codominants later became dominants.

The major management implication is that since small knotty cores must be a prime pruning objective and since this necessitates intensive pruning in three lifts, heavy thinning at the time of pruning is desirable, in order to minimise losses in dominance and stem diameter growth.

The suggested early tending regime to achieve a mean knotty core of 12.5 cm is:

At height 5.0 m prune 4-500 stems/ha to 2.0-2.5 m (and thin out all unpruned stems at each pruning lift)

At height 7.5 m prune 300 stems/ha to 4.3 m

At height 10.0 m prune 200 stems/ha to 6.0 m.

INTRODUCTION AND OBJECTIVES

Loss of the dominance in selectively pruned stems of radiata pine (*Pinus radiata* D. Don) is one of the most serious problems in present day tending practice in New Zealand.

Current procedure in New Zealand is to prune selectively (i.e., to restrict pruning to the more acceptable stems). Brown (1962) in an extensive review of pruning found that studies on the effects of selective pruning were the exception. Those few studies, however, showed that if only selected trees were green-pruned then the depressing effects on increment were greater than would have occurred if all the stems had been pruned. This suggested that selective pruning might result in serious loss of dominance among the pruned stems.

In 1967 a series of trials was initiated to evaluate the problem of loss of dominance and other aspects of pruning. A minor trial examined the importance of the method of selection (Sutton, 1971). Another studied the importance in early tree selection of subsequent changes in tree dominance and form (Sutton, 1973). Although both these factors, especially the second, could explain how stems of acceptable form might miss selection for pruning, neither trial included any actual pruning.

In the major trial reported here the objective was to determine the effects of selective butt log pruning on the size of the knotty cores, on maintenance of dominance, and on subsequent growth and tree form, for a range of pruning frequencies (the number of pruning lifts) and pruning severities (the proportion of the length of green crown removed at each lift).

THE TRIAL

Full details of the trial, the method of calculating the pruning treatments, operational aspects, etc., are available in an unpublished report (Sutton and Crowe, 1968). A summary only is included here.

The trial involved 14 basic butt log pruning treatments. These included most combinations of one-, two-, three- and four-lift pruning to 6 m, with the removal of a nominal 20, 35, 50 and 60% of the length of the green crown at each lift*. For simplicity, treatments are defined by a *frequency/severity* expression, e.g., 2/35% refers to the two-lift pruning treatment in which a nominal 35% of the green crown was removed at each pruning lift.

For any given treatment the height of each pruning lift and the severity of pruning are fixed. To determine the tree height at which each pruning lift should be done to achieve the given severity, the green crown levels were assumed to be as predicted by Beekhuis (1965). Details of the calculated schedules are given later in Table 1 and a graphical summary of all the pruning treatments, as applied, is presented in Fig. 1.

For reasons that will be discussed later (*see* "Severity of green crown pruning") the severity of pruning as actually applied was always greater (on average 15% greater) than the severity value in the treatment specification. For convenience the original, and therefore nominal, severity expressions are continued to be used throughout this report.

* Pruning severity is here defined by the expression of the length of green crown pruned as a percentage of the green crown length at the time of pruning (or for trees already pruned, the green crown length that would have been, had the trees not been pruned earlier).

In addition to the basic pruning treatments the trial included variations of neighbour treatments, viz.: In one-lift pruning, releasing by the removal of neighbouring trees; and in multilift pruning, pruning of various numbers of neighbouring trees to the same height. The results of the neighbour treatments are discussed later (*see* "Effects of neighbour treatment").

Treatments were applied to trees which were both dominant (except for one treatment which was applied to co-dominants) and visually free from malformation at the time of first pruning.

The trial was established in three unthinned adjacent stands planted at 2.4 × 1.8 m, on the highly productive scoria sites of the Northern Boundary in Kaingaroa Forest. The stands were of similar establishment but of different ages, and pruning treatments were allocated according to the tree height at which the first lift was scheduled. The allocation to stands (from now on referred to as blocks) is as indicated in Table 1. Treatments were applied on an individual tree basis with selected stems spaced at least 7 m apart to avoid interactions between treatments. Treatments were allocated, for all intents and purposes, at random: 40 trees to each basic treatment (except in treatments 2/20% and the co-dominant 3/35% where there were only 20 trees) and 20 unpruned controls in each block.

The major operational problem was ensuring that trees were pruned at their scheduled heights (average annual height increment was around 2 m). Scheduling was determined by monitoring the height development of sample stems.

At pruning, measurements were as complete as was practicable because the pruned stems will provide invaluable material for future sawing studies. Records were also kept of the pruning tools used and of the stem deviations.

All stems were measured for diameter and height twice yearly, mid-summer (January) and mid-winter (June). The stands remained unthinned until the completion of the trial (except for some release thinning, which took place in some of the one-lift pruning treatments).

RESULTS

Full results and discussion are included in unpublished reports (Sutton and Crowe, 1972 a and b). The more important results follow.

Tree Parameters at Time of Pruning

In Fig. 1 the following are shown to scale for each lift:

Mean total tree height.

Mean base of the live green crown at the time of pruning (in multiple lift pruning control values were used).

Nominal height of the pruning lift.

Mean height of the green crown base after pruning.

Also recorded are the mean percentage of actual green crown removed and the percentage of nominal green crown specified to be removed.

Pruning Treatments Actually Achieved

Details of scheduled and actual treatments are given in Table 1.

Every effort was made to complete each lift within 0.3 m of the height calculated for the schedule. This was achieved in 25 of the 30 pruning lifts; the other five lifts were within 0.6 m of the calculated height. The co-dominant schedule was applied

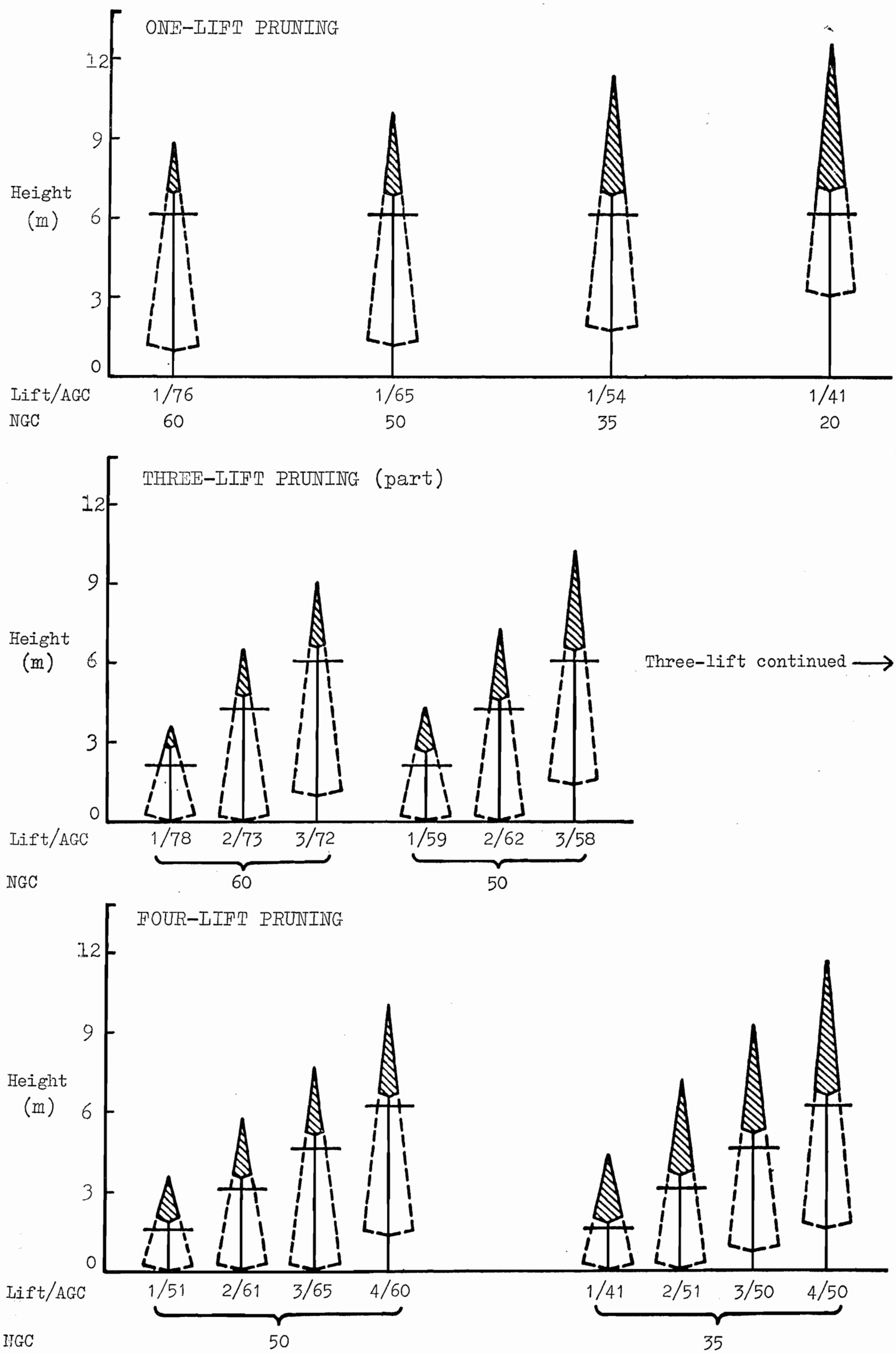
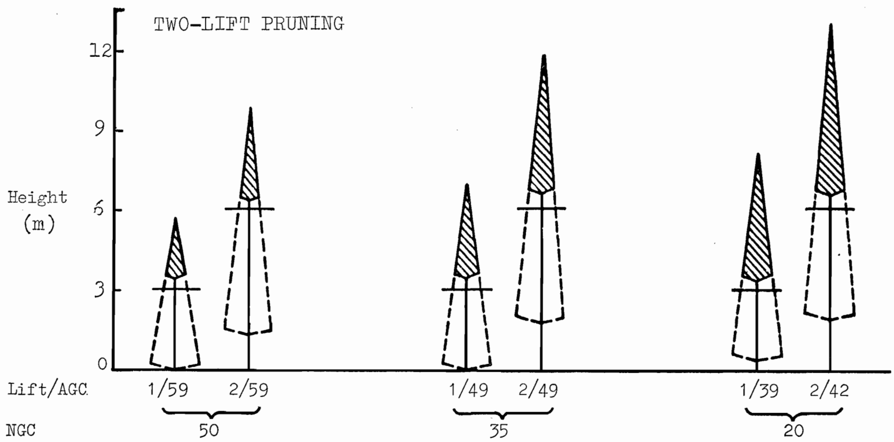
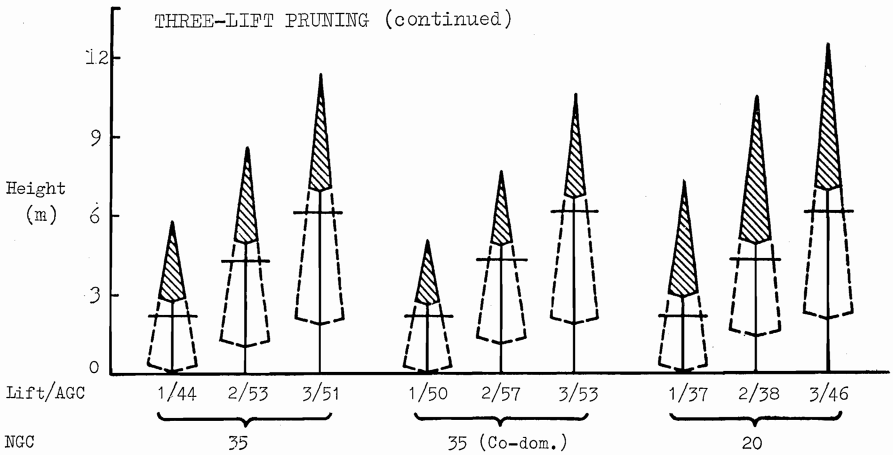
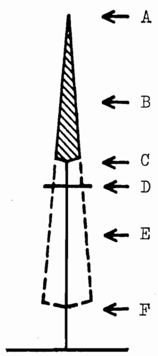


FIG. 1—Schematic summary of all pruning lifts included in the trial.







A = Total tree height

B = Green crown left

C = Base of green crown after pruning

D = Nominal height of pruning

E = Green crown removed

F = Base of live green crown at time of pruning (from controls)

Lift = Pruning lift number — e.g. 1/

AGC = Percentage actual green crown removed — 50

NGC = Percentage nominal green crown to be removed — 35

TABLE 1—Scheduled mean tree heights and actual mean heights at each pruning lift

Pruning lift		Nominal green crown removal 60%			50%			35%			20%		
	(m)	Scheduled height (m)		Actual height (m)	Scheduled height (m)		Actual height (m)	Scheduled height (m)		Actual height (m)	Scheduled height (m)		Actual height (m)
One-lift	0-6.1	9.0	(3)*	8.9	10.1	(3)	9.9	11.6	(3)	11.4	13.1	(3)	12.4
Two-lift	0-3.0	-		-	6.1	(2)	5.9	7.3	(2)	7.2	8.5	(2)	8.3
	3.0-6.1	-		-	10.1		10.1	11.6		12.0	13.1		13.3
Three-lift	0-2.1	3.7	(1)	3.4	4.3	(1)	4.3	6.1	(2)	5.9	7.3	(2)	7.1
	2.1-4.3	6.7		6.4	7.6		7.5	8.5		8.5	10.7		10.3
	4.3-6.1	9.1		9.0	10.1		10.3	11.6		11.3	13.1		12.3
Four-lift	0-1.5	-		-	3.0	(1)	3.5	4.3	(1)	4.4	-		-
	1.5-3.0	-		-	6.1		5.9	7.3		7.1	-		-
	3.0-4.6	-		-	7.9		7.7	9.5		9.2	-		-
	4.5-6.1	-		-	10.1		10.0	11.6		11.6	-		-
								(Co-dominants)					
Three-lift	0-2.1	-		-	-		-	6.1	(2)	5.1	-		-
	2.1-4.3	-		-	-		-	8.5		7.6	-		-
	4.3-6.1	-		-	-		-	11.6		10.7	-		-

* Bracketed numbers refer to the blocks where treatments were located

as if the trees were dominants, so the heights at which trees were pruned were 0.8-1 m shorter, on the average, than in the same schedule involving dominants.

Length of Green Crown

The mean length of green crown (the base of which is defined as the mid-point between the lowest green whorl and the lowest green branch) for unpruned control trees in the three treatment blocks is given in Table 2. The Beekhuis (1965) general predictions under-estimated the green crown length by about 1.0 m at dominant height 10 m, and by about 2.3 m at dominant height 16 m.

TABLE 2—Predicted green crown lengths compared with actual lengths (taken from unpruned controls)

Dominant mean height (m)	Beekhuis predicted length (m)	Actual length (m)	Departure (m)
4	4.0	4.0	0
6	6.0	6.0	0
8	6.9	7.4	0.5
10	7.7	8.7	1.0
12	8.5	9.9	1.4
14	9.3	11.1	1.8
16	10.1	12.4	2.3

Severity of Green-Crown Pruning

The severity of pruning is calculated by expressing the length of green crown pruned as a percentage of total green crown length. For this it is necessary in multi-lift pruning to know where the green crown base would have been if the tree had not been previously pruned. This was assumed to be the same as in the unpruned controls. Mean values for each treatment and individual values for trees were calculated. Mean values and the range for each pruning lift are given in Table 3.

TABLE 3—Intensity of green crown pruning

Pruning lift		Nominal green crown removal											
		60%			50%			35%			20%		
		Actual removed	Actual range	Remaining	Actual removed	Actual range	Remaining	Actual removed	Actual range	Remaining	Actual removed	Actual range	Remaining
	(m)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
One-lift	0-6.1	76.0	58-100	20.5(3)*	65.0	50-79	31.0(3)	54.0	51-73	40.0(3)	41.5	33-57	44.0(3)
Two-lift	0-3.0	-	-	-	59.0	50-89	41.0(2)	49.0	40-72	51.0(2)	39.5	29-55	57.5(2)
	3.0-6.1	-	-	-	59.0	45-76	35.0	49.0	36-81	43.0	42.5	34-55	49.5
Three-lift	0-2.1	78.5	48-100	21.5(1)	59.0	50-69	39.5(1)	44.5	29-61	55.0(2)	37.5	28-45	61.5(2)
	2.1-4.3	73.5	57-100	26.0	62.0	53-84	36.5	53.0	35-68	43.0	38.5	30-51	53.0
	4.3-6.1	72.5	55-100	27.0	58.5	47-91	36.0	51.5	44-72	40.0	46.0	35-55	45.0
Four-lift	0-1.5	-	-	-	51.0	34-88	48.0(1)	41.0	30-68	58.5(1)	-	-	-
	1.5-3.0	-	-	-	60.5	43-90	39.5	51.0	38-76	49.0	-	-	-
	3.0-4.6	-	-	-	65.0	52-87	35.0	50.0	40-72	46.0	-	-	-
	4.6-6.1	-	-	-	60.5	45-82	35.0	50.5	41-74	43.5	-	-	-
									(Co-dominants)				
Three-lift	0-2.1	-	-	-	-	-	-	50.5	38-64	48.5(2)	-	-	-
	2.1-4.3	-	-	-	-	-	-	57.5	49-100	38.0	-	-	-
	4.3-6.1	-	-	-	-	-	-	53.0	43-74	37.5	-	-	-

NOTES: Actual removed % = mean length of green crown removed by pruning as a percentage of mean total green crown length.
Actual range % = range of values (lowest to highest) of actual percentage as defined above.
Remaining % = mean length of green crown remaining after pruning as a percentage of mean total stem height.

* Bracketed numbers refer to the blocks where treatments were located.

Because the green crown proved to be longer than predicted, and because the base of crown remaining after pruning was always higher than that specified, owing to the length of clear internode above the nominal pruning limit, the actual percentages of green crown removed are greater than the nominal intensity on which the schedules were originally based. In practice most schedules were about 10-20% higher, with an average difference of about 15%. For example, a nominal 35% removal was in practice about a 50% removal. Caution should therefore be exercised when comparing pruning severities in this study with those of others.

The trial does not include low intensities of pruning, but since it includes what is regarded as the full practical range of treatments this limitation is somewhat academic.

The range of intensities in Table 3 implies that in the practical application of any given schedule there will be considerable variation in pruning intensity.

The results for treating co-dominants indicate how these stems would fare in a practical application of the 3/35% schedule (similar to many schedules now in general practice). When compared with dominants on the same schedule the co-dominants had, on average, 6% more of their crowns pruned at the first lift, 4.5% at the second lift, and 1.5% more at the last lift.

Diameter Breast Height (o.b.), Knotty Core Sizes and the Height of Occurrence

The mean d.b.h., the mean maximum diameter over pruned stubs (d.o.s.), and its mean height of occurrence, for each pruning lift, are given in Table 4. The maximum diameter over pruned stubs is assumed to be equivalent to the diameter of the knotty core (the real defect core is, however, larger).

TABLE 4—Relation between maximum diameter over pruned stubs (d.o.s.), breast height diameter (o.b.) and height of occurrence

Pruning lift		Nominal green crown removal											
		60%			50%			35%			20%		
		Mean d.b.h.	Mean largest d.o.s.	Mean height d.o.s. occurrence	Mean d.b.h.	Mean largest d.o.s.	Mean height d.o.s. occurrence	Mean d.b.h.	Mean largest d.o.s.	Mean height d.o.s. occurrence	Mean d.b.h.	Mean largest d.o.s.	Mean height d.o.s. occurrence
	(m)	(cm)	(cm)	(m)	(cm)	(cm)	(m)	(cm)	(cm)	(m)	(cm)	(cm)	(m)
One-lift	0-6.1	13.7	18.3	1.4(3)*	15.1	20.0	1.2(3)	16.7	21.1	1.3(3)	17.8	22.2	1.2(3)
Two-lift	0-3.0	-	-	-	9.4	13.4	1.1(2)	10.7	14.9	1.2(2)	12.4	16.5	1.2(2)
	3.0-6.1	-	-	-	13.6	14.6	3.7	15.7	16 6	3.9	16.9	18.2	3.9
Three-lift	0-2.1	5.3	9.5	0.8(1)	6.6	11.0	0.8(1)	9.3	13.2	1.1(2)	11.0	15.1	1.1(2)
	2.1-4.3	9.5	10.5	2.8	11.7	13.2	2.8	12.2	13.5	2.9	13.5	17.2	3.0
	4.3-6.1	10.8	9.2	4.8	13.5	12.5	4.9	14.5	13.7	5.1	17.4	16.6	5.2
Four-lift	0-1.5	-	-	-	5.1	9.2	0.7(1)	6.8	11.1	0.9(1)	-	-	-
	1.5-3.0	-	-	-	9.8	12.3	1.8	12.1	14.7	1.9	-	-	-
	3.0-4.6	-	-	-	11.7	11.2	3.6	14.1	14.1	3.7	-	-	-
	4.6-6.1	-	-	-	13.3	11.7	5.2	16.1	14.9	5.2	-	-	-
									(Co-dominants)				
Three-lift	0-2.1	-	-	-	-	-	-	7.9	11.2	1.0(2)	-	-	-
	2.1-4.3	-	-	-	-	-	-	10.5	11.1	2.9	-	-	-
	4.3-6.1	-	-	-	-	-	-	11.9	11.1	4.8	-	-	-

* Bracketed numbers refer to the blocks where treatments were located.

Results show the expected trends of decreasing knotty core size with increases in both the severity and frequency of pruning. Anomalies are generally attributed to minor differences between blocks.

Mean knotty cores of 15 cm (6 in.) or smaller are only possible if pruning schedules are at least as severe as the nominal 35% with three-lift pruning or the nominal 50% with two-lift pruning.

In an earlier theoretical study (Fenton, Sutton and Drewitt, 1963) it was predicted that the size of the knotty core would tend to increase at each pruning lift. The results from this trial suggest that this is not necessarily so, for with three- and four-lift pruning the maximum knotty core, in the majority of treatments, occurs at the second lift. The presumed explanation is that the earlier theoretical study did not allow for any decrease in stem diameter resulting from the earlier pruning lifts. Thinning at the time of first pruning influences the height/d.b.h. relationship and form functions (Knowles, 1971), so these knotty core results should not be extrapolated to early-thinned stands.

Co-dominants had knotty cores 2.0 to 2.6 cm smaller than the dominants pruned on the same schedule—an important result, since many pruned co-dominants maintained similar growth to that of pruned dominants.

Fig. 2 shows the relationship between d.o.s. and both height and d.b.h. as the latter increase with delays in pruning. Mean values are plotted for each treatment. Regression lines are fitted on the assumption that the relationships in all lifts would have the same slope. The greater scatter of points in the later pruning lifts suggests that the relationships are influenced by the earlier pruning. A closer relationship with d.b.h. than with height is evident. These relationships show that the d.o.s. and hence the defect core generally increases by 1.5 cm with each 1 m increase in height and by 1.1 cm with each 1 cm increase in diameter.

Generalised values from Fig. 2 are presented in Table 5.

These results emphasise the importance of timely pruning in determining the size of the knotty core—*see* later discussion on "what knotty core sizes?".

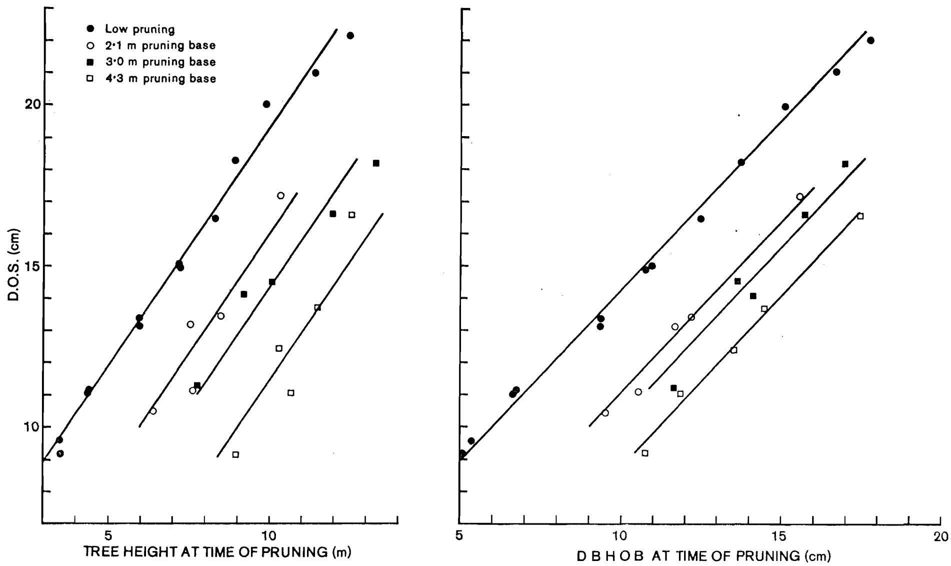


FIG. 2—Linear relationships for tree height and d.b.h., at time of pruning, to diameter over pruned branch stubs (d.o.s.).

TABLE 5—Mean tree height, d.o.s. and d.b.h.o.b.

Mean tree height	Base of pruning							
	Low		2.1 m		3.0 m		4.3 m	
m	D.o.s. cm	D.b.h. cm	D.o.s. cm	D.b.h. cm	D.o.s cm	D.b.h. cm	D.o.s. cm	D.b.h. cm
4	10.4	6.4						
6	13.4	9.2	10.1	9.1				
8	16.3	12.0	13.0	11.8	11.3	11.0		
10	19.3	14.8	16.0	14.6	14.3	13.8	11.4	12.5
12					17.3	16.6	14.4	15.3

Branch Size at Pruning and Total Number of Branches

The total number of branches, the mean diameter of the largest branch, and the total basal area of branches removed per pruning lift are presented in Table 6.

TABLE 6—Number of branches, mean size of the largest branch, and total basal area of branches removed at each pruning lift

Pruning lift		Nominal green crown removal											
		60%			50%			35%			20%		
	(m)	No. of branches	Diam. largest branch (cm)	B.A. of branches (cm^2)	No. of branches	Diam. largest branch (cm)	B.A. of branches (cm^2)	No. of branches	Diam. largest branch (cm)	B.A. of branches (cm^2)	No. of branches	Diam. largest branch (cm)	B.A. of branches (cm^2)
One-lift	0-6.1	62	4.1	265 (3)*	66	4.2	293 (3)	55	4.6	233 (3)	53	4.5	220 (3)
Two-	0-3.0	-	-	-	38	3.3	131 (2)	39	3.3	133 (2)	31	3.4	99 (2)
lift	3.0-6.1	-	-	-	21	3.7	90	21	4.4	101	19	4.1	85
Totals		-	-	-	59	-	221	60	-	234	50	-	184
Three-	0-2.1	37	2.8	102 (1)	37	2.7	107 (1)	30	3.2	102 (2)	33	3.1	112 (2)
lift	2.1-4.3	18	3.1	53	16	3.7	68	16	3.2	58	15	3.9	75
	4.3-6.1	13	2.4	26	13	3.0	42	12	3.7	51	11	3.9	59
Totals		68	-	181	66	-	217	58	-	211	59	-	246
Four-	0-1.5	-	-	-	28	2.6	74 (1)	28	2.8	87 (1)	-	-	-
lift	1.3-3.0	-	-	-	17	3.1	55	16	3.6	74	-	-	-
	3.0-4.6	-	-	-	14	2.9	42	11	3.6	53	-	-	-
	4.6-6.1	-	-	-	11	2.7	34	12	3.5	50	-	-	-
Totals		-	-	-	70	-	205	67	-	264	-	-	-
								(Co-dominants)					
Three	0-2.1	-	-	-	-	-	-	30	2.9	81 (2)	-		-
lift	2.1-4.3	-	-	-	-	-	-	16	2.8	40	-	-	-
	4.3-6.1	-	-	-	-	-	-	13	2.8	37	-	-	-
Totals		-	-	-	-	-	-	59	-	158	-	-	-

* Bracketed numbers refer to the blocks where treatments were located.

The distribution of branches within the butt length (which cannot be influenced by pruning) is somewhat masked by differences between treatment blocks. To overcome this problem, branch distribution can be expressed in percentage terms, as in Table 7.

For three-lift pruning more than half of the branches are removed in the first lift and only 20% in the third lift. Similar reductions in numbers in later prunings are found in the other lifts.

TABLE 7—Percentage distribution of branches

Two-lift pruning		Three-lift pruning		Four-lift pruning	
Lift m	Percentage of branches	Lift m	Percentage of branches	Lift m	Percentage of branches
0 -3.0	64	0 -2.1	54	0 -1.5	41
3.0-6.1	36	2.1-4.3	26	1.5-3.0	24
		4.3-6.1	20	3.0-4.6	18
				4.6-6.1	17
	100		100		100

Trends in the size and basal area of branches pruned have also been masked by the differences between treatment blocks. However, some trends are apparent:

(1) The co-dominants had similar numbers of branches to dominants, but consistently smaller means for the diameter of the largest branch removed in each lift (ranging from 3-9 mm).

(2) For the same pruning intensity, an increase in the frequency of pruning (two-lift to three-lift, and three-lift to four-lift) decreases both the size of the largest branch removed (by up to 7 mm) and the total basal area of branches removed (by 10% or more over the 0-6 m section).

(3) Similar effects are observed with an increase in pruning severity. For every 10-15% increase in the percentage of green crown removed (equivalent to 1.5 m of height growth) the mean size of the largest branch removed per lift decreases by 2 to 8 mm, and the total basal area of branches removed decreases by about 10-20%.

Effects of Pruning on Tree Dominance and Acceptability

Maintenance of Dominance

Dominance status of all stems was assessed at the end of the experiment. Results are summarised in Table 8A.

TABLE 8—Effects of pruning on dominance, stem losses and tree acceptability
A: Percentage of living trees still dominant at trial completion
B: Percentage of losses by death or serious terminal dieback
C: Percentage of stems still acceptable for selection

	No. of pruning lifts	Block No.	Nominal green crown removal 60%	50%	35%	35% (Co-dom.)	20%	Control
A:	One	3	60	55	87	—	90	90
	Two	2	—	53	62	—	79	75
	Three	2	—	—	43	21	79	
	Three	1	41	25	—	—	—	84
	Four	1	—	25	—	—	—	
B:	One	3	12	20	5	—	20	5
	Two	2	—	0	8	—	0	0
	Three	2	—	—	2	10	2	
	Three	1	18	12	—	—	—	5
	Four	1	—	10	0	—	—	
C:	One	3	68	63	83	—	63	70
	Two	2	—	83	88	—	85	60
	Three	2	—	—	83	80	65	
	Three	1	40	48	—	—	—	40
	Four	1	—	45	70	—	—	

Because the four treatments involving three lifts were divided between two blocks, and because the proportion of untreated controls remaining dominant was different in each block, results for the three-lift treatments have been presented with reference to the controls in their block.

Despite the differences between blocks, and some unexplained anomalies in the results, two trends are readily apparent:

(1) Loss of dominance following the removal of a nominal 20% of the green crown was similar to that observed in the unpruned controls.

(2) At greater pruning severities, loss of dominance, generally but not consistently, increased with the increase in both severity and frequency of pruning. For the three-lift schedules, involving a pruning severity of at least the nominal 35% green crown removal, at least 50% of the stems lost dominance.

An unexpected result was the performance of the pruned co-dominants. This treatment was originally included to demonstrate that once trees had lost dominance there was little point in pruning them. Because the co-dominants were shorter at the time of treatment, they were pruned more severely than the dominants, and this should have further reduced their competitive ability. Despite this, 21% of the initially selected co-dominants had grown so well that they were recorded as *dominants* at the completion of the trial.

Mortality and Dieback

It is generally believed that the chances of serious fungal infection, which usually results in either death or severe terminal dieback, increases with heavier pruning (Bassett (p. 50) in Tustin and Bunn, 1970). Since this trial includes a wide range of pruning treatments it should afford a test of this hypothesis.

As expected, there were tree losses during the trial. In Table 8B percentage losses are given. Losses were erratic and there was no consistent trend of greater losses with the more severe pruning treatments.

Tree Acceptability

At the completion of the trial all trees were reassessed for their acceptability for final selection, i.e., stem straightness and complete absence of leader malformation. For this assessment dominance status was ignored. Results are given in Table 8C.

The unpruned controls show the expected trend of an increasing percentage remaining acceptable with the delay in initial selection. Pruning, when the mortality trends given in Table 8B are taken into consideration, invariably improved the chances of stems remaining acceptable (although the difference was statistically significant in block 2 only—chi square test, 0.05 level). It is not known whether this is the result of pruning stress reducing the incidence of malformation or an improvement resulting from corrective pruning*. The absence of any definite trend (even taking the mortality losses in Table 8B into account) towards greater improvement with the more severe pruning treatments suggests that pruning stress is unlikely to be a factor and that the improvement is the result of corrective pruning. Stem acceptability (disregarding losses

* The removal by pruning of ramicorns, double leaders, etc., which would have made the stem unacceptable had they not been removed.

from dieback and mortality) within the range of *practical* pruning treatments is, with one exception, at least 20% better than that observed in the controls. This suggests that the estimates of numbers of stems required at initial selection to ensure adequate selection for a final crop are almost certainly less than would be suggested from studies in untended stands (e.g., Sutton, 1973).

Effects of Pruning on Growth

The effects of pruning on growth were studied by taking the height and basal area growth of the controls as a standard.

Trees were measured for d.b.h. (o.b.) and height twice yearly. Trees were also measured at the time of pruning, as were the unpruned control trees within that block.

Tables 9A and 9B show:

(a) The actual losses (or gains) in basal area and height growth compared with the unpruned controls between the first pruning and the termination of the trial. These losses are also expressed as a percentage of the growth of the controls.

(b) Similar expressions of losses between each pruning lift, and in the period between the last pruning and the termination of the trial.

Also presented in graphical form in Figs. 3 and 4 are the height and basal area development of five treatments involving three-lift pruning. Results have been shown in two sets because treatments were divided between two blocks and because the subsequent growth of the controls was different in each block.

Height Increment

In all treatments pruning led to some loss of height growth (Table 9a). With the removal of a nominal 20% of the green crown (actually removal was an average 40%) the actual height losses were 0.2 to 0.8 m, or 2 to 9% of the increment of the controls. With more severe pruning the loss of height increment was greater, the loss consistently increasing with the increase in pruning severity. For the three-lift pruning, height increment losses were 0.8, 1.1, 2.3, and 3.2 m for the nominal pruning severities of 20, 35, 50 and 60%, respectively. These represented 9, 11, 25.5, and 32.5% less than the height increment of the unpruned controls over the same growth periods.

There was also a trend, not always consistent, for height increment losses to be greater with an increase in pruning frequency.

These results generally conform with the results for the maintenance of dominance given earlier (Table 8A). As a broad generalisation, losses in height increment of 1 m or more result in at least 50% of the pruned stems losing dominance.

With all pruning treatments involving a nominal 20% or 35% green crown removal and/or only one or two pruning lifts, the depression of height increment after the completion of the last pruning lift generally lasted no longer than one year. This contrasts with those treatments involving three or four lifts with a nominal pruning severity of 50% or more where depression of height increment continued and was made worse by each successive pruning. These trends are demonstrated in the figures—Fig. 3 shows a restoration of height increment in the less severe treatments, while Fig. 4 shows a continuing increment loss in the more severe treatments.

Actual height increment losses in the co-dominant treatment were similar to those of the dominants pruned on the same schedule.

TABLE 9A—Mean tree height increment loss compared with control over period since pruning

Pruning	Period	Nominal green crown removal											
		60%			50%			35%			20%		
		Period (months)	Actual loss (m)	Percent loss	Period (months)	Actual loss (m)	Percent loss	Period (months)	Actual loss (m)	Percent loss	Period (months)	Actual loss (m)	Percent loss
One-lift	Since pruning	46	1.1	14.5(3)†	41	0.8	12.0(3)	32	0.6	12.0(3)	27	0.3	8.0(3)
Two-lift	Between lifts 1 & 2	-	-	-	27	0.8	15.5(2)	27	0.3	6.0(2)	27	0.0	0.0(2)
	Since lift 2	-	-	-	28	0.5	9.0	23	0.3	9.0	16	0.2	6.0
	Since 1st pruning	-	-	-	55	1.2*	12.5	50	0.6	7.0	43	0.2	2.0
Three-lift	Between lifts 1 & 2	23	1.2	29.5(1)	24	0.9	21.5(1)	14	0.0	0.0(2)	22	0.3	8.0(2)
	" " 2 & 3	15	0.2	5.5	14	0.6	22.0	17	0.9	24.0	12	0.3	12.5
	Since lift 3	16	1.8	60.0	12	0.8	38.5	23	0.2	4.5	16	0.2	6.0
	Since 1st pruning	54	3.2	32.5	50	2.3	25.5	54	1.1	11.0	50	0.8	9.0
Four-lift	Between lifts 1 & 2	-	-	-	16	0.6	21.0(1)	18	0.3	9.5(1)	-	-	-
	" " 2 & 3	-	-	-	12	0.3	13.5	13	0.3	12.0	-	-	-
	" " 3 & 4	-	-	-	14	0.5	16.5	15	0.0	0.0	-	-	-
	Since lift 4	-	-	-	12	0.3	15.5	4	0.0	0.0	-	-	-
	Since 1st pruning	-	-	-	54	1.7	17.0	50	0.6	7.0	-	-	-
								(Co-dominants)					
Three-lift	Between lifts 1 & 2	-	-	-	-	-	-	14	0.2	5.5(2)	-	-	-
	" " 2 & 3	-	-	-	-	-	-	17	0.9	24.0	-	-	-
	Since lift 3	-	-	-	-	-	-	23	0.3	9.0	-	-	-
	Since 1st pruning	-	-	-	-	-	-	54	1.4	14.0	-	-	-

* Totals may not add owing to rounding

† Bracketed numbers refer to the blocks where treatments were located

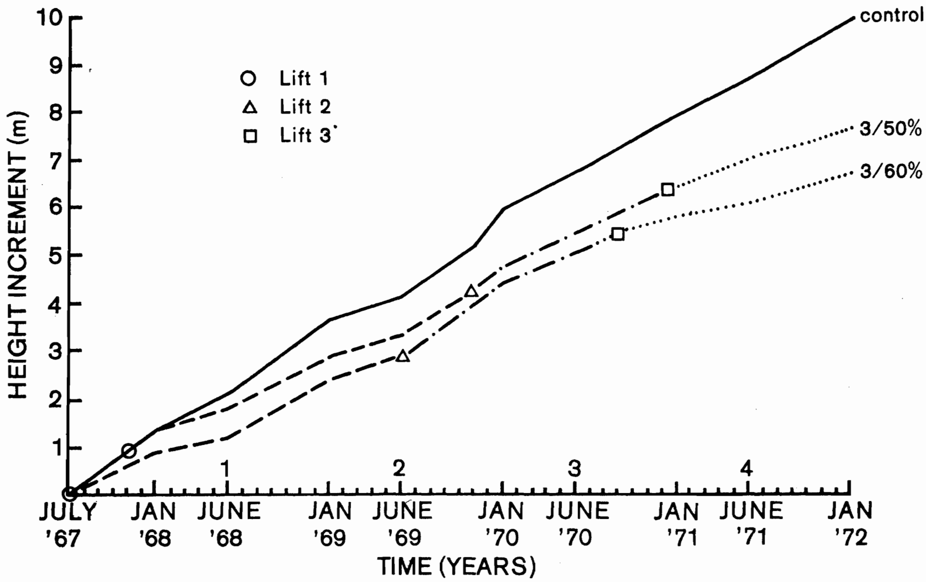
TABLE 9B—Mean tree basal area increment loss at breast height compared with control over period since pruning

Pruning	Period	Nominal green crown removal											
		60%			50%			35%			20%		
		Period (months)	Actual loss (m^2)	Percent loss	Period (months)	Actual loss (m^2)	Percent loss	Period (months)	Actual loss (m^2)	Percent loss	Period (months	Actual loss (m^2)	Percent loss
One-lift	Since pruning	46	0.011	50.0(3)†	41	0.008	42.5(3)	32	0.002	12.0(3)	27	0.001**	10.0**(3)
Two-lift	Between lifts 1 & 2	-	-	-	27	0.006	42.0(2)	27	0.004	29.0(2)	27	0.003	24.0(2)
	Since lift 2	-	-	-	28	0.006	40.5	23	0.003	22.0	16	0.002	21.3
	Since 1st pruning	-	-	-	55	0.012	41.5	50	0.007	25.5	43	0.005	23.0
Three-lift	Between lifts 1 & 2	23	0.008	60.5(1)	24	0.007	49.0(1)	14	0.002	33.5(2)	22	0.001	12.5*(2)
	" " 2 & 3	15	0.007	78.0	14	0.007	69.5	17	0.004	48.5	12	0.001	18.0
	Since lift 3	16	0.009	80.0	12	0.005	57.0	23	0.004	33.0	16	0.002	24.5
	Since 1st pruning	54	0.024	72.5	50	0.019	57.5	54	0.011*	38.0	50	0.005*	18.0
Four-lift	Between lifts 1 & 2	-	-	-	16	0.002	27.0(1)	18	0.003	26.0(1)	-	-	-
	" " 2 & 3	-	-	-	12	0.007	84.0	13	0.004	51.0	-	-	-
	" " 3 & 4	-	-	-	14	0.006	55.0	15	0.005	53.0	-	-	-
	Since lift 4	-	-	-	12	0.004	55.0	4	0.002	47.0	-	-	-
	Since 1st pruning	-	-	-	54	0.018*	55.0	50	0.014	43.0	-	-	-
								(Co-dominants)					
Three-lift	Between lifts 1 & 2	-	-	-	-	-	-	14	0.003	43.5(2)	-	-	-
	" " 2 " 3	-	-	-	-	-	-	17	0.007	81.0	-	-	-
	Since lift 3	-	-	-	-	-	-	23	0.006	50.0	-	-	-
	Since 1st pruning	-	-	-	-	-	-	54	0.016	58.5	-	-	-

† Bracketed numbers refer to the blocks where treatments were located

* Totals may not add owing to rounding

** Gains, not losses, through neighbour thinning



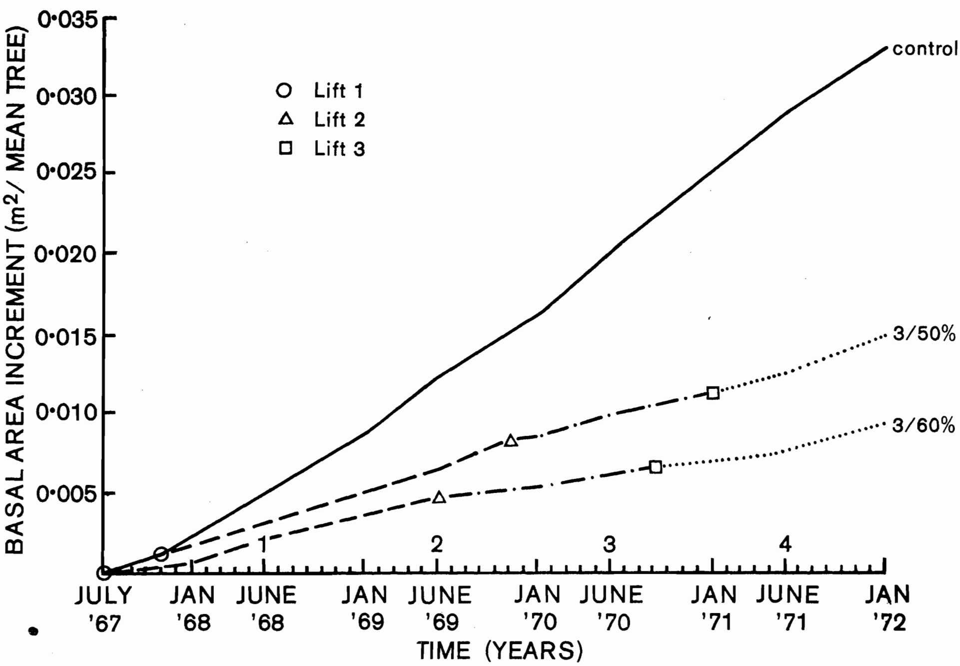


FIG. 3—Height and basal area development of the three-lift pruning treatments in Block 1.

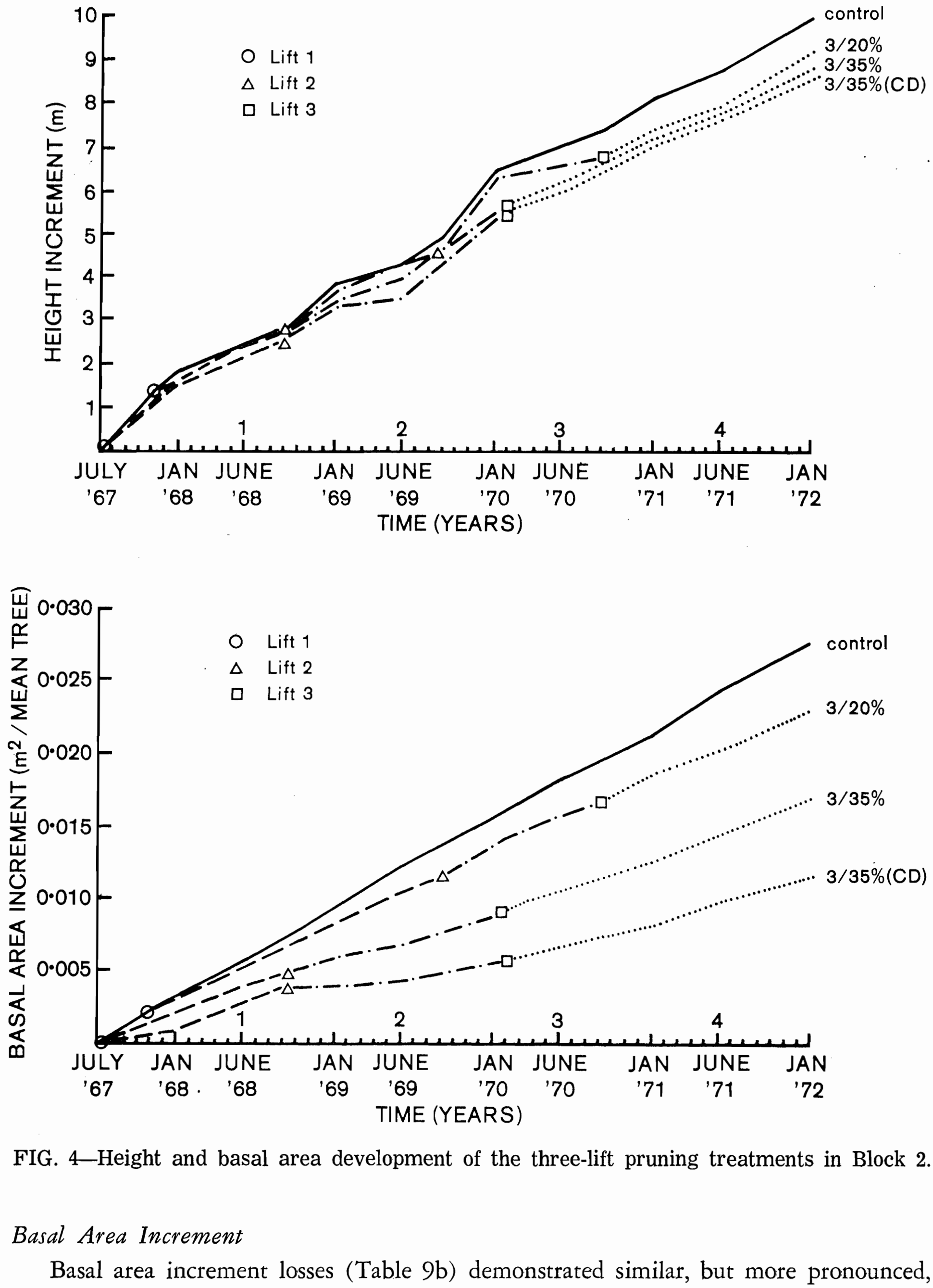


FIG. 4—Height and basal area development of the three-lift pruning treatments in Block 2.

Basal Area Increment

Basal area increment losses (Table 9b) demonstrated similar, but more pronounced, trends to those observed in height increment.

With the exception of the 1/20% treatment which produced a slight gain in basal area growth, all other treatments resulted in a loss which consistently increased with the increase in pruning severity. For the three-lift prunings basal area losses were

0.005, 0.011, 0.019 and 0.024 m^2 per tree for the nominal pruning severities of 20, 35, 50 and 60% respectively; these losses represented respectively 18, 38, 57.5 and 72.5% of the basal area increment of the unpruned controls over the same growth periods.

There was also a trend, not always consistent, for basal area increment losses to be greater with an increase in pruning frequency.

Basal area increment, even in the less severe treatments, was rarely ever restored to the level of the unpruned controls. This is shown in Figs. 3 and 4.

The co-dominant treatment maintained basal area growth similar to the 3/50% treatment.

Effects of Neighbour Treatment

In the initial establishment of the trial, variations in the treatment of neighbouring stems were incorporated to determine what growth stimulus could be obtained by reducing their competitive ability.

Analysis of growth data failed to demonstrate any general release effect by either the selective thinning or selective pruning of neighbouring stems. It would be wrong to interpolate this result as inferring that thinning is not important in pruning, as evidence from combined pruning and thinning experiments shows that thinning is important in pruned stands (unpublished results by the writers, and Knowles, 1971).

Neighbour treatment was important in the development of adventitious shoots—see below.

Effects of Pruning on Form

Log form in itself is only important at felling. Although many overseas studies have shown that pruning can affect log and tree form, this is only important if the effect is permanent.

In this study log form was assessed at the end of the trial by measurement of the stem volume of the bottom 6 m (as suggested by A. G. D. Whyte, pers. comm.). For each treatment the regression of the volume in the bottom 6 m to basal area at d.b.h. (o.b.) was calculated. Tests of significance between treatments failed to show any trends. This does not mean that differences in log form did not exist earlier in the trial, only that, if they did, they have been eliminated by subsequent growth.

Effects of Pruning on Adventitious Shoot Development

Soon after the establishment of the pruning trial, adventitious shoots (or "epicormic" branches) were observed on some of the pruned stems. It appeared that shoots were more abundant and longer in the heavier pruning treatments, on the northern aspect of the stems, and on pruned stems whose neighbours had also been pruned.

Since adventitious shoots could potentially reduce clearwood production (assumed to be the major objective in pruning), a study was made of the distribution, relative abundance and maximum length of these adventitious shoots with respect to pruning treatment, stem aspect and neighbour treatment. In some treatments assessments were repeated at yearly intervals to follow development.

Assessment Methods

Full details of assessment methods are given in Sutton and Crowe (1972b). Different methods were used at different times and in different blocks. For results given here the assessment method can be summarised:

Trees were first examined for the presence of at least one shoot (used to calculate the percentage of trees with shoots). Next, for trees with shoots the pruned portion was subdivided into 1.5 m "sections" and the presence of shoots per section noted (used to calculate the percentage incidence). Finally both the length of the longest shoot and the total number of shoots per section were assessed.

In block 1 the assessment was more intensive, with the tree further subdivided into N-E - S.W. "sectors".

Results

Results by treatments are summarised in Table 10.

TABLE 10—Adventitious shoots: Assessment results by treatment (Assessment in 1971 only)

Block	Treatment	Percentage of total trees with shoots	Of these percentage incidence on stem	Mean length of longest per 1.5-m section (cm)	Density index (Mean no. per 1.5-m section)
1	4/35%	65	@	5.6	@
	4/50%	81	@	13.0	@
	3/50%	76	@	8.1	@
	3/60%	100	@	18.0	@
2	2/20%	20	31	2.3	2.0
	2/35%	21	44	16.0	7.6
	2/50%	38	44	6.9	6.8
	3/20%	5	25	4.6	1.0
	3/35%	44	52	10.2	6.9
	3/35% (Co-dom.)	45	50	5.6	4.0
3	1/20%	0	0	0.0	0.0
	1/35%	3	25	2.5	1.0
	1/50%	12	31	11.7	1.6
	1/60%	35	33	25.9	7.3

@ Alternative method of assessment, results not included.

As expected, the percentage of stems with adventitious shoots, the number of shoots per stem, the proportion of stem area occupied by shoots and the length of the longest shoot increased with more severe pruning; increases are also evident with greater pruning frequency. In treatments removing a nominal 35% of the green crown, at least 45% of stems produced adventitious shoots. Shoots of over 10 cm in length were common in most of the moderate to severe treatments of all pruning frequencies.

The evidence from the consecutive assessments showed that the number of adventitious shoots decreased with time (to as little as a tenth of their original number within two years), but those shoots which survive continue to increase in size.

An analysis of the percentage incidence for years 1969 and 1971 of four treatments, by aspect, is given in Table 11A and by neighbour pruning treatment in Table 11B.

TABLE 11—Adventitious shoots

A: Effects of stem aspect

B: Effects of pruning neighbouring trees

	Stem aspect / No. of neighbours pruned	4/35% 1969	4/35% 1971	4/50% 1969	4/50% 1971	3/50% 1969	3/50% 1971	3/60% 1969	3/60% 1971
A: Percentage incidence	North	48	27	71	33	72	29	90	39
	East	35	16	52	19	57	18	79	30
	South	20	8	40	11	46	9	73	22
	West	34	17	57	20	60	18	85	30
B. Percentage incidence	0	20	13	40	14	56	17	85	28
	1	34	13	58	17	64	19	78	21
	2	40	14	59	20	47	16	78	36
	6	43	25	64	30	69	22	87	37

Results show that the northern aspects consistently had the most adventitious shoots, and southern aspects the least, and that an increased number of neighbouring trees pruned increased the numbers of shoots. The other two parameters length and density showed similar trends.

It is not known for how long the adventitious shoots will continue to grow, or what proportion will survive. Nor is it known how these adventitious shoots will affect timber quality, but presumably on some of the stems, where the shoots have already reached branch-like proportions (and appear to be still growing), they will reduce clearwood yields.

The Future of the Trial Area

At the completion of this study all surviving pruned stems were heavily thinned to ensure maximum diameter growth. They will be used in future sawing trials to provide both quantitative and qualitative information on clearwood recovery as affected by tree size, knotty core size and pruning treatment. No adventitious shoots were removed, and their effect on wood quality will also be assessed.

MANAGEMENT IMPLICATIONS

Since this trial incorporates a wide range of pruning treatments, and since almost every aspect (except the effects of combining thinning and pruning) has been assessed, we now have a basis for evaluating all practical pruning regimes in conventionally planted unthinned stands. In the following discussion an attempt is made to evaluate the results of the trial in terms of their implications for management. The discussion takes the form of answers to commonly asked questions on pruning, viz:

What knotty core sizes?
How many pruning lifts?
In what circumstances does severe pruning succeed?
Should only dominants be pruned?
How many trees should be pruned?
What criteria for tree selection?
Thinning — when and how heavy?
Any other considerations?
An optimum butt log pruning schedule?

What Knotty Core Sizes?

A theoretical study, in part supported by sawing results, indicated that, in order to obtain the same proportion of clearwood yield in the butt log to compensate for an increase in knotty core diameter of 1 cm, the final d.b.h. of the tree must be increased by 2.5 cm (Sutton, 1972). The results of this trial give a means of estimating the knotty core size for the butt log pruning of any practical pruning regime (*see* Tables 4 and 5, and Fig. 2). Results show that for all pruning regimes the knotty core increases by approximately 1.5 cm for every 1 m increase in height growth. since most radiata pine on North Island sites is growing 2 m or more per year during the period in which pruning is carried out, delays in the application of a scheduled pruning of even a few months can have a significant effect on clearwood yields and on pruning profitability.

To obtain a mean knotty core of 15 cm or less, the pruning schedule should be at least as severe as the nominal 35% green crown removal in three lifts, i.e.:

Prune 0 - 2.1 m at tree height 6.0 m
Prune 2.1 - 4.3 m at tree height 8.5 m
Prune 4.3 - 6.0 m at tree height 11.5 m

or the nominal 50% green crown removal in 2 lifts:

Prune 0 - 3.0 m at tree height 6.0 m
Prune 3.0 - 6.0 m at tree height 10.0 m

For mean knotty core sizes of around 12.5 cm the pruning regime would have to to be at least as severe as the nominal 50% crown removal in three lifts, i.e.:

Prune 0 -2.1 m at tree height 4.5 m
Prune 2.1-4.3 m at tree height 7.5 m
Prune 4.3-6.0 m at tree height 10.0 m

The timing of the first lift could be delayed to about tree height 5.0-5.5 m without the mean core size in this lift becoming greater than 12.5 cm.

Since the objective in pruning should be to aim for the smallest possible core size, the 12.5 cm schedule given above should be seriously considered by management (see following discussion on "an optimum pruning schedule?").

How Many Pruning Lifts?

This question, especially in relation to the merits of two- as opposed to three-lift pruning for the butt log, has been the subject of some debate in the past. It is generally believed that pruning in fewer lifts reduces overall costs, but increases the size of the knotty core. At the 1970 FRI Pruning and Thinning Symposium (Tustin and Bunn, 1970) opinions were divided on the extent of monetary savings with two-lift pruning. The cost advantage over three-lift pruning appears to be marginal. The major problem is the limited reach of a man on the ground with one pruning tool, in practice a maximum of about 2.5 m. Therefore, in two-lift pruning the first lift requires two tools to reach 3 m. Hence a three-lift operation costs little extra. An advantage of three-lift pruning is that the first pruning can be done earlier when branches are smaller and pruning costs correspondingly lower.

Results from this trial do not provide information directly of use in costing. They do, however, confirm that the size of the largest branch and the total basal area of branches removed are less with an increase in the number of lifts; by pruning in three as opposed to two pruning lifts the size of the largest branch removed decreased by up to 8 mm, and the total basal area of branches removed decreased by about 10%.

The knotty core is also affected by the number of pruning lifts. The knotty core decreased by

about 5 cm for two- as opposed to one-lift pruning;
about 1-2.5 cm for three- as opposed to two-lift pruning;
about 0.3 cm for four- as opposed to three-lift pruning.

In practice, the differences between two- and three-lift pruning would be greater, since many two-lift pruning schedules are ground to 2-2.5 m and then 2-2.5 m to 5.5-6 m, and not as in the trial—ground to 3 m and then 3 m to 6 m. With this two-lift pruning the knotty core would be 3 cm larger than in three-lift pruning.

These considerations argue strongly for pruning in three lifts which, in fact, is now standard practice in most New Zealand forests (James, Sutton and Tustin, 1970).

In What Circumstances does Severe Pruning Succeed and Should Only Dominants be Pruned?

Obviously a reasonably severe pruning schedule is necessary to keep knotty cores as small as possible, and although tree losses tend to increase with heavier pruning, these losses are more than offset by gains in final tree acceptability resulting from the generally better form in pruned stems. The latter, at least in part, apparently results from corrective form pruning which is possible if trees are pruned at an early age.

Loss of dominance is, however, likely to be very important if stands are to be pruned in three lifts at the severity considered necessary to achieve a small knotty core. At these intensities (35 to 50% nominal green crown removal—in reality 45 to 60%) — 50 to 75% of the pruned stems could lose dominance if stands remain unthinned after pruning. Since it is considered essential to prune at these severities to restrict the core size, it is necessary for all pruning to be combined with thinning.

The co-dominant treatment was originally included to demonstrate that once trees had lost dominance they were most unlikely to regain it, especially where they were pruned more severely than their dominant neighbours. In this trial the co-dominants had 50-60% of their green crown removed in three lifts. Despite this and despite their lower crown status, 20% of them were considered dominant at the termination of the trial, and the mean tree growth was similar to that of dominants pruned to the same severity.

This result, and the results of crown status studies in unthinned stands which demonstrated considerable interchange of dominance in early stand development (Sutton, 1972), suggest that selective pruning should not necessarily be restricted to dominants. Co-dominants have an advantage over dominants in that they have smaller knotty cores—about 2.5 cm smaller at each lift.

Because thinning is necessary to prevent eventual increment loss in dominants, and because an adjacent trial indicates that co-dominants (at least in young stands) will respond as well as the dominants to such thinning, the inclusion of good form co-dominants in pruning selection seems justified.

How Many Trees Should be Pruned?

If consideration is limited to management regimes similar to those for short rotation sawlogs (Fenton and Sutton, 1968; Fenton *et al.,* 1972), these trials suggest that after initial selection, losses from subsequent malformation should not be more than 50%, and it is known that malformation above 10 m, even on these malformation-prone sites (excluding the worst areas) is rarely more than 5% (Sutton, 1973). This would suggest that only 400-500 stems/ha need to be initially selected to ensure a final crop of 200 stems/ha.

If stands are not to be thinned until after the completion of the last pruning lift (where dominance losses of up to 75% can be expected, *see* Table 8A), even the initial selection of 700 stems/ha may be insufficient to ensure adequate selection for a final crop stocking.

What Criteria for Tree Selection?

A study of the relative efficiencies of various selection methods (Sutton, 1971) showed that the application of even the best of the conventional selection systems (selecting the best two stems in every four) did not ensure that every acceptable stem would be pruned. This could only be achieved if all acceptable stems were selected irrespective of spacing.

A study of the changes in tree dominance and form in a young radiata pine stand (Sutton, 1973) showed that the past emphasis on dominance as the primary basis for selection was misplaced. It was suggested that stem straightness (since it is permanent) should be the most important consideration; leader malformation (which was shown to have an even chance of correction with normal stand development) should be next and dominance should only be a third consideration. Results from this study add support to these conclusions.

Thinning — When and How Heavy?

In previous discussion the need for small knotty cores has been stressed. This can only be achieved with a moderately severe, multiple lift pruning schedule. The results of this trial show that such pruning in stands left unthinned must result in considerable losses in dominance and diameter growth. As the results from another trial (Knowles, 1971) have shown, dominance losses can be eliminated and losses in diameter growth greatly reduced by heavy early thinning, preferably at the time of the first pruning lift and certainly no later than the time of the last lift. For this reason alone early thinning is considered essential in selectively pruned stands. Also, costs of thinning are greatly reduced if the thinning is done early. This is compatible with current management proposals for short rotation sawlog regimes where intermediate yields are not required.

It is known that the increased diameter growth following early thinning will result in slightly larger knotty cores in the second and third pruning lifts than were found in this selective pruning trial (Knowles, 1971). However, this is considered preferable to the alternative of loss of dominance and diameter growth. Core sizes in a thinned stand can be controlled with a moderately severe, multiple lift, pruning schedule. Full evaluation of this aspect must await results from the younger pruning and thinning trials now established.

The results of the eclectic (or selective release) thinning show that this releasing measure gives little or no immediate increase in diameter growth. It is far better, and cheaper in the long run, to thin out all unwanted trees as soon as they can be recognised.

Any Other Considerations?

Adventitious shoots are likely to be more numerous and longer as a result of thinning. If so, and if the shoots prove responsible for a loss of clearwood production, then a later pruning to remove them could be justified. This is standard practice on some species in Queensland.

The failure to detect any consistent effects of pruning on butt log form by the time all pruning was completed suggests that this factor need only be considered at final felling.

Studies on the basic wood properties of trees in the pruning trial have been started, and initial results suggest that this too is unlikely to be a major consideration (D. Cown, pers. comm.).

In applying any practical pruning schedule some loss of height growth can be expected. For stands where thinning is combined with pruning, basal area increment loss should be less than where stands are left unthinned. The 3/35% treatment (mean knotty core around 15 cm) lost 0.9 m height growth between the time of first and last pruning lift; the 3/50% treatment (mean knotty core around 12.5 cm) lost 1.5 m height growth in the same period. Even if similar losses occur in thinned stands, this is equivalent to only about one-half and two-thirds respectively of the expected annual growth. Even if the rotation is lengthened by a year, it is a minor consideration compared with a 10-year gain in achieving a final crop tree of similar diameter as a result of the heavy thinning (Fenton *et al.,* 1972).

An Optimum Butt Log Pruning Schedule?

Assuming that maximum clearwood production is the primary objective in pruning, the optimum pruning schedule would appear to be:

At mean crop height 5.0 m prune to 2.0-2.5 m
At mean crop height 7.5 m prune to 4.3 m
At mean crop height 10.0 m prune to 6.0 m

The number of stems which should be pruned at each stage will depend, in large part, on the thinning prescription. If unselected stems are removed at the time of each lift (or at least at the first and last lifts) then the number of stems to prune should be: 400 to 500 stems/ha at the first lift, 300 stems/ha at the second lift and 200 stems/ha at the final lift. These numbers will provide adequate selection at each stage.

If, however, stands are not to be early-thinned and if the initial spacing is the conventional 2.4 × 1.8 m or similar, then 700 stems/ha should be the minimum number of trees selected for first pruning. But even this number may not be adequate if thinning is to be delayed until after the last pruning lift.

Selections should be made without regard to spacing (except perhaps at the last pruning lift) on the basis of:

First — stem straightness
Second — leader malformation
Third — dominance.

Such a schedule should achieve a mean knotty core of around 12.5 cm (possibly nearer 15.0 cm in the upper region of the butt log because of increased diameter growth resulting from the early thinning). Loss of height increment with this schedule is not expected to be greater than 1.5 m (equivalent to about eight months longer rotation).

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