PRUNING TRIAL WITH SUGI
(Cryptomeria japonica)

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ABSTRACT

A trial is described which was designed to study the effects of pruning (green foliage removal) on growth of five-year-old Sugi.

At pruning, stand height averaged 4.5 m and diameter (b.h.) 8.3 cm. Stand density was 1850 stems/ha and green crown extended to within 0.3 m of forest floor.

Three levels of pruning were applied:

(a) Pruned to 1.2 m height on stem — a 40% removal of green crown.

(b) 1.8 m — a 60% removal.

(c) 2.4 m — a 76% removal.

The amount of foliage removed was based upon calculations of crown surface area.

Results show that all pruning treatments depressed diameter and height growth over a four-year period. Basal area losses over the period were 6% for (a), 17% for (b), and 23% for (c), when compared with unpruned trees.

It is concluded that to avoid large growth losses 40-50% actual foliage removal be set as the upper limit at low pruning. This equates to 30-35% removal of lineal green crown. These findings generally concur with recent Japanese pruning studies.

INTRODUCTION

Since 1964 some 70 ha of Sugi (*Cryptomeria japonica*) have been planted in pure stands within the Auckland Regional Authority's water catchment Hunua Ranges.

As at 1977, Sugi comprised 5% of the total exotic forest estate with *Pinus radiata* the dominant planted conifer at *c.* 90%.

Sugi was originally planted as part of a series of species trials which sought to evaluate potential for timber production and suitability for growing in a water catchment (Barton, 1972).

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Early growth of Sugi on the upland sites was very encouraging with height increment equalling that of radiata for *c.* five years. After this period radiata's growth accelerates, whereas Sugi maintains a steadier rate of development.

On the basis of early optimism, plantings of Sugi were increased during 1967-70. The area planted has since declined as it became apparent that the species could not match radiata in wood production and because of uncertainties about marketing of the timber.

Uses for wood of Sugi in New Zealand are not clearly defined at present although it has been suggested by J. S. Reid and I. L. Barton (in Weston, 1968) that timber might be suitable for window sashes and weatherboards or logs peeled for veneers.

Such special end uses demand logs which yield high quality knot-free timber. To obtain such quality in trees which may be harvested between 40 and 60 years will require artificial removal of live branches for quality clearwood production.

The first step in clearwood production begins with low pruning, this taking place at a young age and before trees have reached any great stature. At this "youthful" stage, trees are in an active phase of development and removal of living foliage (dependent upon degree) is very likely to have an adverse effect upon growth, even if only of a transitory nature.

Before applying pruning regimes to a tree species it is prudent to know what effect a given intensity of pruning might have upon subsequent growth. It follows that any drastic reduction (or ill thrift) caused by pruning would be contrary to sound management practice and detrimental to the prime pruning objective, that of maximum clearwood production.

This small trial looks at the effect of three pruning intensities on growth over four years in a five-year-old stand of Sugi.

Before describing the trial and results, a brief review is given of some relevant pruning research from Japan.

RECENT STUDIES IN JAPAN

Pruning has been practised with Sugi for several hundred years in Japan (Fujimori, 1975) and pruning systems vary from region to region for production of specific local products (Spiers, 1966).

Recent pruning research has focused on developing standard technical systems of pruning (Fujimori, 1975). Towards this end a series of studies were conducted by Government Forest Experiment Stations at Kyoto and Tokyo. Results of these studies are reported in a series of bulletins (Fujimori, 1970, 1972, 1975; Fujimori and Waseda, 1972; Takeuchi and Hatiya, 1977a, b).

The first of these studies looked at biomass production, growth and contribution of leaves and branches in sections of the crown (Fujimori, 1970).

Fujimori showed that the stratum with largest leaf weight occurred near the middle of the crown. Just above this region was the stratum with the largest branch increment and below, the stratum with largest branch weight. "The stratum with the highest degree of contribution to trunk production is that with the largest branch increment" (Fujimori, 1970).

This ecological study was followed by practical experiments which looked at the effect of *pruning intensity* on stem growth (Fujimori and Waseda, 1972; Takeuchi and Hatiya, 1977b), and at different methods of pruning and the effect upon stand structure (Fujimori, 1972).

It was shown that pruning up to the stratum with largest branch weight (or nearly to that with largest leaf weight) could be done without serious growth losses. To keep loss of growth within acceptable limits it was suggested that the upper limit for actual foliage removed be 40%. This equates with around 30% removal of lineal green crown (Fujimori and Waseda, 1972).

Both Fujimori and Waseda (1972) and Takeuchi and Hatiya (1977b) showed that the degree of pruning and subsequent reduction of diameter and height increment were closely correlated.

Fujimori and Waseda also emphasised that, for accurate examination of pruning effect, the ratio of removed foliage to total foliage should be used rather than ratio of pruned to tree height, or ratio of lineal green crown removed to green crown length. Fujimori and Waseda found that the relationship between the *intensity of pruning treatment* (*i.e.*, ratio of removed foliage to total foliage) and reduction in the rate of stem growth (expressed as D^2H) seemed to be free of stand density effect in the sampled stands. Tree ages ranged from 9 to 10 years with stem densities of 2 700 to 4 500 ha, and heights of 5 to 7 m.

Takeuchi and Hatiya (1977b) added support for this relationship and showed that a rough estimate of volume loss could be predicted directly from the amount of foliage removed.

An important product of the studies is a thorough dissertation on the technical system of pruning (Fujimori, 1975). In this report Fujimori synthesises the early fundamental studies into management systems for production of pruned logs and poles.

One such pruning guide shows pruning in four steps commencing at age 8 with a tree height of 6.5 m. Pruning continues at two-yearly intervals up to age 14 when a final pruned height of 6.5 m is achieved. This schedule involves around 25% lineal green crown removed at each step, equivalent to *c.* 35% removal of actual green foliage.

These Japanese studies have proved to be valuable in confirmation and interpretation of some results from the local Hunua trial here reported.

STUDY AREA AND METHODS

Location Site and Layout

The trial is located in a small Sugi stand at an altitude of *c.* 420 m, on a site having a north-east aspect with slope of six degrees. The soil is classified as Hunua clay loam, a yellow-brown earth derived from weathered greywacke and Hamilton ash — fertility low to medium (Soil Bureau, 1954).

Annual rainfall recorded at a nearby site over 13 years is *c.* 2 000 mm with monthly averages ranging from 130 mm (Jan.) to 208 mm (Aug.). Mean annual air temperature at a station some 3 km from the site is 13.5°C with monthly averages ranging from 8.7°C (July) to 18.6°C (Feb.).

By contrast rainfall for Kyoto Japan over a five-year period averaged *c.* 1 600 mm per year with monthly averages ranging from 38 mm (Dec.) to 328 mm (June). Annual air temperature was 15.7°C with monthly averages from 3.6°C (Jan.) to 28.5°C (Aug.). (Japan Meteorological Agency, 1973; T. Fujimori, pers. comm.)

Kyoto has greater climatic extremes than Hunua with higher temperatures and rainfall during the growing season. One would not expect such a marked seasonal effect on tree growth at Hunua owing to the more equable climate. Indeed, growth activity may not entirely cease on favourable Hunua sites during a mild winter.

The stand was planted with two-year nursery stock in 1965 and trees were five years old from planting when the trial was commenced in December 1970. Trees were planted at 1.8 × 2.4 m spacing (2 220 stems/ha) but at time of pruning mortality had reduced the stand to 1 850 stems/ha. Trial plot boundaries enclosed nine rows of trees covering 0.08 ha.

Treatments

On all trees green branches extended to within *c.* 0.3 m of soil surface. Canopy had just closed (Fig. 1) and ground vegetation almost suppressed.

Three nominal levels of pruning intensity were applied:

(a) Base of stem to 1.2 m height on trunk.
(b) 0 - 1.8 m.
(c) 0 - 2.4 m.

A selection of control trees were left unpruned. Within six rows, groups of three to five trees were selected and pruned to the prescribed height and these were alternated with groups of unpruned trees. This gave two rows of each treatment with control groups scattered among the pruned stems. Table 1 gives details of the stand at pruning.

In addition, a sub-plot with one row of each treatment (without control trees) was established for measurement of

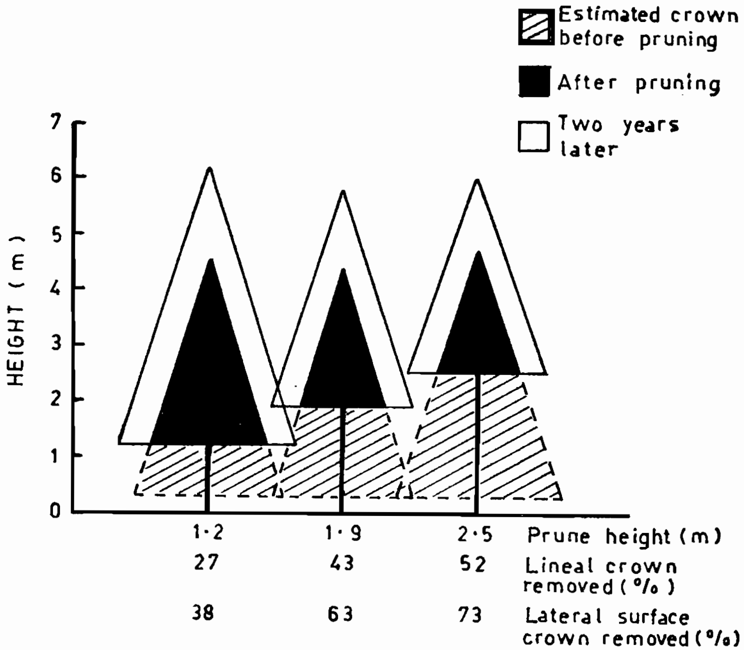

FIG. 1: *Crown profiles for three pruning levels (sub-plot treatment).*

TABLE 1: DETAILS OF STAND AND TREATMENTS

Nominal Treatment	*No. Stems*	*Mean d.b.h. (cm)*	*Mean height (m)*	**Mean Lineal Crown Removed (%)*	*Mean Lateral Surface Area Crown Removed (%)*
Control	49	7.6 (3.5-10.2)	4.4 (2.7-5.2)	—	—
0-1.2 m	35	8.1 (6.1-11.2)	4.5 (3.6-5.2)	28 (23-33)	40 (34-48)
0-1.8 m	33	8.6 (4.6-11.9)	4.5 (3.3-5.2)	42 (34-52)	60 (51-78)
0-2.4 m	33	9.1 (4.8-13.2)	4.6 (3.6-5.2)	54 (47-67)	76 (67-89)
Total	150	—	—	—	—
Means	—	8.3	4.5	—	—

In parentheses range of values.
*Mean of calculations for each individual tree.

crowns. Figure 1 shows average crown profiles and spacing of stems for the three pruning intensities in the sub-plot. The percentage of crown removed in the sub-plot varied slightly (Fig. 1) from the average crown removal for the total trial as shown in Table 1.

The pruning height for each treatment was measured accurately on each tree and all branches removed up to the marked level with secateur pruners. Usually the length of pruned stem to first green branch was slightly more than the nominated measure. A measurement after pruning in the sub-plot (42 stems) showed that final pruned levels were little different on average from the prescribed treatments. (Refer Fig. 1 for final pruned heights in the sub-plot.)

All trees were measured for diameter (b.h.) and height at yearly intervals until 1974.

With sub-plot trees an additional measure was that of crown base for estimation of crown area. This was done by measuring radius of crown base at four points (N, S, E, W) with base taken as length of longest branch at point of measure.

RESULTS AND DISCUSSION

Stem form, Branches and Taper

The stand exhibited much diversity amongst individuals in stem form, foliage, branching habit and bark texture — although height and diameter tended to be more uniform than in a radiata plantation of the same age. In many trees form in the lower stem was poor with butt sweep and twisted trunks prevalent, due not only to inherited traits but also to wind exposure during the establishment phase. Angle of branches varied, with some very upright (acute angle) through right-angle to pendulous. Branch diameters (at point of attachment to stem) ranged from 0.25 to 3.3 cm (mean 1.4 cm) and number of branches per metre of stem from 16 to 26 (mean 21).

Taper in the lower trunk was pronounced with an average reduction of 4.2 cm diameter per metre of pruned stem.

This variation in stem shape together with bark texture, fluting and other outgrowths, made it difficult to cut branches flush with the trunk.

Foliage Removal

A common method of indicating pruning intensity is to express green crown removal as a percentage of total green crown before pruning. With Sugi of this age, green crown extended almost to ground level, so lineal crown removed was directly expressed as a percentage of tree height.

Although lineal crown removed is an easy measure to calculate, it does not provide any estimate of actual foliage removed. Such a measure is required if a better picture of the effect of pruning intensity upon tree growth is to be obtained. This is in line with the conclusions of Fujimori and Waseda (1972). Reference to Fig. 1 shows that expressing pruning severity in a lineal sense can be quite misleading.

In a Sugi stand of this age (before or just after canopy closure) the crowns tend to approximate a conoid shape. This allows simple measurements of crown base (radius) and tree height to be used for calculation of crown surface area.

This was done for the 42 trees in the sub-plot trial and lateral surface area of crowns calculated from the formula:

Lateral surface area of a cone — $\frac{1}{2}$ perimeter $\times$ slant height.

The use of cone shape to estimate surface areas of crowns in young stands appears justified by the studies of Kajihara (1975). He shows that the geometric shape of crowns in 6- and 8-year-old Sugi stands (before and just after canopy closure) does closely approximate a cone. However, Kajihara shows that as stands develop after crown closure (and with aging) the total crown divides distinctly into two parts. The upper part exposed to sunlight has a geometric shape between a cone and a parabaloid while the lower shaded part is a cylinder. Because of this division Kajihara suggests that calculations of crown surface area for the upper crown be not based upon a simple geometrical solid, but upon one which conforms exactly as possible to actual crown shape. Such a refinement was not considered for this trial because the cone shape was so marked.

In examination of the effect of foliage removal on individual trees Fujimori and Waseda (1972) and Takeuchi and Hatiya (1977b) calculated foliage weights from a number of felled sample trees. They used this to estimate actual amounts of foliage removed during pruning and expressed this as a percentage, or ratio of leaves removed for each pruning intensity.

Quantity of foliage may be expressed by several units such as weight and surface area, and all are closely related (Kittredge, 1944).

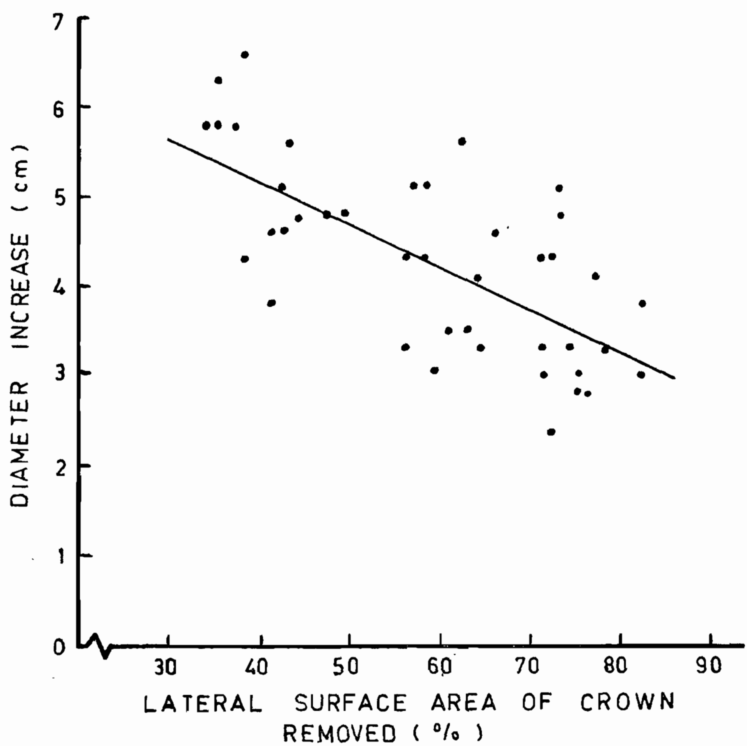

FIG. 2: *Relationship between lateral surface area of crown removed at pruning and diameter increase at breast height after two years (r = 0.71).*

This close relationship between foliage weight and crown surface area allows for a direct comparison of pruning effect between this trial and the Japanese experiments.

Effect of Pruning on Growth

It was perhaps fortuitous that for the first two years after pruning the stand remained in a relatively free growth state, and the effect of pruning treatments could be studied on trees which were not affected by excessive competition. After this period canopy had again closed (Fig. 1) and density began to restrict growth.

A reduction in diameter and height growth was evident for all pruning treatments when compared with control trees. Figure 2 shows the effect of foliage removal on diameter growth of trees in the sub-plot. Although the trend of decreasing diameter increment with increased foliage removal is well defined, the scatter of points shows the considerable variation in response of individual trees. Some variation is attributable to initial tree size, but it was also evident that some trees were more tolerant of foliage removal than others (or at least had a better recovery rate).

Basal area progress is illustrated in Fig. 3 showing slower growth rates for pruned trees. Table 2 gives details of percentage growth losses for several parameters at two and four years of age when compared with unpruned trees.

Fujimori and Waseda (1972) used a greater range of pruning treatments (35-87% foliage removal) than those covered in this trial. They followed the effect on growth in 9- and 10-year-old trees over a two-year period. To express the reduction in growth

TABLE 2: PERCENTAGE GROWTH LOSSES IN DIAMETER, HEIGHT, BASAL AREA, AND D^2H FOR PRUNING TREATMENTS (at two and four years after pruning)

Treatment and (% Foliage Removed)	*% Growth Reduction**							
	Diameter		*Height*		*Basal Area*		*D^2H*	
	2 yr	*4 yr*	*2 yr*	*4 yr*	*2 yr*	*4 yr*	*2 yr*	*4 yr*
1.2 (40)	6	6	9	10	5	6	6	8
1.8 (60)	22	18	16	14	20	17	19	19
2.4 (76)	35	26	28	31	30	23	27	26

*Calculated from:

$$\frac{\text{Increase in pruned trees} - \text{Increase in control trees}}{\text{Increase in control trees.}} \times 100$$

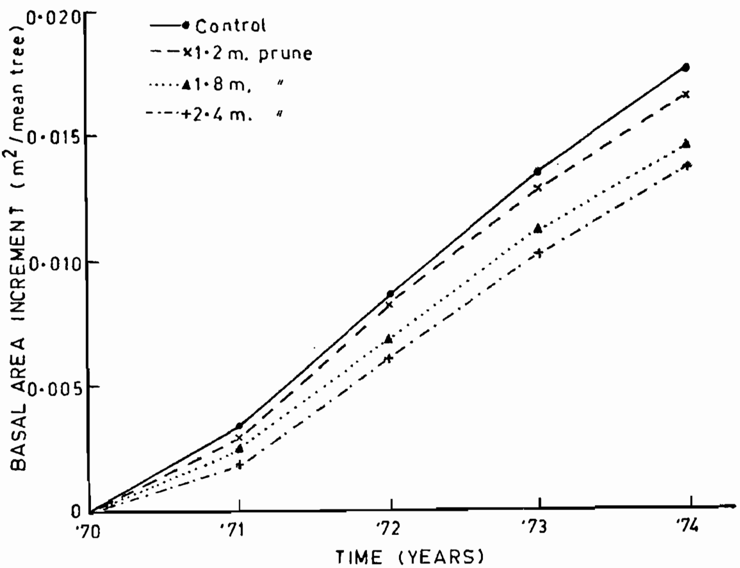

FIG. 3: *Progress of basal area from time of pruning.*

compared with unpruned trees they used the term D^2H (where D = d.b.h. and H = height), and compared the "removal ratio of leaves" (%) with the "reduction rate of D^2H" (%).

Fujimori (1975) showed that a 20% removal of foliage gave a 5% reduction of D^2H, 40% removal a 14% reduction, 60% a 31% reduction, and 80% a 53% reduction over the two-year period. These figures can be compared with the D^2H reduction for this trial as shown in Table 2. Loss of growth was not as severe as that obtained by Fujimori (1975) for similar levels of foliage removal.

The result from this trial supports the view of Fujimori and Waseda (1972) that removing up to 40% of green foliage at pruning (in trees at this stage of development) does not appear to have a serious effect on growth. In this case growth losses were below 10% at four years for the 40% pruning treatment.

Tree growth is related closely to area of foliage available for production of photosynthates, and to the efficiency of such foliage. Fujimori (1970) pointed out that the crown stratum which most influenced stem growth was that with the largest branch increment and this stratum was found just above the middle of the green crown.

Figure 1 shows that the 38% treatment did not remove foliage from this middle crown region, whereas the 63% treatment was just below, and the 73% treatment just above middle crown. Clearly any incursion into this "productive" part of the crown will have serious effects upon tree growth. Another point is that the crown area in the 38% treatment was greater after two years than before pruning (Fig. 1). However, the 63% treatment barely regained the same crown area and the 73% treatment still had a crown area less than that before pruning.

In such circumstances stem growth must suffer as the trees' reserves and energy are drawn to replenish lost foliage and a rebuilding of the "productive" crown region. Rate of foliage replacement was greater over two years in the 63 and 73% treatments than in the 40% treatment (*i.e.*, 165% increase in crown surface area compared with 125% increase). This suggests a greater channelling of available photosynthates to crown renewal, at the expense of stem development.

CONCLUSION

Results show that tree growth has been depressed by the three pruning treatments applied in this trial. Reduction in growth becomes more severe with an increase in amount of foliage removed. However, at the lowest level of foliage removal (40% of green crown area) growth loss over four years was less than 10% — this is regarded as acceptable.

This result agrees (in general) with data from recent Japanese experiments but growth losses were not as severe in the Hunua trial as in the Japanese studies for similar levels of pruning intensity. Because of this (and taking some account of a more favourable growing season at Hunua), then the upper limit for actual foliage removal for Sugi at low pruning can be set in the range 40-50%. This equates with around 30-35% removal of lineal green crown.

ACKNOWLEDGEMENTS

I am very grateful for the interest shown in this small project by Dr Takao Fujimori, Chief of Silviculture (Second Unit) of Forestry and Forest Products Research Institute, Ibaraki, Japan. His helpful advice and constructive comments have materially improved the content of this paper. I am indebted to the General Manager, Auckland Regional Authority, for permission to publish this paper.

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