COMPARISON OF THE GROWTH OF VEGETATIVE PROPAGULES AND SEEDLINGS OF *PINUS RADIATA*

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ABSTRACT

This paper reports the results, during the first 5 years after planting, of a field trial designed to compare the growth of seedlings with that of grafts and cuttings taken from ortets of different ages.

The difference in size at age 5 could be attributed mainly to differences in the size of the trees at planting. However, the calculation of relative growth rate (RGR) values, and the correction of these values for covariance on tree size, enabled growth rates to be looked at independently of planting size. The corrected data for the fourth and fifth years then showed that (i) grafts had lower RGRs than cuttings, apparently because of graft incompatibility; (ii) during the first three years the seedlings had higher RGRs than cuttings.

The use of cuttings, rather than seedlings, in a plantation establishment programme will lengthen the time from planting to canopy closure. Information is not yet available on growth effects subsequent to that time.

INTRODUCTION

There is increasing and widespread interest in establishing plantations with rooted cuttings rather than seedlings (e.g., *see* papers in this volume by Kleinschmit, Lepistö and Rauter). With radiata pine (*Pinus radiata* D. Don) the case for this has been well made (Fielding, 1964, 1970; Thulin and Faulds, 1968; Libby *et al.,* 1972), and many authors stress the virtues of coupling vegetative propagation with a genetic improvement programme. The advantages of doing this with radiata pine have been summarised by Libby *et al.* (ibid); briefly they are a reduction of the stem defects associated with the juvenile habit, additional genetic gain from selection, improved uniformity of crop, and faster multiplication of genetically improved material. These advantages must be weighed against some accepted disadvantages such as earlier and more abundant production of stem cones; and some potential disadvantages of uncertain magnitude, of which the most important is probably slower growth.

Sweet (1973) reported the assessment, 3 years after planting, of a trial to compare the growth of seedlings with that of grafts and cuttings taken from trees of different ages. The juvenile propagules (seedlings, and grafts and cuttings from 6-year ortets) differed widely in both growth and form from mature propagules (grafts or cuttings from older ortets). The results suggested that the use of mature cuttings for plantations might, during the first 3 years of growth, reduce stem diameter by 20%, and volume by some 40%, compared with juvenile material. A problem in obtaining those estimates arose because planting stock size varied in the different ortet age groups when the trial was established. Planting size proved to be the dominant factor influencing size three years after planting. The data thus needed adjustment to be meaningful. This was done primarily by analysis of covariance.

The trial has since been assessed for a further two years, and three years' diameter and volume measurements are now available for the five years that the trial has been established.

THE TRIAL

Briefly (for full details *see* Sweet, 1973), the trial consisted of two experiments (grafts and cuttings) each containing 5 groups of plants (propagules from ortets of different ages) × 5 clones per group × 9 ramets per clone. A balanced incomplete block design was used. The vegetative propagules were interplanted with seedlings in the ratio of 3 seedlings to one clonal ramet. Initial spacing was 2.7 m × 2.7 m, but this was increased (by thinning of seedlings) to 5.5 m × 2.7 m during the 1972-73 growing season. Seedlings (initially planted as "fillers") were included in the assessment of each experiment as a sixth "group", comprising five series each of nine trees. The quality of the seedlings was poor compared with the grafts, and their heights were low. The groups in each experiment are:

Graft experiment S2, G6, G15, G25, G43, G66
Cutting experiment S2, C6, C10, C19, C23, C43

The code has the following basis: S = seedling, G = graft, C = cutting. The numerical suffix is the age of the ortet in years from sowing, at the time when the trial was established in the field in 1968.

Data to be presented

This paper will utilise the following data:

(i) Height measurements taken every year from the time of planting (1968) until 1973.
(ii) Basal diameter measurements taken annually from 1971 to 1973.
(iii) Stem form factor $\left(= \frac{\text{diameter } \frac{1}{2} \text{ height}}{\text{basal diameter}}\right)$ calculated annually from 1971 to 1973.
(iv) Stem volume measurements calculated annually from 1971 to 1973.
(v) A subjective assessment of stem crookedness and of malformation (scored 1-4) in 1973.

The number of trees planted in the trial was 540, but by 1973 only 497 were judged assessable for height, basal diameter, stem straightness and stem malformation. Because of problems of measuring half-height diameters on forked trees, volumes and stem form factors were calculated for 456 trees only, i.e., some 85% of the trees initially planted.

In presenting results, considerable use will be made of the parameter relative growth rate (RGR). This parameter copes with the pre-existing differences in plant size between the various groups. Relative growth rate is defined as "the increase in size per unit of size per unit of time", and may be calculated from the formula:

$$RGR = \frac{\mathrm{Log}_e S_2 - \mathrm{Log}_e S_1}{t_2 - t_1}$$

where S_2 and S_1 are plant sizes at times t_2 and t_1 respectively (*see* Blackman, 1919). The calculation makes no assumption about the way in which growth rate changes with time (Williams, 1946). The use of RGR is illustrated for height growth in Fig. 1 taking two hypothetical trees which have the mean height of the shortest and tallest groups in this trial at the time of planting. The mean relative height growth rate (RHGR) for the whole trial from 1968-1971 (Sweet, ibid.) has then been applied throughout to both plants to examine height differences which would develop over that period, if that RGR obtained. Fig. 1 shows that if the two hypothetical trees grew at the same RHGR as one another, the *ratio* of their starting heights remained constant (2.5 : 1) but the *actual* height difference between them increased from 39.5 cm in 1968 to 270 cm in 1971. The plots for natural log of height against time show parallel lines for the two trees, indicating that this type of plot also has value in examing the growth of trees of different initial size.

The situation examined in Fig. 1 is an exponential growth one in that RGR was selected to remain constant with time. In practice, however, plant growth is seldom exponential and RGRs normally decline with time. Such a situation occurs in the experiments reported here, with volume and diameter growth being closer to the exponential situation than height growth. Exponential growth is not a prerequisite to the use of the relative growth rate approach (Williams, 1946) but when (as here) RGR values decline with time it is necessary to consider whether this may represent a decline

FIG. 1

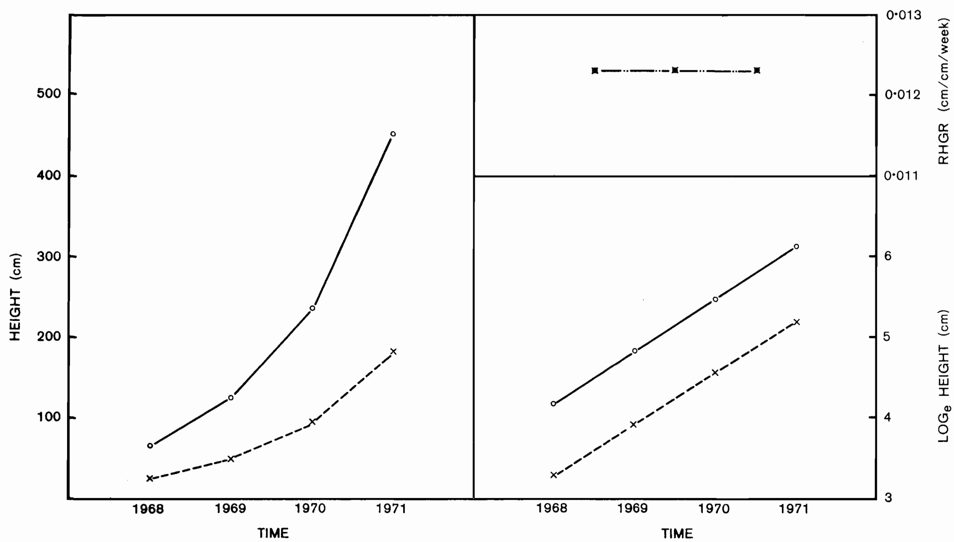

FIG. 1—The application of a constant relative height growth rate (RHGR) to two hypothetical trees over a 3-year-period.

with tree size. If so, a comparison of RGRs of plants of markedly differing size should only be made after they have been corrected for covariance on tree size. This approach has been followed in this paper.

In the presentation of results, *actual* height, volume and diameter data will not be discussed, although mean 1973 values for all growth parameters assessed are presented in Table 1. The main bases of presentation consist of (i) natural logs of growth data plotted against time, and (ii) RGR data plotted against time.

RESULTS

Height Growth

1973 mean heights are presented in Table 1. Figs. 2 and 3 respectively show $\log_e$ height plotted against time and RHGR plotted against time for the 12 groups in the experiment.

Fig. 2 shows that in 1973, as at the time of planting, the grafts were taller than the cuttings. The seedlings increased their rate of height growth much more rapidly than the vegetative propagules for the first two years after planting, but since then the height rankings of all groups have changed little. Fig. 3 shows that in terms of RHGR the cuttings in fact overtook the grafts during the 1970-71 growing season and have subsequently exceeded them. Groups C19, C23 and C43 had significantly (at 1% level) higher RHGR height values than groups G25, G43 and G66 for every year since 1970.

For the period 1971-73 the mean RHGRs for seedlings, cuttings and grafts respectively were 0.438, 0.441 and 0.347 m/m/year. On these figures RHGR of the mean graft was 21% below that of the mean cutting. However, the general pattern in Fig. 3 of a reduction in RHGR with time sugests the need to adjust RHGRs by covariance analysis (see earlier). Using the average within-group regression of RHGR on 1971 height the mean RHGRs for the period 1972-73 were adjusted on the basis of the overall mean heights in 1971. The regression accounted for 25% of the within-group variance. Mean adjusted RHGRs for seedlings, cuttings and grafts respectively were 0.425, 0.412 and 0.383 m/m/year. Based on these figures the mean RHGR of the grafts is only 7% lower than that of the cuttings.

TABLE 1—Mean 1973 assessment data

	Graft experiment						Cutting experiment					
	S2	G6	G15	G25	G43	G66	S2	C6	C10	C19	C23	C43
Tree height (m)	6.9	7.9	7.6	7.1	7.3	7.4	6.8	7.5	7.0	6.3	5.6	4.7
Stem basal diam. (cm)	17.1	19.5	15.4	12.0	13.1	12.6	17.0	19.4	13.8	11.0	9.0	7.3
Stem volume (cc × 1000)	54.2	81.7	57.4	35.1	42.0	39.8	57.1	79.0	41.7	25.7	17.3	10.6
Stem form factor	0.46	0.45	0.58	0.63	0.60	0.64	0.49	0.46	0.56	0.62	0.65	0.65

FIG. 2

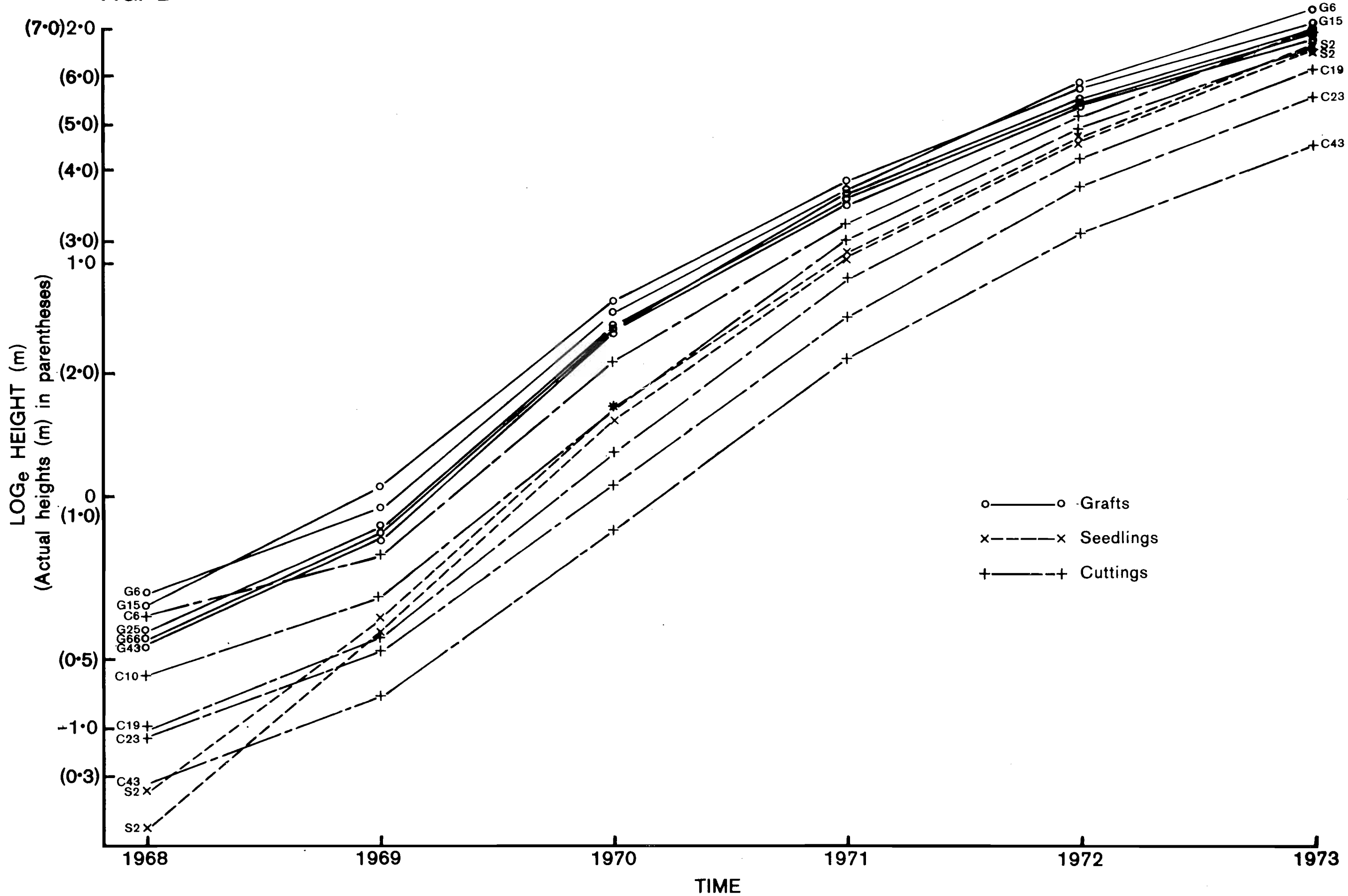

FIG. 2—Changes in $\log_e$ height growth with time for the 12 groups of trees in the trial.

FIG. 3

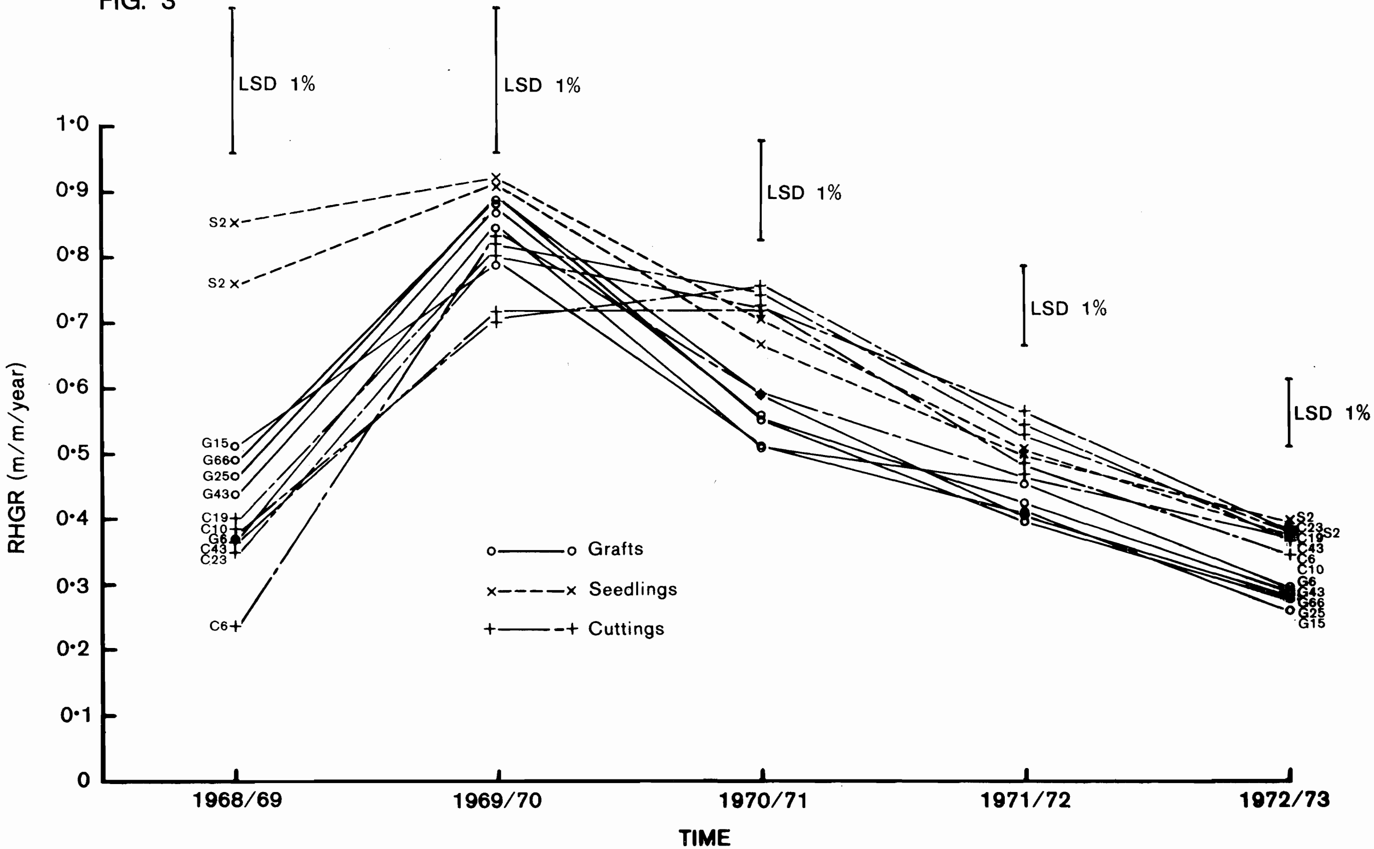

FIG. 3—Changes in relative height growth rate (RHGR) with time for the 12 groups of trees in the trial.

Basal Diameter

1973 mean diameters are presented in Table 1. Fig. 4 shows $\log_e$ diameter plotted against time, and relative diameter growth rate (RDGR) plotted against time, for the 12 groups in the experiment.

FIG. 4

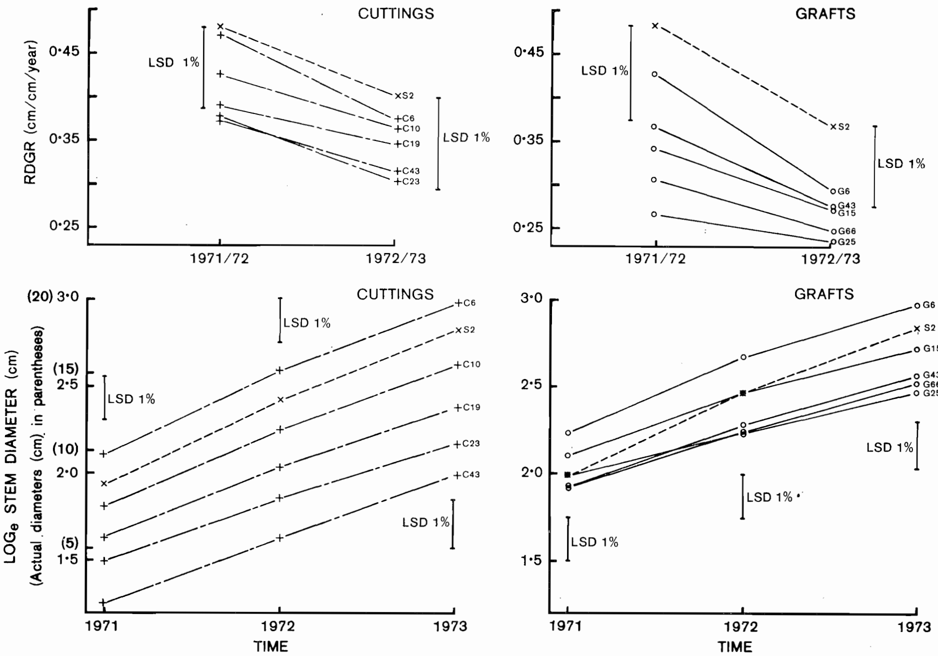

FIG. 4—Changes in $\log_e$ diameter growth and relative diameter growth rate (RDGR) with time for the 12 groups of trees in the trial.

The $\log_e$ diameter values changed little in ranking during the course of the measurement period in the graft experiment: there the grafts are clearly falling behind the seedlings. The seedlings had a higher RDGR than both cuttings and grafts over the two measurement periods, but the differences were statistically significant mostly in the graft experiment. In the cutting experiment, the seedlings were significantly higher in RDGR than the cuttings ($P < 0.01$) only in the 1971-72 period, and this was restricted to groups C23 and C43. There was in the cuttings a negative association between the ranking for RDGR and the age of the parent ortets.

As with height, RDGR values decline with time. Accordingly the mean RDGRs for the period 1971-73 were adjusted in the same way as height was for covariance on 1971 diameter. Unlike height, however, the within-group regression on 1971 diameter accounted for only 5% of the within-group variance. After adjustment the mean RDGR of the cuttings was 18% lower than the seedlings, while that of the grafts was 12% lower than that of the cuttings. The unadjusted percentages were 13% and 19% respectively.

Stem Volume

1973 mean volumes are presented in Table 1. Fig. 5 presents data for $\log_e$ stem volume plotted against time, and relative volume growth rate (RVGR) plotted against time. The $\log_e$ volumes changed little in ranking between the three assessments, the only important change being the decline of the grafts relative to the seedlings. The RVGR data, however, show that between 1971 and 1973 the seedlings have maintained a slightly higher RVGR than both the cuttings and grafts. This was statistically significant at the 1% level only in the case of some groups of grafts.

As with height and diameter, so also RVGR declined with time, and accordingly the mean RVGRS for the period 1971-73 were adjusted in the same way as height was. The regression accounted for only 6% of the within-group variance. After adjustment the cuttings had a mean RVGR 11% lower than the seedlings, while mean RVGR of the grafts was 15% lower than that of the cuttings. Unadjusted percentages were 9% and 21% respectively.

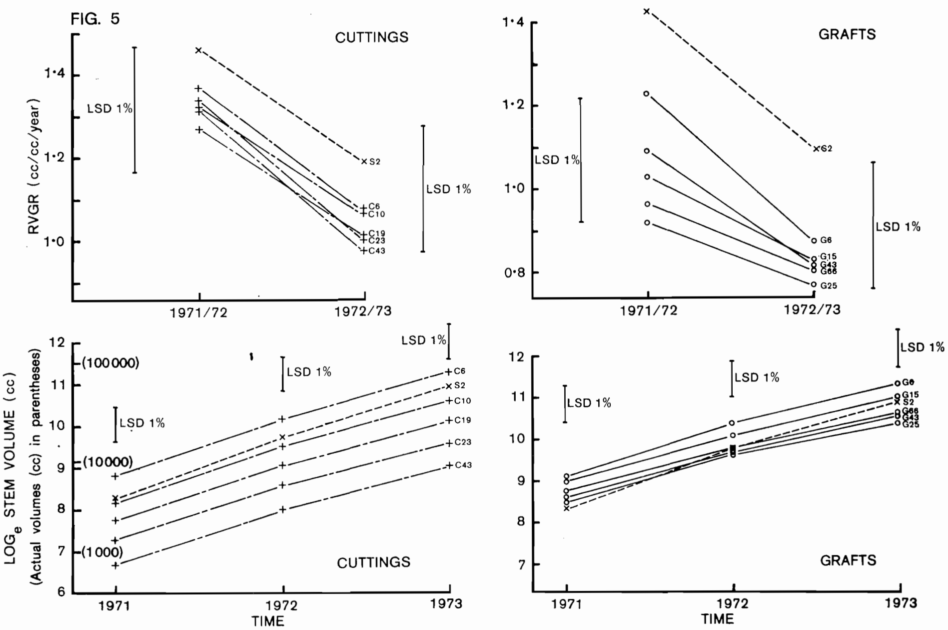

FIG. 5—Changes in $\log_e$ volume growth and relative volume growth rate (RVGR) with time for the 12 groups of trees in the trial.

Stem Form Factor

Form factors for the 12 groups in the experiment for the years 1971 to 1973 are illustrated in Fig. 6, and 1973 values are presented in Table 1. The pattern of stem form has changed little since 1971; and in 1973 there is still significantly less stem taper in the mature grafts and cuttings than in the seedlings and groups G6 and C6. At each date the stem form factor was unrelated to within-group variance in tree size.

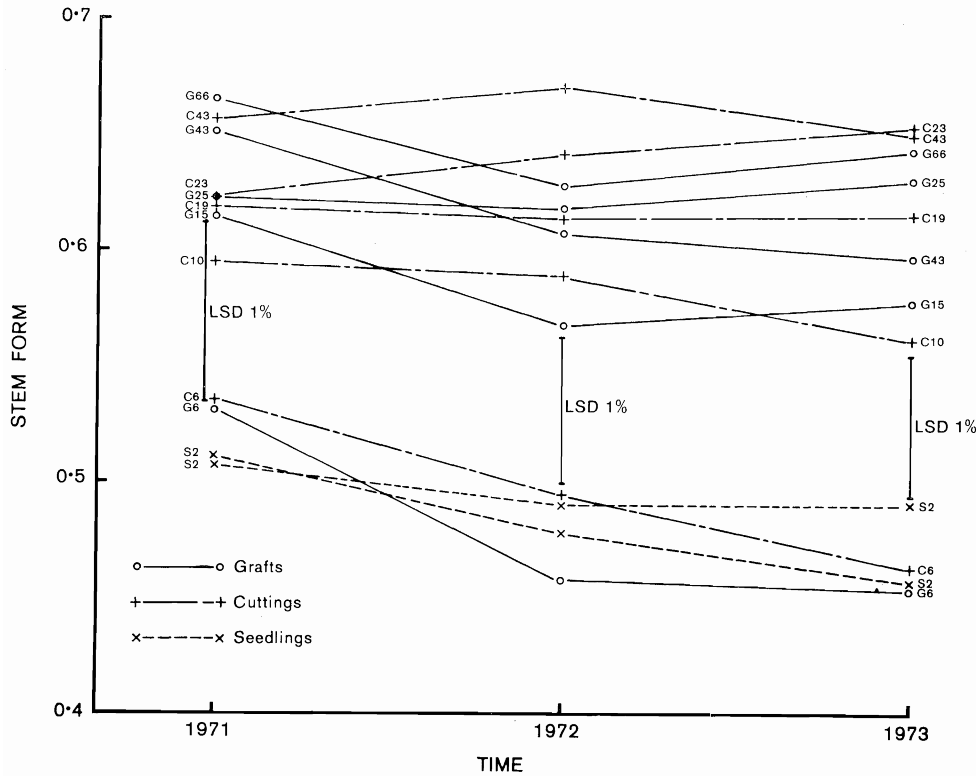

FIG. 6—Changes in stem form $\left(= \frac{\text{diameter half-height}}{\text{basal diameter}}\right)$ with time for the 12 groups of trees in the trial.

Crookedness and Malformation

Data are presented in Table 2. The juvenile propagules (seedlings, G6 and C6) were less straight than the mature ones (all other groups) but the differences were not statistically significant. There was no correlation, overall or within-groups, between stem crookedness and tree height (r within group = −0.11).

TABLE 2—Stem crookedness and malformation results — 1973*

	Graft experiment						Cutting experiment					
Parameter	S2	G6	G15	G25	G43	G66	S2	C6	C10	C19	C23	C43
Stem crookedness	4.50 ab	4.15 ab	3.78 ab	3.35 ab	3.05 b	3.39 ab	4.83 a	4.13 ab	3.88 ab	3.95 ab	3.64 ab	3.92 ab
Stem malformation	2.00	1.38	1.36	1.27	1.10	1.26	1.86	1.58	1.14	1.07	1.02	1.03

* The higher the value, the more pronounced the trait.
Values for individual trees of a group were meaned.
Stem crookedness means which do not share a common letter differ at the 1% level by Duncan's test.

The seedlings had more stem malformation than most of the vegetative propagules: statistical analysis is not presented because of serious lack of homogeneity of variance between groups. Again there was no correlation between stem malformation score and tree height (r within group = −0.02).

DISCUSSION

The similarity of the slopes of $\log_e$ size against time for the 12 groups for height, diameter and volume shows clearly that the *major* differences in size in the trial 5 years after planting still result from differences in the size of the planting stock, *not* from differences in RGR. The volume differences present in 1973 (Table 1) indicate clearly how important this fact is to plantation establishment practices.

Two major RGR effects showing up in the trial are noteworthy—the first is the early superiority in relative height growth rate of the seedlings over the clones, an effect which has been shown in other experiments (e.g., *see* papers by Libby and by Shelbourne and Thulin in this issue). The second effect is the lower relative growth rates that the grafts showed in comparison with the cuttings during the last two years of growth. Although this latter effect was partly explainable in terms of tree size, covariance adjustment still left appreciable RGR differences, particularly in diameter and volume growth, and there can be little doubt that the remaining differences are due to graft incompatibility (*see* Sweet and Thulin, 1972). Seventeen grafts in the trial were dropped out of the 1973 assessment because of marked incompatibility symptoms, but these data suggest that there is an increment loss in grafts well before symptoms are recognisable externally.

If plantations in New Zealand are to be established with cuttings of radiata pine, the initial phenotypic selection is envisaged in trees aged about 8 years (Thulin and Faulds, 1968). It then requires a further 15 years to test and multiply the selected clones before starting large-scale plantation establishment. Meanwhile, maturation will proceed unless it can be checked by manipulative treatments (Libby *et al.,* 1972). The likelihood of this is still uncertain.

Accepting the above timetable the interest lies in comparing the growth of cuttings from 8 to 23-year-old ortets with that of seedlings. We will thus examine further the behaviour of Groups S2, C10 and C23 in this trial for the period 1971 to 1973. Some mean RGR figures for these groups, adjusted by the average regression within all groups using 1971 size, are presented in Table 3. The table shows that between the 3rd and

TABLE 3—A comparison of adjusted* RGR data for years 3 to 5 after planting (unadjusted values are given in parentheses)

Group	Mean RGR Height m/m/year	Mean RGR Stem diameter cm/cm/year	Mean RGR Stem volume cc/cc/year
S2	0.421 a (0.435)	0.445 a (0.441)	1.306 a (1.322)
C10	0.413 b (0.418)	0.390 b (0.396)	1.172 b (1.193)
C23	0.418 ab (0.469)	0.312 c (0.341)	1.112 c (1.170)

* The basis for adjustment is defined in the text.
For any parameter, values without a letter in common differ significantly at the 1% level in t-test comparisons.

5th year after planting the seedlings had in each case the highest RGR for height, diameter and volume growth. They also had the poorest tree form (Table 2).

Taking a hypothetical tree equal in respective size parameters to the mean C10 cutting in 1971, and applying to it in turn the mean S2, C10 and C23 RGR values for 1971-73 adjusted for 1971 size, the percentage loss in increment which would result from the use of cuttings as compared with seedlings over this period can be calculated. The figures show a volume loss of 23.4% for group C10 and 32.1% for group C23. For diameter loss the values are 10.4% (C10) and 23.4% (C23), and for height the values are 1.5% (C10) and 0.7% (C23). These values are lower than those existing during the first three years of the trial during which height losses of the C10 and C23 cuttings, compared with seedlings, were 44% and 47% respectively (Sweet, 1973).

Such growth losses in cuttings will clearly influence the length of time from planting to canopy closure. In plantings of uniform-sized trees seedlings would close canopy before cuttings, and this (everything else being equal) would affect the length of the rotation. However, the experiment has not yet provided a comparison of seedling and cutting growth rates under closed canopy conditions, and such information is required before the full effect of these growth differences on a cutting establishment programme can be evaluated. It should become available from future assessments.

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