ment, the correlations tended to depend upon the nature of the environment and whether the plants are genetically related. A highly significant negative correlation between height growth and fibre length was demonstrated to exist within one clone. The interpretation of earlier work is discussed.

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Trees Grown from Cuttings Compared with Trees Grown from Seed (Pinus radiata D. Don)

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1. Introduction

A plantation Programme based on rooted cuttings, if practicable, offers possibilities of large genetic improvements through the selection of superior clones. Also, there is the possibility of further improvements because of differences between trees grown from cuttings and trees grown from seed — differences associated with the method of propagation itself.

In the Australian Capital Territory (A. C. T.), rooted cuttings of *Pinus radiata* D. DON have been planted on an experimental scale almost annually since 1938, and a lot of material is therefore available for studying differences between cuttings and seedlings.

Some clones compared with seedlings in this paper had been raised from trees selected for fast growth rate, trunk straightness and small, wide-angled branches. Such selection can be expected to have had an appreciable effect on branch size and angle and on related branching characteristics such as the number of whorls of branches on the annual shoot: selection for small branches tends to reject trees with only few whorls of branches, and the number of whorls of branches on the annual shoot is related to the number of branches in the whorl (FIELDING, 1967). It is postulated however that the selection has not had an important effect on the other characteristics studied (bark thickness, taper and foliage), because as far as is known, such characteristics are not related to those which were under selection.

It is considered that, except for the particular branching characteristics of the selected clones discussed in the previous paragraph, the differences discussed in this paper between cuttings and seedlings are basically a result of the difference in the propagation method and that they are effects of cyclophysis. Cyclophysis (BÜSGEN and MÜNCH, 1929) may be defined as the expression in the vegetatively propagated individual of properties associated with the age of the parent plant or the developmental stage of the shoot used as the cutting or scion.

Changes associated with aging and development appear to be universal in woody species (SCHAFFALITZKY, 1959), and there are numerous examples of the carryover of such changes into vegetatively propagated progenies.

The cuttings and seedlings compared in this paper differ in physiological age by only a few years, but it is not entirely surprising that such a small age difference should be associated with distinct differences in many characters, because rapid changes are obvious during the first 5–7 years of the life of the seedlings — changes in buds, foliage, branching, crown shape and flowering.

Some of the differences between cuttings and seedlings are very marked in the case of cuttings raised from older trees. For example, in *Figures* 2 *ancl* **3** the smooth bark, low taper, and small branches of the clones which had been raised from 16-yr.-old seedling trees make the trees of these clones strikingly different from trees of seedling origin.

Very little information is available on the influence of the properties of the shoot on the characteristics of the tree grown vegetatively from the shoot. Many results in this paper are preliminary in nature. The subject deserves intensive study since changes so induced in a tree provide the forester with another possible means (in addition to improvements by cultural methods and breeding) of developing trees of greater or special value.

2. Definitions

In this paper the term "cutting" refers not only to a shoot cut from the tree and set in the nursery but also to any tree raised from a cutting, including large, mature trees.

Cuttings from seedling ortets are referred to as "first-propagation cuttings", cuttings from which are referred to as "second-propagation cuttings".

"Setting" refers to placing the cut shoot in the nursery soil.

"Planting" refers to planting the rooted cutting in the plantation.

The terms "0.1 ht." and "0.5 ht." refer to levels on the trunk at one-tenth and one-half respectively of the total height of the tree.

3. Materials and Methods

The comparisons of cuttings and seedlings were made between 1964 and 1967. In only one comparison are the cuttings and seedlings planted in a replicated test. In all others the clones are compared with seedlings growing on a nearby and apparently very similar site in a plantation of the same age and with the same spacing between the trees.

All the seedlings were routine A.C.T. stock planted when approximately 10 months old. The seed had been collected in South Australia and A.C.T. plantations. The provenance of the original American seed collections is unknown, but the characteristics of the A.C.T. trees suggest that they originated from one or both of the two northern provenances in California.

The cuttings were vigorous first- and second-order branch shoots which were collected and set in autumn. The rooted cuttings were planted in the winter of the following year — approximately 14 months after the cuttings were collected. The shoots were cut to a length of approximately 6 in. and set to a depth of approximately 3 in. in the soil. The cuttings of the 27½-yr.-old plantation were set in a nursery bed. Those of all the other plantations discussed in this paper were set in 6 × 1¾-in. galvanized iron tubes filled with a loam soil.

All were first-propagation cuttings except for second-propagation cuttings in one lean and one taper comparison.

The rooted cuttings of each of the comparisons of cuttings and seedlings had been raised from shoots of similar type taken from a particular position in the crown. They had been given the same nursery treatment and had been planted at the same time as the seedlings.

Comparisons in three young plantations — aged 4, 5 and 6 years (see Table 1). — In the 4-yr.-old plantation, three randomly selected trees in each of 8 clones planted in unreplicated rows were compared with 24 seedlings located within 75 ft. of the clones. In the seedling stand, all trees of a height reasonably comparable with the clones were measured but forked trees were rejected. The clones had been raised by cuttings taken from seedlings (selected for favourable branching, trunk straightness and vigour) in 6- and 7-yr.-old plantations.

In the 5-yr.-old plantation, 33 seedlings were compared with 26 clones in 4 blocks of a randomized block test, the unit plots of which were single trees. Twenty-five of the clones had been raised from cuttings collected from seedlings in a 6-yr.-old plantation, the remaining clone from a seedling in a 5-yr.-old plantation. Fourteen of the parent trees had been selected for favourable branching, trunk straightness and vigour and 12 for high or low wood density. The seedlings were located within approximately 100 ft. of the clones. All seedlings in the stand were measured except forked trees and several particularly large trees.

In the 6-yr.-old plantation, 3 randomly selected trees in each of 6 clones planted in unreplicated rows were compared with 18 neighbouring seedlings located within 25 ft. of the clones. The clones had been raised from cuttings taken from seedlings (selected for favourable branching, trunk straightness and vigour) in a 4-yr.-old plantation. In the seedling stand, trees of a height reasonably comparable with the clonal trees were selected but forked trees were rejected.

Lean comparisons in five plantations ranging in age from 4½ to 27½ years (see Table 2). — The horizontal displacement of the tip of the tree from the centre of the trunk at ground level was measured in 4½- and 6½-yr.-old plantations.

The comparison of cuttings and seedlings in the 4½-yr.-old plantation was based on 2 trees of each of 5 clones, and

Table 1. — Comparisons of Cuttings and Seedlings of *P. radiata* in three Young Plantations in the A.C.T.

		4-Yr.-Old Plantation				5-Yr.-Old Plantation				6-Yr.-Old Plantation			
		Cuttings		Seedlings		Cuttings		Seedlings		Cuttings		Seedlings	
		Mean	C(7)	Mean	C	Mean	C	Mean	C	Mean	C	Mean	C
Ht. (ft.)		10.17	14.7	9.07	11.9	9.83	20.4	10.06	15.3	17.51	10.9	16.78	15.1
D.B.H. (in.)		1.59	25.3	1.55	23.2	1.49	29.6	1.69	23.1	2.83	14.1	3.04	18.4
No. Whorls(1)		5.9	23.5	6.7	31.9	7.0	22.5	6.7	24.9	13.3	9.4	11.8	17.8
Bark(2)	0.1 ht.	17.5	16.4	17.5	26.9	18.5	16.6	19.0	21.0	14.1	17.0	16.7	26.0
%	0.5 ht.	23.4	15.0	20.2	39.5	22.7	15.9	20.9	15.6	15.7	11.4	16.0	18.2
Taper u.b.(3)		203.4	20.4	239.2	24.7	193	20.4	221	29.0	184.2	13.6	242.9	9.5
Branches	No.	19.54	34.3	26.88	29.4	18.61	34.1	27.15	28.2	32.28	18.9	39.89	21.5
0.1—0.5	No. per whorl	7.01	18.5	6.62	15.6	5.72	22.8	6.93	15.6	6.19	9.2	7.43	14.8
ht. (4)	No. per ft.	5.79	33.3	7.68	22.1	4.65	21.1	6.73	25.6	4.78	16.9	5.99	24.5
	S.A. per in.(5)	55.7	30.1	71.9	50.5	40.3	50.6	60.3	46.6	59.9	21.3	105.0	45.4
Ht. D.B.H. Ratio(6)		787.4	12.0	721.7	14.4	688.8	20.9	609.5	15.7	623.3	7.0	559.2	12.7

1. Excluding branches less than 6 in. above ground and any branches of the current annual shoot at the top of the tree the needles of which had not begun to develop or which were only partly elongated.
2. The sectional area of the bark expressed as a percentage of the underbark sectional area of the stem. Bark thickness measured on 2 small pieces of bark cut from the stem at each level on opposite sides of the stem.
3. Change in diameter u.b. in. per ft. (×1000) between 0.1 ht. and 0.5 ht.
4. Branches measured o.b. at the stem in a horizontal direction by calipers.
5. Sectional area (sq. mm.) per in. Based on the total sectional area of the branches and the distance between the centres of the internodes on either side of the zone of measured branches.
6. Based on ht. (ft.) and d.b.h. (in.).
7. Coefficient of variation. The coefficient for the cuttings is based on the within-clone standard deviation.

Details of the cuttings and seedlings are given in Section 3 of the text.

Table 2. — Comparisons of Leans of Cuttings and Seedlings of *P. radiata* in the A.C.T.

Age of Stand	Displacement (in.)*)		Lean (degrees)**)		
	4½ yr.	6½ yr.	7½ yr.	16½ yr.	27½ yr.
Cuttings	2.54	3.95	0.96	2.44	2.64
Seedlings	3.50	7.10	1.96	4.32	4.56

*) Horizontal displacement of tip of tree from centre of trunk at ground level.
**) Measured by the instrument shown in *Figure 1* from top to base of tree in the 7½-yr.-old stand, the basal 20 ft. of the trunk in the 16½-yr.-old stand, and the basal 30 ft. of the trunk in the 27½-yr.-old stand.
Details of the comparisons are given in Section 3 of the text.

10 seedlings. The second and fifth trees were selected in each clone. The nearest seedling within 10 per cent of the height of each cutting was selected for comparison. The trees of each pair were less than 75 ft. apart. The cuttings had been raised from shoots taken from seedlings (selected for favourable branching, trunk straightness and growth rate) in 6- and 7-yr.-old plantations. The mean d.b.h. and height of the cuttings were 1.99 in. and 13.6 ft. respectively, and those of the seedlings, 2.22 in. and 12.9 ft.

The comparison in the 6½-yr.-old plantation was based on 2 trees of each of 4 clones and 8 seedlings. The trees of each pair of cuttings and seedlings (which were selected for comparison as in the 4½-yr.-old plantation) were less than 40 ft. apart. The cuttings had been raised from shoots taken from seedlings (selected for the above favourable characteristics) in a 4-yr.-old plantation. The mean d.b.h. and ht. of the cuttings were 3.50 in. and 23.1 ft. respectively, and those of the seedlings, 3.50 in. and 21.9 ft.

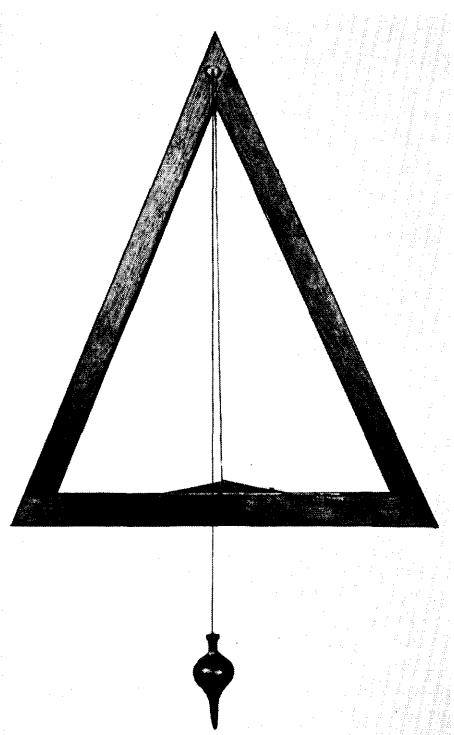

Figure 1. — The instrument used for measuring leans. The base is approximately 14½ inches and the height 16¾ inches. The part of the trunk to be measured is aligned with the brass rod at the centre, and the horizontal triangular indicator at the base is aimed at the trunk. The lean is read on the scale against the plumb bob line.

The angle of lean was measured in plantations aged 7½, 16½ and 27½ years by means of the instrument shown in *Figure 1.*

The comparison in the 7½-yr.-old plantation was based on 12 trees of 9 clones, and 12 seedlings. Pairs of cuttings and seedlings of comparable diameter were selected within 40 ft. of each other. The cuttings had been raised from shoots taken from 3- to 5-yr.-old plantations of first-propagation cuttings which had been raised from shoots taken from unselected seedlings in 4- to 6-yr.-old plantations. The mean d.b.h. of the cuttings and seedlings was 4.13 and 4.25 in. respectively.

The comparison in the 16½-yr.-old plantation was based on 3 dominant and co-dominant trees of each of 14 clones and 18 nearby seedlings of comparable size. The cuttings had been raised from shoots collected from trees selected for favourable branching, trunk straightness and growth rate in a 6-yr.-old seedling plantation. The mean height of the seedlings and of the first tree of each clone were 72.9 ft. and 74.6 ft. respectively.

The comparison in the 27½-yr.-old plantation was based on 19 trees of 6 clones and 19 nearby seedlings of comparable size. The cuttings had been raised from shoots collected from trees selected as showing marked differences in branching in 4- and 5-yr.-old seedling plantations.

Bark thickness and taper comparisons in 16½- and 27½-yr.-old plantations (see Figures 7—10). — In the 16½-yr.-old plantation, diameters overbark (o.b.) and underbark (u.b.) were measured at 6 levels (1, 3, 5, 7, 9 and 15 ft.) on 3 dominant and/or co-dominant trees of each of 14 clones, and 18 trees of a neighbouring seedling stand. The trees were randomly selected in each clone and taken in order in the seedlings. Heights and diameters were as follows: —

		Cuttings	Seedlings
Ht. (ft.)	Mean	74.6	72.9
	S.E.	0.9	1.3
D.U.B. at 5 ft. above ground (in.)	Mean	8.86	7.98
	S.E.	0.29	0.25

The difference in mean diameter is considerable, but an analysis of the data showed no definite relationship between percentage bark and d.u.b. at a particular level.

In the 27½-yr.-old plantation diameters (o.b. and u.b.) were mesaured at 5 levels (1, 5, 10, 15, and 20 ft.) on 2 dominant and/or co-dominant trees of each of 5 clones and one tree of a sixth clone, and 11 neighbouring seedling trees. The trees were selected in order in the clones: then a seedling of d.b.h. comparable with each clone tree and located within 50 ft. of it was selected. The mean diameters (o.b.) at 5 ft. above the ground were: cuttings, 14.42 in.; seedlings, 14.34 in. Mean heights were: cuttings, 109 ft.; seedlings, 112 ft.

4. Bark thickness

Cuttings and grafts which have been raised from older *P. radiata* seedlings (over 12 years of age) have particularly thin bark on the lower part of the trunk — a striking feature of such trees. *Figures 2 and 3* illustrate cuttings raised from trees growing in 16-yr.-old plantations (approximately 17 years from seed). The bark of the lower part of the trunks of these trees is very thin — as is shown by its smoothness. A similar effect is claimed to have caused taxonomic confusion in poplars (May, 1963).

Cuttings raised from seedlings growing in 4- to 7-yr.-old plantations have also tended to develop thinner bark than seedlings on the lower part of the trunk. Comparisons of the bark thickness of such cuttings and seedlings have been made in plantations aged 4, 5, 6, 16½ and 27½ years.

In the 4-yr.-old plantation *(Table 1, Figure 4)*, the differences in bark thickness are not large: at 0.1 ht. 5 of the mean bark thicknesses of the 8 clones lie below the seedling regression line and only 2 means lie above it; at 0.5 ht., however, the cuttings, in general, have slightly thicker bark than the seedlings.

In the 5-yr.-old plantation *(Table 1, Figure 5)*, 22 of the 26 clone means lie below the seedling regression line for 0.1 ht., but as in the 4-yr.-old plantation, the cuttings tend to have slightly thicker bark than the seedlings at 0.5 ht.

In the 6-yr.-old plantation *(Table 1, Figure 6)*, the mean bark thickness at 0.1 ht. of all 6 clones is definitely below the seedling regression line. Even at 0.5 ht., 5 of the 6 clone means lie below the corresponding regression line.

In the 16½-yr.-old plantation (in which diameters and bark thickness were measured at 7 heights above ground) the mean bark percentages of the cuttings were less than those of the seedlings at all heights up to 9 ft. *(Figure 7)*. The mean under-bark diameters of the cuttings and seedlings of this plantation differed (Section 3), but an analysis of the relationship between bark thickness and under-bark diameter at a particular height on the clones and seedlings did not show a definite relationship between these two variables.

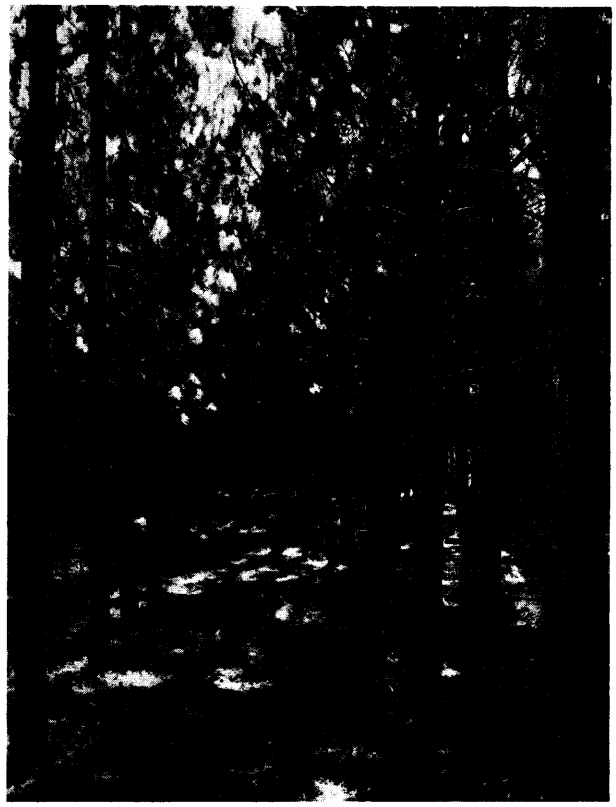

Figure 3. — A clonal stand 16 years after planting. Clone 944 (on the left) had been raised from cuttings collected from a seedling in a 16-yr.-old plantation. On the right are 3 second propagation cuttings of clone 560 which had been raised from shoots collected from a 5-yr.-old plantation of first propagation cuttings, which in turn had been raised from shoots collected from a tree in a 6-yr.-old seedling plantation. — Note the thin branches, narrow crowns and smooth bark of clone 944. The low taper of the trees is also evident. These features are characteristic of such cuttings which have been raised from older seedlings.

Figure 2. — A tree of clone 944, 16 years after planting and 7 in. d.b.h. It had been raised from cuttings collected from a 16-yr.-old seedling plantation. The smooth bark (which is also thin) is characteristic of such cuttings which have been raised from older seedlings. Seedlings in 16-yr.-old plantations typically have rough, thicker bark.

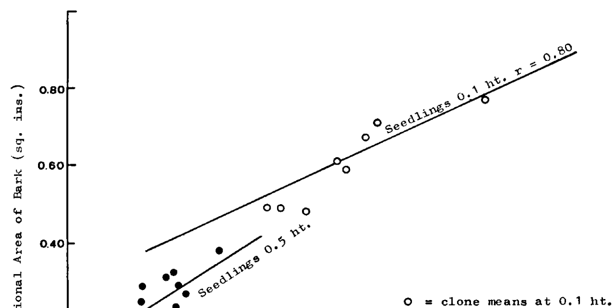

Figure 4. — The bark thickness of cuttings and seedlings in a 4-yr.-old plantation of *Pinus radiata* at Blue Range in the A.C.T. — Means of 8 clones, and regressions of sectional area of bark (sectional area overbark — sectional area underbark) on sectional area underbark of nearby seedlings.

In the 27½-yr.-old plantation *(Figure 8)* the mean bark percentage of the cuttings is definitely less than that of the seedlings at the ½ ft., 5 ft. and 10 ft. levels, but the differences at 15 ft. and 20 ft. are negligible.

The above comparisons show that little or no difference is obvious in the bark thickness of cuttings and seedlings

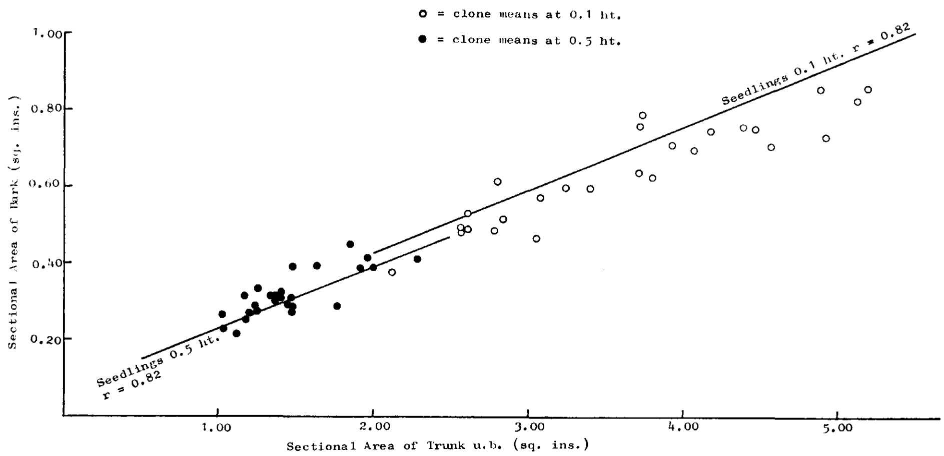

Figure 5. — **The bark thickness of cuttings and seedlings in a 5-yr.-old plantation of *Pinus radiata* at Blue Range in the A.C.T. — Means of 26 clones and regressions of sectional area of bark (section area overbark — sectional area underbark) on sectional area underbark of nearby seedlings.**

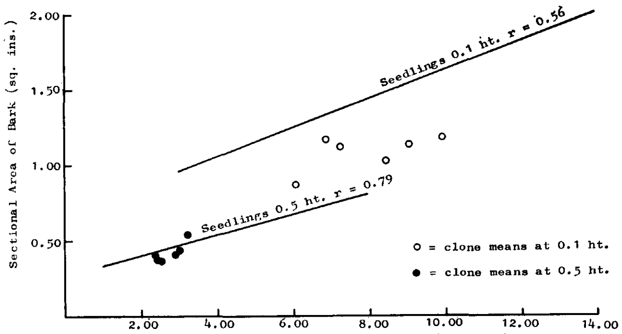

Figure 6. — **The bark thickness of cuttings and seedlings in a 6-yr.-old plantation of *Pinus radiata* at Kowen in the A.C.T. — Means of 6 clones and regressions of sectional area of bark (sectional area overbark — sectional area underbark) on sectional area underbark of nearby seedlings.**

in the 4-yr.-old plantation, but the difference is definite in the 6-yr.-old plantation and very marked in the 16½- and 27½-yr.-old plantations. The bark of the cuttings in these older plantations tends to be much thinner than that of the seedlings up to a height of approximately 10 ft. above the ground.

5. Taper of the trunk

The seedlings were planted at approximately 10 months of age when characteristically thin and willowy, whereas

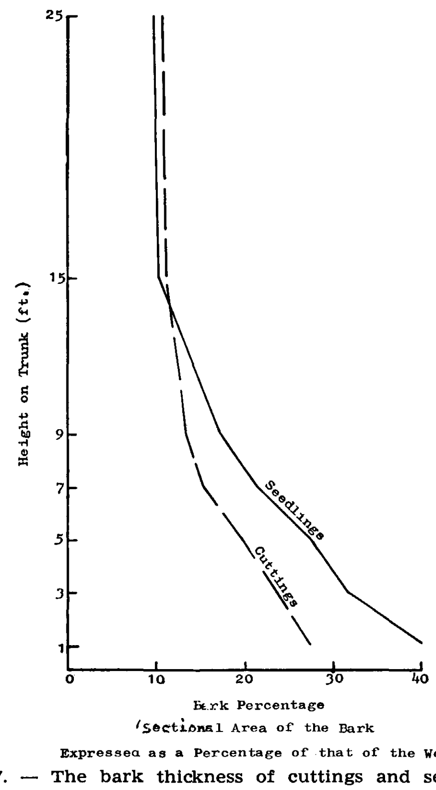

Figure 7. — **The bark thickness of cuttings and seedlings in a 16½-yr.-old plantation of *Pinus radiata* at Blue Range in the A.C.T.**

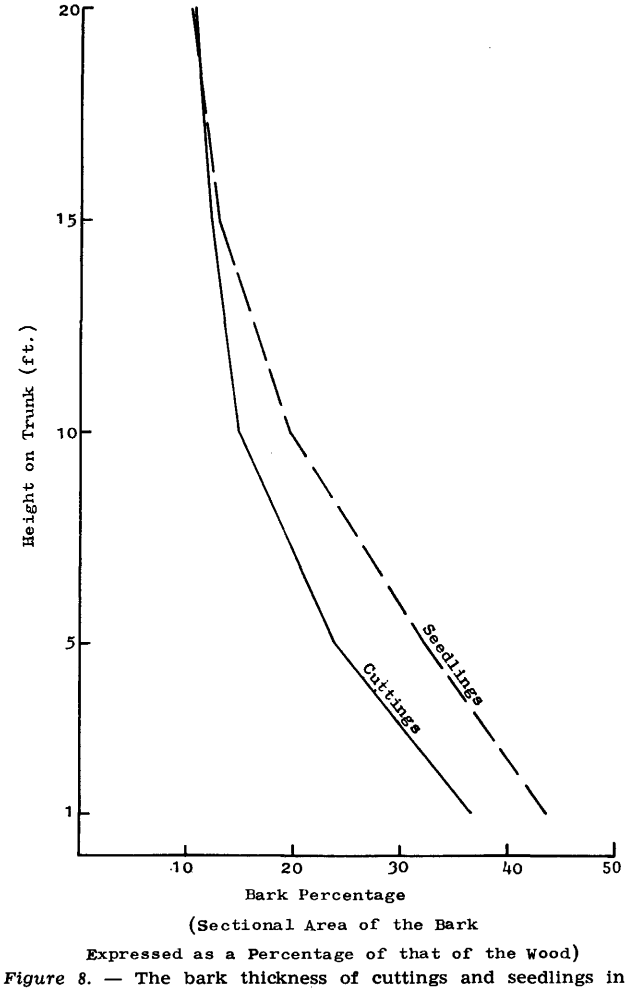

Figure 8. — **The bark thickness of cuttings and seedlings in a 27½-yr.-old plantation of *Pinus radiata* at Blue Range in the A.C.T.**

the shoots collected for cuttings were produced on the parent tree in the spring preceding the autumn in which they were collected; i.e. they were planted approximately 20 months after they were produced on the tree. At the time of planting the stem of a cutting therefore tends to be thick relative to that of the seedling of comparable height.

Ratios of height to diameter at 0.5 height in two young plantations in the A.C.T., in which cuttings and seedlings were planted in randomized tests, are as follows: —

1-Yr.-Old Plantation			2-Yr.-Old Plantation		
Cuttings	Seedlings	Signif. of Difference	Cuttings	Seedlings	Signif. of Difference
49.6	62.9	$P < .01$	57.6	59.8	N.S.

It can be seen that the height : diameter ratio of the cuttings is less than that of the seedlings in the 1-yr.-old plantation, but in the 2-yr.-old plantation the difference is negligible. The mean heights of the cuttings and seedlings were 9.0 in. and 11.0 in. respectively in the 1-yr.-old plantation and 32.0 in. and 33.2 in. respectively in the 2-yr.-old plantation.

In experiments made in the A.C.T., differences in cutting length over the range generally used in a cuttings nursery have not greatly influenced the subsequent rate of height growth of the cuttings. It is therefore postulated that the ht.: diam. ratio would not be substantially affected by the variations in cutting length likely to be used in a nursery.

Studies made in plantations aged between 4 and 27½ years *(Table 1; Figures 9 and 10)* have shown that in these older stands, the cuttings are definitely less tapered than seedlings in the basal part of the trunk.

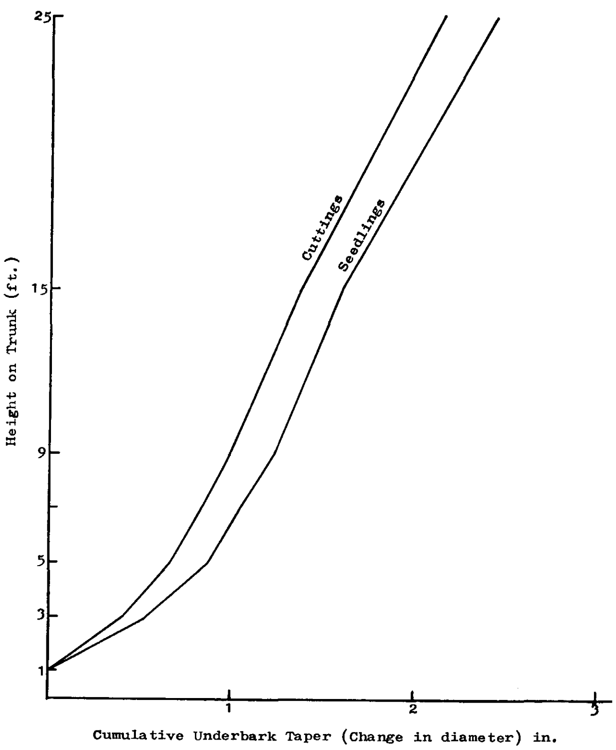

Figure 9. — The cumulative underbark taper of cuttings and seedlings in a 16½-yr.-old plantation of *Pinus radiata* at Blue Range in the A.C.T.

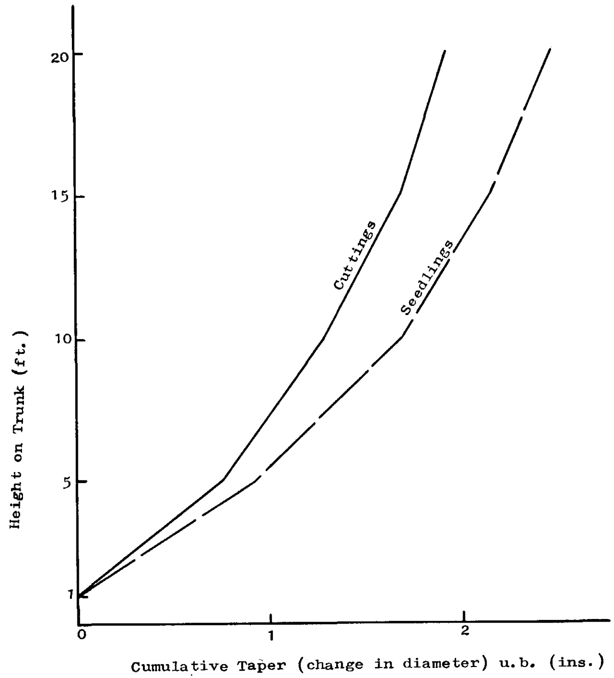

Figure 10. — The cumulative underbark taper of cuttings and seedlings in a 27½-yr.-old plantation of *Pinus radiata* at Blue Range in the A.C.T.

Corresponding data for a 7-yr.-old plantation in which 3 clones of second-propagation cuttings were compared with a neighbouring stand of 22 seedlings are as follows: —

	Cuttings	Seedlings
Taper	0.173	0.256
Ht.-D.B.H. ratio	630	538

The clones had been raised from cuttings collected from 4- and 5-yr.-old clonal plantations, which in turn, had been raised from cuttings collected from 3- and 4-yr.-old seedling plantations.

In the 16½-yr.-old plantation the underbark taper of the cuttings between 1 ft. and 9 ft. above ground is less than that of the seedlings *(Figure 9)*, mean tapers (in. per ft.) being as follows: —

	Ht. above Ground (ft.)					
	1—3	3—5	5—7	7—9	9—15	15—25
Cuttings	0.20	0.13	0.07	0.07	0.06	0.08
Seedlings	0.26	0.16	0.09	0.17	0.06	0.08

A comparison of the underbark tapers between 1 ft. and 9 ft. by diameter classes in this plantation is as follows: —

	Diam. Class (ins. u.b. at 5 ft.)					
	6.5—7.49		7.50—8.49		8.50—9.49	
	Mean	N	Mean	N	Mean	N
Cuttings	0.779	10	0.987	16	1.069	7
Seedlings	0.730	4	1.366	8	1.485	4
Signif. of Diff.	N.S.		$P < .01$		$P < .05$	

In the 27½-yr.-old plantation the underbark taper of the cuttings was found to be less than that of the seedlings

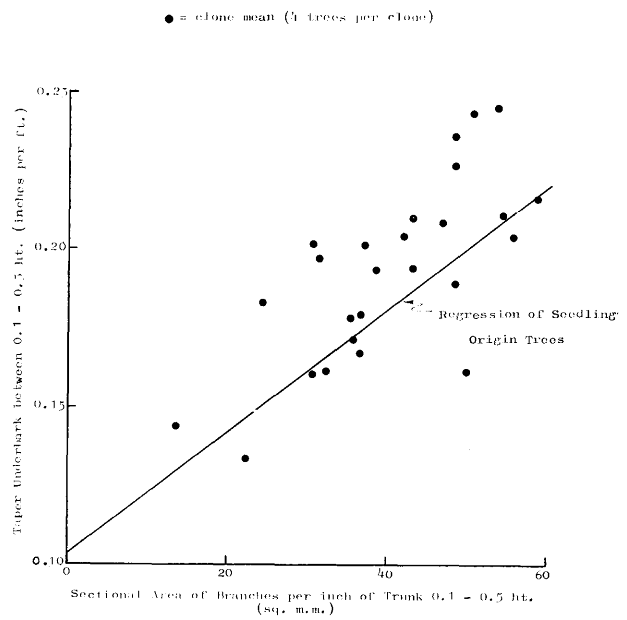

Figure 11. — The relation between the underbark taper of the trunk and the sectional area of the branches in a 5-yr.-old plantation of *Pinus radiata* cuttings and seedlings at Blue Range in the A.C.T. — Means of 26 clones and regressions of underbark taper on sectional area of branches of 33 nearby seedlings. Branches measured overbark in a horizontal direction at the trunk.

over all measured sections of the trunk — up to a height of 20 ft. *(Figure 10).*

The basic reasons for the low taper of cuttings may lie both in their light branching and in changes induced by cyclophysis which result in a tendency for a different distribution of increment in the base of the trunk. The markedly smaller sectional area of branches on the cuttings *(Table 1)* and the fact that the cuttings and seedlings do not differ greatly in the relation between the sectional area of the branches and underbark taper *(Figure 11)* suggest that at least in young plantations, the lighter branching of cuttings may have an important role in causing their lesser taper. However, the low taper of the base of the trunk of the cuttings in the 16½- and 27½-yr.-old plantations suggests that other properties associated with physiological aging may also play a part because the branches on the base of these trees were dead. The mean height of the lowest live branch on the trees in the 27½-yr.-old plantation was approximately 55 ft.

The cuttings of the four younger plantations (4-, 5-, 6- and 16½-yr.-old) were obtained from trees selected for small branches (as well as wide-angled branches, straight trunks, and fast growth rate), but those of the 27½-yr.-old plantation were obtained from trees selected to represent a range of variation in A.C.T. plantations. It is thought that the selection has not influenced the taper of the cuttings to any marked extent.

6. Lean of the trunk

In all stands in which the leans of the trunk of cuttings and seedlings have been compared *(Table 2)* the mean lean of the cuttings was found to be less than that of the seedlings.

Although the comparisons are not based on replicated tests but on rows of cuttings growing alongside rows of seedlings, the consistency of the differences strongly indicate that they are not merely site effects. The cuttings in three of the stands had been raised from seedlings selected for favourable branching, trunk straightness, and vigour, and it is possible that such selection reduced lean. However, the cuttings of the other two stands (7½ and 27½ years old) were not raised from selected seedlings and they also lean much less than comparable seedlings growing next to them. It is concluded that the method of propagation affects the lean of *P. radiata* and that cuttings which have been raised by the methods used in the A.C.T. tend to grow more vertically than seedlings. It is postulated that this tendency of cuttings to grow more vertically than seedlings is an effect of cyclophysis, and possibly related to differences between cuttings and seedlings in apical dominance, crown width, and/or root development (Section 11).

Leaning trunks tend to be crooked. Consequently the greater verticality of cuttings can be expected to be associated with improved trunk straightness.

7. Branching characteristics

Comparisons of branching characteristics are given in *Table 1.*

The cuttings of *Table 1* were raised from trees selected for favourable branching, trunk straightness and vigour. The effect of this selection on the branching differences between cuttings and seedlings is unknown. It has been general experience in the A.C.T. that such selection tends to favour trees with many whorls over those with few whorls. It is thus felt that the more numerous and larger branches on the seedlings reflect the method of propaga-

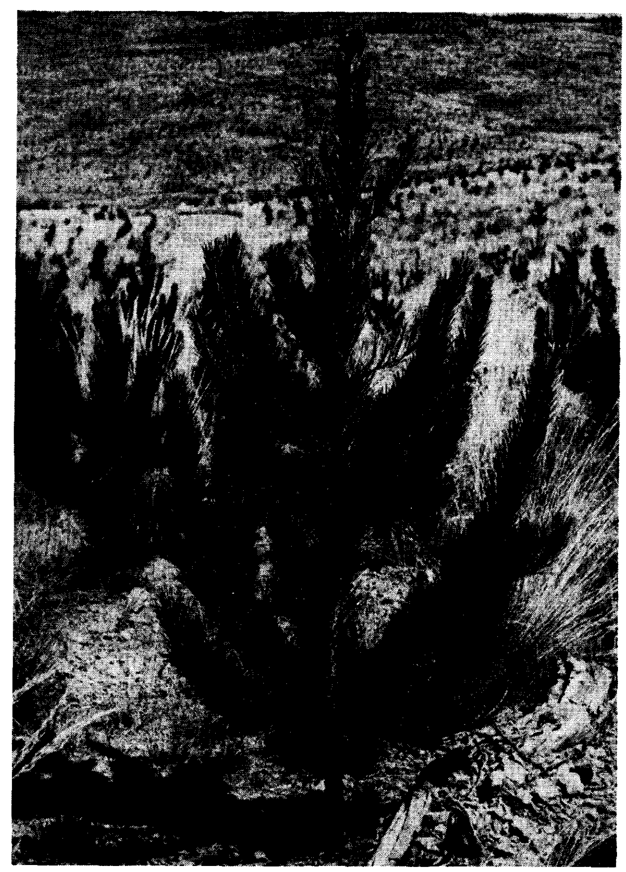

Figure 12. — The open type of crown typical of a young *P. radiata* cutting. The tree, which is in a 3-yr.-old plantation, was raised from a shoot collected from a 4-yr.-old seedling plantation. Compare with the seedlings in *Figure 13.*

Figure 13. — A *P. radiata* seedling growing in the same plantation as the cutting in *Figure 12* and illustrating the denser crown typical of a seedling.

tion. It must be realized, however, that the comparisons are not replicated tests.

In general, the crowns of young seedlings are considerably denser than those of young cuttings *(Figures 12 and 13)*.

8. Flowering characteristics

Cuttings tend to produce female flowers at an early plantation age and trunk cones tend to be prevalent on the lower part of the trunk.

The numbers of trees bearing conelets or cones were assessed in the 5-yr.-old plantation of *Table 1*, when this plantation was 5½ years of age. The results are as follows: —

	Cuttings	Seedlings
Percentage of the trees with conelets or cones	35	9
Mean No. of conelets or cones per tree	1.12	0.21

Nineteen of the 26 clones bore conelets or cones.

A similar assessment in the 6-yr.-old plantation of *Table 1* when this plantation was 6½ years of age gave the following results: —

	Cuttings	Seedlings
Percentage of the trees with conelets or cones	83	56
Mean No. of conelets or cones per tree	8.00	5.17

All 6 clones bore conelets or cones.

The results of an assessment of flowering in a test of cuttings and seedlings in a 2½-yr.-old plantation, in which plots of 25 (5 × 5) trees were planted in 4 randomized blocks, are as follows: —

Treatment	Total No. of Female Flowers on the Trees
Seedlings (tubed stock)	0
Seedlings (open-root stock)	0
First-propagation cuttings	0
Second-propagation cuttings of clone, a	11
Second-propagation cuttings of clone, b	1
Second-propagation cuttings of clone, c	10
Second-propagation cuttings of clone, d	1
Second-propagation cuttings of clone, e	7

The first-propagation cuttings were raised from 20 seedlings in a 3-yr.-old plantation. The second-propagation cuttings were raised from a 3-yr.-old plantation of first-propagation cuttings, which, in turn, were raised from a 4-yr.-old seedling plantation. Although the results refer to flowering in a very young plantation, the greater flowering of the second-propagation cuttings suggests the possibility that such second-propagation cuttings are of greater physiological age with respect to flowering than are the first-propagation cuttings.

9. The buds and foliage of cuttings and seedlings

Cuttings and seedlings in young plantations differ markedly in their buds. The first buds produced by young seedlings are simply clusters of green primary leaves. As the seedlings age, these "juvenile" buds are gradually replaced by the resinous buds typical of older trees. By the age of five years, all (or almost all) the buds are generally of the mature type.

The buds of young cuttings raised from young seedlings with mature buds do not show a marked reversion to the juvenile type. Buds showing green primary leaves are not common on cuttings: even on cuttings in 1-yr.-old plantations the buds are generally all of the mature type.

The development of fascicle shoots on the stem is much more common on young seedlings *(Figure 14)* than on young cuttings and may add considerably to the amount of foliage on the seedlings.

The appearance of the foliage of *P. radiata* changes greatly with age. Also the foliage of young seedlings and young cuttings differs in appearance and it is not to be unexpected that there are considerable anatomical differences between their needles — as has been found for different aged trees of other pines (Helmers, 1943; White and Beale, 1963). Here is a likely field of fruitful research.

10. Browsing damage to cuttings and seedlings

In the A.C.T., the foliage of young *P. radiata* cuttings has been found by general experience to suffer greater browsing damage than that of young seedlings: it seems that sheep, rabbits and native animals all prefer the foliage of cuttings, and grasshoppers also seem to prefer young cuttings to young seedlings. Pawsey (1951) reported that sheep and rabbits browse cuttings more severely than seedlings in South Australia.

The evidently greater palatability of the foliage of young cuttings is shown by the results of an assessment of attack in an unfenced 1½-yr.-old plantation at Gibraltar Ck. in the A.C.T. The assessment covered 8 replicated tests each of which included seedlings and cuttings raised from young trees. The damage to most of the trees was only slight, being merely the browsing of some needles, but the buds of occasional trees had been chewed. The number of

Figure 14. — Fascicle shoots at the base of a *P. radiata* seedling in a 3-yr.-old plantation — a common feature of young seedlings but rather rare on cuttings.

trees attacked in each of 31 seedling plots and 31 neigbouring plots of cuttings were recorded. The mean number of trees per plot attacked were: cuttings, 65.1 per cent: seedlings, 27.9 per cent. The difference is highly significant. It is not known which animals were responsible for this browsing but it is thought that wallabies, kangaroos and possibly rabbits may have caused it. Wombats and brumbies (wild horses) are also to be found on the area and may possibly browse pines. Professor W. J. Libby (personal communication) has found in California that *P. radiata* seedlings are browsed more severely than cuttings — the reverse of Australian experience.

11. Root systems of cuttings and seedlings

Studies in the A.C.T. have shown that the root systems of cuttings and seedlings differ to some extent: the differences appear to develop at an early age in the plantations and persist for many years.

Root dissections have been practicable on only a small number of cuttings and seedlings, but the limited data available from such dissections suggest that cuttings, at least during the first few years in the plantation, tend to have thicker roots and a smaller top-root ratio than seedlings. Such a difference is not incompatible with what might be expected as a result of physiological aging. A high top-root ratio could conceivably be an adaptation of young seedlings resulting from natural selection for fast rate of top growth as compared with rate of root growth — a characteristic which might have value in overtopping and suppressing neighbouring seedlings in young stands.

Root dissections in a 2½-yr.-old experimental plantation of seedlings and cuttings at Kowen in the A.C.T. showed that the dry weight of the roots of the cuttings was considerably greater than that of the seedlings, although the differences were not significant at $P < .05$. The experiment comprised 3 treatments (open-root 10-month-old seedlings, tubed 10-month-old seedlings, and tubed cuttings raised from shoots taken 12 months previously from seedlings in a 4-yr.-old plantation) replicated in 4 randomized blocks, with unit plots of 25 plants. The roots of one tree were excavated in each plot, the comparisons therefore being based on 4-tree averages. All roots to a distance of 4 ft. from the stem were carefully dug up. The results of the work are summarized as follows: —

	Mean Diam. o.b. of tree at Ground Level	Mean Oven-Dry Wt. of Roots
Open-root seedlings	26 mm	30.9 gm
Tubed seedlings	30 mm	48.5 gm
Tubed cuttings	29 mm	71.6 gm
Diff. for signif. $P < .05$		43.5 gm

Measurements of the roots in the upper zone of the soil of five older stands have shown that the cuttings in these stands tend to have fewer roots near the soil surface than do seedlings — in other words, in the upper zone of the soil, the roots of cuttings tend to be slightly deeper than those of seedlings *(Table 3).*

Further comparisons of the root systems of cuttings and seedlings are planned as material becomes available. Also, the growth of the root systems of cuttings and seedlings is being recorded in current A.C.T. work in order to study the possible development of such differences.

12. The rate of growth of cuttings and seedlings

The height differences between the cuttings and seedlings stands that have been compared in the A.C.T. are not large *(Table 1).*

Two replicated tests including cuttings and seedlings were planted in 1964: at 2 years of age the differences between the mean heights of cuttings and seedlings were not significant. The first test comprised 8 treatments — tubed

Table 3. — The Root Systems of Cuttings and Seedlings of *P. radiata* in the Surface 10 inches of Soil in Various A.C.T. Plantations.

	Plantation age (years)	Depth of Root Zone*) Surface — 2 in.		2 in. — 6 in.		6 in. — 10 in.	
		Cuttings	Seedling	Cuttings	Seedling	Cuttings	Seedling
Mean No.	6½	1.12	1.50	6.74	8.50	2.37	1.50
Roots per	7½	0.67	1.89	2.99	4.00	1.44	1.77
Tree**)	15½	1.64	2.58	3.86	6.58	1.57	0.83
	27½	0.91	3.09	3.54	6.34	4.28	3.91
Mean Sectional Area of	6½	1.30	1.58	7.28	7.93	1.80	1.45
Roots	7½	0.85	3.67	10.19	9.56	4.97	2.68
per Tree	15½	6.81	23.76	21.89	25.18	3.44	1.66
(sq. in.)	27½	10.86	41.70	51.19	47.99	41.31	23.01

*) Measurements made at 1 ft. from the trunk in a horizontal direction. The "Surface — 2 in." zone includes the roots showing at the soil surface and those the tops of which are not deeper than 2 in. below the surface. The "2 in. — 6 in." zone includes those roots the tops of which lie below a depth of 2 in. but not deeper than 6 in., and the "6 in. — 10 in." zone, roots the tops of which lie below 6 in. but not deeper than 10 in. In the 6½- and 7½-yr.-old plantations. roots less than ½-inch diameter were disregarded: in the other 3 plantations, roots less than 1-inch diameter were disregarded.

**) Means are based on the following numbers of trees: —
6½-yr.-old plantation — 8 pairs of cuttings and seedlings.
7½-yr.-old plantation — 9 pairs of cuttings and seedlings.
27½-yr.-old plantation — 11 pairs of cuttings and seedlings.
15½-yr.-old plantation — 14 cuttings and 12 seedlings.

seedlings, open-root seedlings, cuttings taken from seedlings in a 3-yr.-old plantation and cuttings taken from five different clones of first-propagation cuttings in a 3-yr.-old plantation. The test was laid out in four randomized blocks with unit plots of 25 trees. Mean heights in 1966 were as follows: —

seedlings 25.9 inches;

cuttings taken from seedlings 24.9 inches;

cuttings taken from first-propagation cuttings 26.6 inches.

The second test comprised three treatments (tubed seedlings, open-root seedlings and cuttings taken from trees in a 4-yr.-old seedling plantation) laid out in four randomized blocks with unit plots of 25 trees. Mean heights at 2 years of age were: —

Open-root seedlings	32.4 inches;
tubed seedlings	29.6 inches;
cuttings	33.4 inches.

No replicated tests including both cuttings and seedlings were planted in the A.C.T. before 1964, and consequently sound comparisons of the rate of growth of cuttings and seedlings in older plantations are not practicable. The rate of growth during the first few years in the plantation is influenced to a considerable extent by the physiological age of the rooted cuttings used as planting stock. Cuttings taken from seedlings over 15 years old have grown slowly during the first few years in A.C.T. plantations. Such effects have been the general experience in the A.C.T., and they have been reported for cuttings of *P. radiata* in South Africa (Sherry, 1947). However, the results of the above replicated tests in 2-yr.-old plantations and comparisons made in older plantations in the A.C.T. show that except for cuttings taken from old trees the rate of growth of well-rooted, healthy cuttings compares favourably with that of seedlings.

The oldest measured cuttings were up to 118 ft. in height at 28 years of age, and were similar in height to neighbouring seedlings.

It can be concluded that, except for cuttings taken from old trees, the method of propagation itself (by cuttings or by seed) does not strongly influence growth rate. However, clones vary greatly in their rate of growth and it can be expected that high-yielding clones can be developed by selection.

Summary

In the A.C.T. rooted cuttings of *P. radiata* have been planted on an experimental scale almost annually since 1938. This paper compares various characteristics of trees raised by cuttings taken from young seedlings with the characteristics of seedlings.

Only in recent years have the cuttings and seedlings been planted together in randomized tests. Consequently, almost all the comparisons are unreplicated: they are between cuttings and seedlings of the same age growing close together, and any effects of site differences cannot be evaluated. However, the consistency of the differences indicate that they are expressions of real differences between cuttings and seedlings.

It is considered that the differences are basically effects of cyclophysis — a carryover into the rooted cutting of properties associated with the age of the parent tree or the developmental stage of the shoot.

The cuttings compared with seedlings in this paper were raised from seedling trees less than 8 years old. These cuttings were found to differ from seedlings as follows: —

(a) The cuttings tend to have thin bark at the base of the trunk. Although there was little or no difference in bark thickness in a 4-yr.-old plantation, a definite difference was found in plantations aged 6 years and older. In the oldest plantation studied (27½ years old), the cuttings tended to have markedly thinner bark than the seedlings up to a height of approximately 10 feet from the ground.

(b) The cuttings tend to have low taper over the lower part of the trunk. In all plantations aged 4 years and older (up to 27½ years) that were studied, the mean underbark taper of the cuttings in the lower part of the trunk was considerably less than that of the seedlings. The lighter branching of the cuttings and the fact that the cuttings and seedlings of three young stands studied did not differ greatly in the relation between the sectional area of the branches and under-bark taper between 0.1 and 0.5 height suggest that the low taper of cuttings (at least in young plantations) is due largely to their light branching. However, the low taper of the base of the trunk of older cuttings, on which all basal branches are dead, suggests that other properties associated with cyclophysis may be also involved.

(c) The cuttings tend to grow more vertically than the seedlings.

(d) Although it has not been practicable to make a thorough comparison of the root systems of cuttings and seedlings the limited work that has been done suggests that the root systems of cuttings and seedlings differ to some extent. In two young plantations (less than 3 years old), the cuttings were found to have thicker roots and a greater weight of roots than the seedlings. In an assessment of the lateral roots in the surface 10 inches of soil in plantations ranging in age from 6½ to 27½ years, the lateral roots of the cuttings tended to be somewhat deeper than those of the seedlings.

(e) Branch measurements were made in 4-, 5- and 6-yr.-old plantations. In these stands the cuttings tended to have fewer branches and a smaller sectional area of branches per unit length of trunk than the seedlings. The cuttings had been raised from trees selected for favourable branching characters but there is no known reason for expecting fewer branches per unit length of trunk as a result of such selection.

(f) The crowns of cuttings in young plantations tend to be less dense than those of seedlings.

(g) The cuttings, as expected, tend to start producing ovulate strobili sooner than the seedlings.

(h) The foliage of young cuttings differs from that of young seedlings. The cuttings tend to have "mature" buds even in plantations only one year old whereas the buds of seedlings are mainly "juvenile" in plantations up to about 4 years old. The development of fascicle shoots on the stem is much more common on young seedlings than in young plantations of cuttings.

(i) The foliage of cuttings has tended to suffer more browsing damage than that of seedlings.

(j) Except for cuttings taken from old trees, no evidence has been found that the method of propagation itself (by cuttings or by seed) has strongly influenced the growth rate of plantations. Cuttings taken from seedlings over 15 years old have grown slowly during the first few years.

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