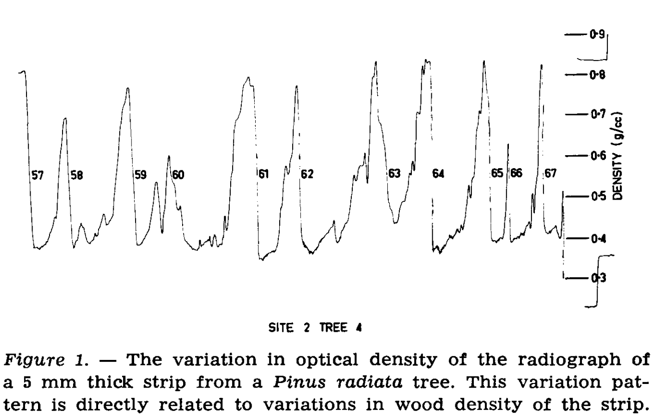
Table 1. — Monthly totals of precipitation and "effective rainfall" during the estimated growing seasons of *P. radiata* at Mt. Crawford from 1957 to 1967.

Growth period	Estimated date of commencement	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Estimated date of cessation	Seasonal total
						Precipitation (mm)							
1957/58	Sept. 20	7.0	50.0	36.0	6.5	1.0	9.0	34.5	13.0	189.5		May 30	346.5
1958/59	Sept. 1	92.0	116.0	18.0	25.0	4.0	49.0	60.5	2.5	17.0	’	May 30	384.0
1959/60	Sept. 22	18.0	60.0	14.5	66.5	6.5	62.5	29.5	105.0	102.0		May 8	464.5
1960/61	Sept. 1	147.0	24.5	43.5	3.5	8.5	20.0	6.5	137.0	20.0	88.0	June 19	498.5
1961/62	Sept. 13	16.0	19.5	43.5	23.0	39.5	9.0	31.5	2.5	154.0	35.5	June 7	374.0
1962/63	Sept. 11	28.5	139.5	22.0	31.5	55.0	6.5	1.0	84.0	99.0	137.5	June 5	604.5
1963/64	Sept. 11	38.0	18.0	13.0	2.5	16.0	13.5	4.0	41.5	40.5	106.5	June 30	293.5
1964/65	Oct. 1		94.0	65.0	18.5	0.5	Nil	10.0	38.5	106.5		May 30	333.0
1965/66	Sept. 12	29.5	16.5	47.5	37.5	18.5	22.5	34.0	12.0	69.5		May 30	287.5
1966/67	Oct. 3		32.0	34.0	117.0	25.0	40.0	8.0	4.0	55.5	7.5	June 12	323.0
						Effective rainfall (mm)							
1957/58	Sept. 20	6.0	18.5	24.5	—	—	—	20.0	9.5	96.5	—	May 30	175.0
1958/59	Sept. 1	68.0	83.5	—	—	—	29.0	46.5	—	16.5	—	May 30	243.5
1959/60	Sept. 22	13.0	43.5	—	26.5	—	17.5	16.0	57.5	42.0	—	May 8	216.0
1960/61	Sept. 1	107.5	12.0	13.0	—	—	—	—	85.5	8.5	47.0	June 19	273.5
1961/62	Sept. 13	14.5	6.5	8.0	4.5	11.5	—	13.5	—	82.0	23.5	June 7	164.0
1962/63	Sept. 11	19.0	95.5	—	20.0	17.5	—	—	36.0	67.5	28.0	June 5	283.5
1963/64	Sept. 11	34.0	16.5	—	—	—	—’	—	24.5	34.5	78.5	June 30	188.0
1964/65	Oct. 1		69.0	30.0	—	—	—	—	30.0	84.0		May 30	213.0
1965/66	Sept. 12	27.5	9.0	26.5	18.0	—	14.5	18.0	—	43.5		May 30	157.0
1966/67	Oct. 3		23.0	14.5	51.5	13.5	29.0	—	—	37.5	6.0	June 12	175.0

Wood characteristics were determined for each growth ring from the 1957/58 growing season onwards as follows:

(a) Average tracheid length: A strip from the late wood was macerated and 50 whole tracheids were taken at random and measured at 40 magnifications using a projection microscope.

(b) Ring width and density characteristics: The 6 mm radial strips were allowed to dry over a saturated solution of sodium dichromate to an equilibrium moisture content of approximately 10 per cent., and a precision sanding machine was used to convert them to a finished size of 5.00 ± .05 mm. Using the technique of Polge (1965), contact radiograms of these strips were obtained and scanned by means of a double beam microdensitometer. The resulting continuous traces could be calibrated in terms of wood density (see example in *Figure 1*). Individual growth rings were identified and marked on the traces for each tree. For each annual ring, the maximum and minimum excursions of density, the width of the ring components for which density values were less than 0.5 g/cc and greater than 0.6 g/cc, respectively, and the width of the ring were read directly from the curves. The area contained between a line parallel to the abscissa and the curve was obtained and used to calculate the mean density for each growth



SITE 2 TREE 4

Figure 1. — The variation in optical density of the radiograph of a 5 mm thick strip from a *Pinus radiata* tree. This variation pattern is directly related to variations in wood density of the strip. A linear scale of wood density is shown and is positioned by means of calibrating marks. The dormant period which occurs during July and August is a convenient position to mark the successive years of growth.

ring. As the experiment involved only wood formed from 1957 onward, i. e. wood outside the seventh growth ring from the pith in the case of the youngest plantation, and thus not subject to heartwood formation (Nicholls and Dadswell, 1965), it was deemed unnecessary to treat specimens to remove resinous infiltrates.

4. Results and discussion

The observations of Fielding and Millett (1941) have shown that the temperature above which cambial activity takes place in *Pinus radiata* is close to the 8° C proposed by MacDougal (1921). Lindsay (1929) estimated that this corresponds to a mean air temperature of 10—13° C in spring but he was not certain of the air temperature at which growth ceases in autumn. In the present study estimates were based on mean air temperatures of 9.5—10.5° C for the commencement of growth in the spring and 8.5—9.5° C for the autumnal cessation. These temperatures are associated with a nominal growth period from September 15 to June 5 varying by ±25 days in individual years (see *Table 1).*

Shepherd (1965) reviewed the evidence relating growth and environment and concluded that *P. radiata* possesses "a correlation system which is particularly sensitive to prevailing environmental conditions". He supported the findings of Millett (1944 a) that rainfall was the most important single meteorological factor influencing growth. Skene (1969) observed that the response in diameter growth to rain in this species is almost immediate. Therefore an attempt was made to relate rainfall to the incremental growth recorded on the continuous densitometric records.

Efforts to establish such relationships are complicated by several factors. Only a proportion of the recorded rainfall reaches the forest floor and a portion of this is lost as run-off, the amount varying according to surface slope, soil type and moisture content, and intensity of rainfall. Evaporation losses within a forest are less than, and variously related to the published values obtained outside the stand (Millett, 1944 b); transpiration losses are variable and considerably reduced when the crowns are wet, and *P. radiata*

Table 2. — Linear regression equations relating mean ring width (y) (mm) of *Pinus radiata* trees and rainfall (x) (mm) at Mt. Crawford during the period 1957 to 1967.

Site	Tree group	Rainfall data	Regression equation	r^2
1	Control	"Effective" rainfall	$y = 0.00767^{*}x + 0.139$	0.462
	Fertilized	"Effective" rainfall	$y = 0.0143^{*}x - 0.448$	0.533
2	Control	Seasonal precipitation	$y = 0.00757^{NS}x + 0.508$	0.373
	Control	"Effective" rainfall	$y = 0.0253^{**}x - 1.818$	0.853
3	Control	"Effective" rainfall	$y = 0.00155^{NS}x + 0.216$	0.346
	Fertilized	"Effective" rainfall	$y = 0.00285^{NS}x + 0.817$	0.0903

NS not significant
* significant at 5 per cent. level
** significant at 1 per cent. level

foliage has the ability to absorb water from the atmosphere (Johnston, 1964).

Data from contemporaneously formed rings were grouped and treatment means were calculated for each of the features under review.

For the control trees from site 2 the relationship between ring width and precipitation during the estimated growing season is illustrated in *Figure 2*. In the same figure an improved association is depicted based on "effective rainfall", (see *table 1)* i. e. the value obtained from the daily precipitation data by ignoring small, isolated falls of rain, limiting the acceptable amount of rain in any 24 hour interval and making an allowance for evaporation only after recorded periods of rain. Linear regressions were calculated for the appropriate non-irrigated tree groups from the three sites and are set out in *Table 2*. It was considered that the use of "effective rainfall" provided good estimates of the monthly rainfall totals which contributed to the annual increments of the non-irrigated trees, and could therefore be used in the interpretation of the densitometric records. It is interesting to note that the effective rainfall figures represent less than one third of the total annual precipitation and one half the precipitation during the growing season.

Figure 3 has been prepared to show the influence of supplementary watering and fertilizer treatment on ring width. Although at site 1 the ring widths of the trees receiving fertilizer in 1953 were consistently greater than those of the control trees, it cannot be stated within the period under review, whether this superiority is due to the fertilizer, or the result of inherent differences between the two groups of trees. For this site therefore only two compound groups were distinguished viz. irrigated and non-irrigated trees.

From *figure 3* it can be seen that the response to supplementary watering at site 1 is immediate, and results in an increase in ring width of some 80 per cent. other than in the growth period for 1966/67. It is noticeable that the pattern of growth in the irrigated trees follows the annual variation in rainfall (see *Table 1)*, which is some indication of the part played by atmospheric conditions in the overall growth response. This was noted by Fielding and Millett (1941) and is further illustrated by the reduced growth of the irrigated trees during 1966/67. Millett (1944 a) has pointed out that however great the precipitation there is little growth of *P. radiata* at Canberra during January and February because of high temperatures and evaporation. These two months are also the hottest and driest months at Mt. Crawford and therefore here too growth would tend to be inhibited. The most marked effect of the irrigation regime during the 1966/67 season would thus be expected in December, March, and April. However December 1966 was unique in that 117 mm of rain were recorded (see *Table 1)*. and this in conjunction with the 102 mm of sup-

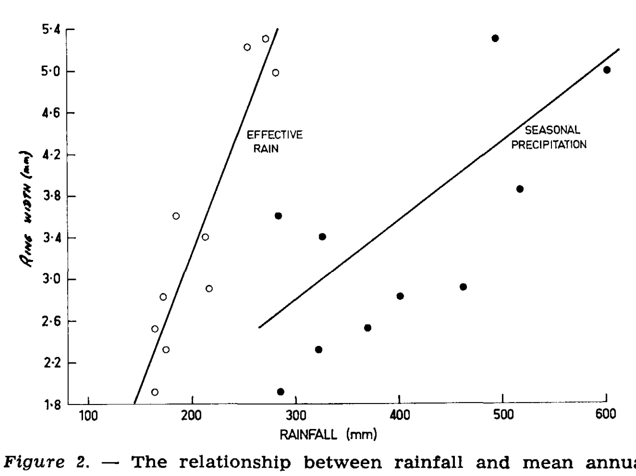


Figure 2. — The relationship between rainfall and mean annual increment for three *Pinus radiata* trees from site 2 at Mt. Crawford.

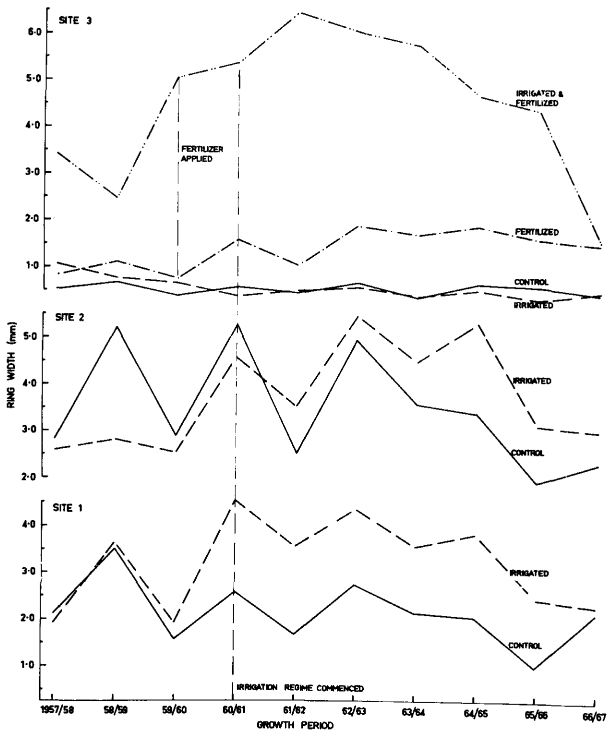


Figure 3. — The mean variation in ring width from 1957 to 1967 for groups of *Pinus radiata* trees grown on three sites at Mt. Crawford showing the influence of irrigation and fertilizer treatment.

plementary water has presumably produced an overwet soil condition which is not optimum for growth (KOZLOWSKI, 1958). Furthermore, during March and April only 12 mm of precipitation were recorded. Thus virtually no advantage was gained in the irrigated trees during the 1966/67 growth period.

The irrigated trees at site 2 did not exhibit superior ring widths until the second year of the watering regime and improvements were less than those recorded at site 1. This lessened response compared to site 1 may be due to the greater age of the trees at site 2 or may be associated with edaphic factors.

An inspection of the variation patterns for the trees at site 3 shows that the control trees are suppressed. Although there is a tendency to follow the rise and fall of annual rainfall (see *Table 1*) the response is minute. Supplementary water has no effect on the annual increment of the irrigated group of trees. The application of superphosphate to the fertilized group during the latter half of 1959 did not produce a response during the 1959/60 growing season, but significant and sustained improvements in growth were subsequently recorded confirming that nutrient levels had been a limiting factor. It is interesting to note that mineral nutrition influences root growth and in nutritionally poor stands an increase in stem growth requires enlargement of the root system (LYR and HOFFMAN, 1967). Judged on the growth rate prior to any differential treatment at this site, viz. during the 1957/58 and 1958/59 seasons, the trees receiving both fertilizer and supplementary water are inherently more vigorous or enjoy a more favourable micro-environment than the other groups at site 3. These trees showed an immediate and dramatic response to fertilizer treatment and a further improvement in diameter response when supplementary watering commenced. As before this response was not maintained during the 1966/67 growing season.

It is also of interest to ascertain separately the influence of irrigation on the early wood and the late wood components of the annual increment. Great difficulties are encountered in defining the position of the early wood — late wood boundary where the change from thin-walled to thick-walled cells is not abrupt (see *Figure 1*). POLGE and KELLER (1968) have avoided this difficulty by proposing a series of density levels and considering the amount of the ring with density greater than and less than each level in turn. In the present study two such levels were chosen and the portion of the ring with density less than 0.5 g/cc and that with density greater than 0.6 g/cc were separately investigated corresponding to "early" and "late" wood respectively. It can be seen however from *Figure 1* that if the excursions of minimum density rise or fall, a lesser or greater amount of the ring will be included in the component with density less than 0.5 g/cc. Thus it is necessary to take account of this point and refer to *Figure 4* (minimum density patterns) when using *Table 1* to interpret the variation in the amount of "early wood" in terms of rainfall data. Similar arguments apply to the other ring component which has been considered (see *Figure 7* depicting maximum density).

The influence of irrigation and fertilizer treatment on the production of "early" wood at the three sites is illustrated in *Figure 5*. For the trees from site 1 an immediate response to supplementary watering is apparent at the inception of the irrigation regime in the 1960/61 growing season. It is tempting to explain the progressive diminution in apparent gain in the amount of "early" wood

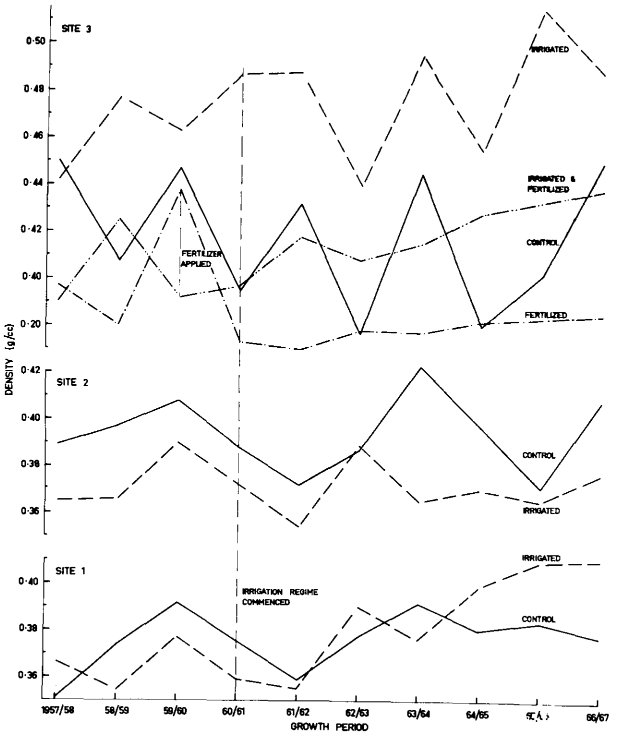


Figure 4. — The variation in minimum density from 1957 to 1967 for groups of *Pinus radiata* from three sites et Mt. Crawford showing the influence of irrigation and fertilizer treatment.

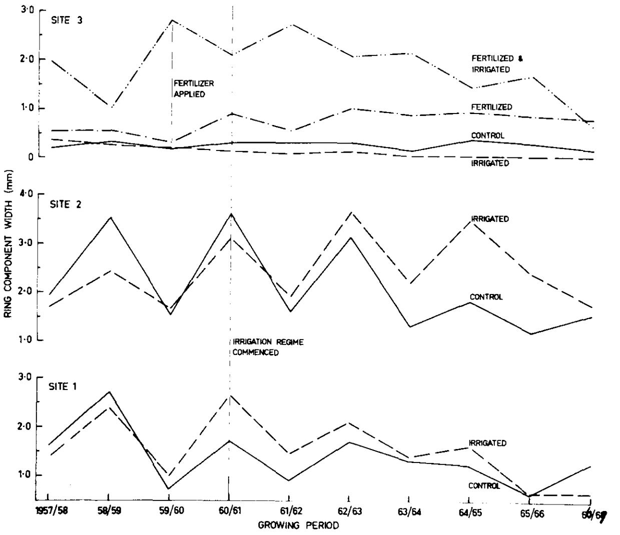


Figure 5. — The variation in the width of the ring component with density less than 0.5 g/cc from 1957 to 1967 for groups of *Pinus radiata* from sites at Mt. Crawford showing influence of irrigation and fertilizer treatment.

for the irrigated trees compared to the control trees in terms of the patterns of variation in minimum density for the two groups. However such an explanation can readily be disproved. If instead of a fixed density level such as 0.5 g/cc a value of say 0.125 g/cc greater than the minimum is chosen to define wood laid down in the early months of each growing season, the amount of "early" wood is independent of the actual value of the minimum density. Such a convention is more tedious to use than that of a fixed density level, and in the case of the trees from site 1 did not produce any sensible departure from the patterns depicted in *Figure 5*. In general the formation of "early" wood takes place from the beginning of the growth season until approximately December and therefore only a fraction of the benefit accruing from the irrigation programme will be apparent in considerations of this phase of the annual increment. Furthermore the fraction will be a variable one depending on the distribution of rainfall in the particular growing season. For example from *Table 1* it is apparent that the "early" wood season is not likely to include December in the 1963/64 growth period and thus little benefit will be apparent as a result of supplementary watering, whereas an increased soil moisture content during December 1961/62 could be expected to produce some response. The improvement in response as a result of irrigation is seen to be greater at site 2 than at site 1 from 1963 onwards. This may be associated with differences in water storage capacity between sites which influence the significance of rainfall in controlling growth, (SHEPHERD, 1965). The trees at site 2 are 25 years older than those at site 1 and this may also be a factor, in the same way that increased dominance within a stand has been shown to decrease the significance of rainfall in favour of soil moisture as a growth controlling factor (SHEPHERD, 1965). There was no response to irrigation in this ring component for the unfertilized trees at site 3 which is not unexpected in view of the previous discussion relative to ring width.

The variation patterns shown in *Figure 6* feature the portion of the annual ring with density greater than 0.6 g/cc and this is in general formed at a time when a considerable effect could be derived from the irrigation programme. This effect might be immediate or might only be felt as a pretreatment whereby the soil moisture content was able to be maintained at such a level that the root systems were more responsive to the onset of autumnal rains.

From *Figure 6* and *Table 1* it can be seen that there is a good relationship between effective rainfall and width of "late" wood for the control trees at site 2, but the non-irrigated trees at sites 1 and 3 do not show any real reaction to variations in rainfall. The response to supplementary watering for the trees from site 1 is more marked for

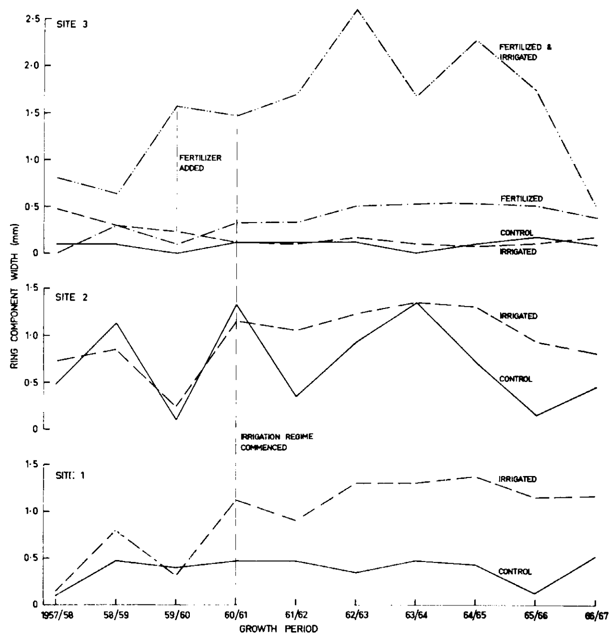


Figure 6. — The variation in the width of the ring component with density greater than 0.6 g/cc from 1957 to 1967 for groups of *Pinus radiata* from three sites at Mt. Crawford showing the influence of irrigation and fertilizer treatment.

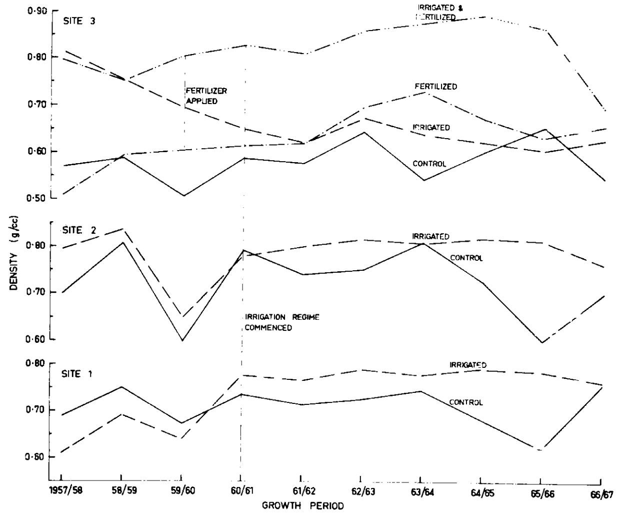


Figure 7. — The variation in maximum density from 1957 to 1967 for groups of *Pinus radiata* from three sites at Mt. Crawford showing the influence of irrigation and fertilizer treatment.

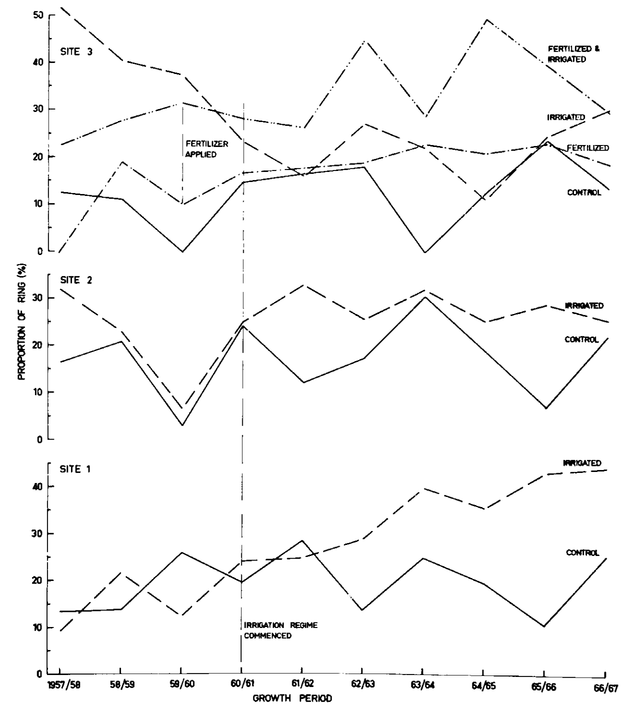


Figure 8. — The variation in the proportion of the ring width greater than 0.6 g/cc from 1957 to 1967 for groups of *Pinus radiata* from three sites at Mt. Crawford showing the influence of irrigation and fertilizer treatment.

the "late" wood than for the "early" wood component. Furthermore there is no reduction in this response during the 1966/67 growth period. Sizeable improvements following irrigation are also apparent in the trees from sites 2 and 3. The responsiveness of the control trees at site 2 to the heavy autumnal rains which were a feature of the 1963/64 season has minimized the gain shown by the irrigated trees at that time. It may be noted from *Figure 7* that the 1963/64 season also exhibited a noteworthy peak in maximum density for the control trees at site 2. The pattern of variation for the irrigated trees from sites 1 and 2 is generally unchanging and is in contrast to the profile for the trees from site 3 which received both irrigation and fertilizer treatment. The latter shows an increase in "late" wood width during the 1962/63 and 1964/65 seasons and a sharp decline in the 1966/67 period. This sharp decline may be associated with a similar decline in the maximum density depicted in *Figure 7*. As there were good autumnal rains from 1963 to 1965 there is no apparent reason for the outstanding response during 1962/63 and 1964/65 and the poor reaction during the 1963/64 season.

If the incidence of "late wood" is expressed as a proportion of the annual increment — the equivalent of the traditional percentage late wood — the profiles shown in *Figure 8* are produced. It can be seen that in terms of this factor the effect of irrigation is to increase the proportion of late wood for the trees at sites 1 and 2 and for the fertilized trees at site 3. These findings are in agreement with other workers in this field (see for example, Paul and Marts, 1954 and Howe, 1968).

Little has been reported on the relationship between environmental factors and the excursions of minimum and maximum density. Wood density is a complex characteristic and in conifers mainly reflects variations in tracheid diameter and wall thickness. These two characteristics are controlled by independent physiological processes although they may vary simultaneously (Larson, 1963). Therefore the above relationships may not be attributable to single environmental factors. Polge and Keller (1968) have suggested that there is an inverse relationship, between minimum density and rainfall at the beginning of the growing season, and between maximum density and rainfall prior to the production of late wood. An inspection of the variation patterns for minimum density *(Figure 4)* in the present study shows a similarity between profiles for the groups from site 1 and 2 suggesting that a common factor could influence values for this parameter. Although a relationship could not be established involving rainfall, a linear regression was calculated expressing the mean minimum density (y) (g/cc) for the trees from sites 1 and 2 in terms of the average mean temperature (x) (^{0} C) for August and September such that.

$y = 0.0137\,x^{*} + 0.2578$ (S. E. of regression coefficient = 0.0044). Deviations from this average relationship may occur because of temperature differences between the microclimates of individual trees and because of individual responses to a given set of environmental conditions. At site 3 the control and irrigated trees are suppressed and are therefore not expected to react systematically to environmental factors but the response of the fertilized group can be seen to be somewhat similar to that of the groups at the other two sites.

The variation patterns for maximum density set out in *Figure 7* are similar for the control groups at sites 1 and 2 and similarity also exists between the profiles for the irrigated groups from these two sites. It can be seen that supplementary watering has some effect on maximum density. For this variable however there are large differences between trees within a group which make it difficult to interpret the role of climatic factors. It is suggested that maximum density is influenced by the mean temperature at the individual location at the time of late wood formation, the latter being governed by effective rainfall. All trees from the control group at site 2 responded similarly from 1958 to 1961 but there were differences within the group in several subsequent years. These deviations might be explained in terms of differing soil moisture contents at the micro-environmental level, differing abilities among individual trees to respond to relatively small amounts of soil moisture and variations in environmental temperature from tree to tree. In one of the control trees from site 2 (the example shown in *Figure 1)* similar maximum density values were recorded for the 1959/60 and 1965/66 growing seasons. Referring to *Table 1* it will be seen that the most likely time of late wood formation was during April and May in the first instance and during May in the latter case. Mean temperatures were similar (9.3 and 9.8^0 C respectively) and it was interesting therefore to investigate cell diameter and wall thickness for each growth ring. The late wood cells were observed to have similar diameters and wall thikness in both the radial and tangential directions. The increased maximum density values following the inspection of the irrigation programme are consistent with the above-mentioned hypothesis. Supplementary watering during the summer months advances the time when late wood formation may begin and results in late wood formation taking place under conditions of increased temperature.

As the effect of irrigation has been shown to increase the proportion of late wood it is not unexpected that average density also should be increased by supplementary watering. *Figure 9* depicts the variation patterns for this feature. The trees at site 1 are seen to have increased density values following irrigation. The trees at site 1 are seen to have increased density values following irrigation. The trees at site 2 also exhibit a tendency to form denser wood following irrigation. At site 3 however, it is difficult to assess the effect of supplementary watering although the fertilized trees show a clear trend to increasing density values until the 1966/67 growing season.

A difficulty in establishing the influence of irrigation on average tracheid length is the determination of the optimum sampling position within the growth ring. Ideally material should be examined which was formed at the time the irrigation was in progress. It is not possible however to accurately select such a sample. If the whole growth ring is used the effect due to supplementary watering may be obscured by extraneous material. As the densitometric data had demonstrated that the late wood could be influenced by irrigation this was chosen as the sampling position in

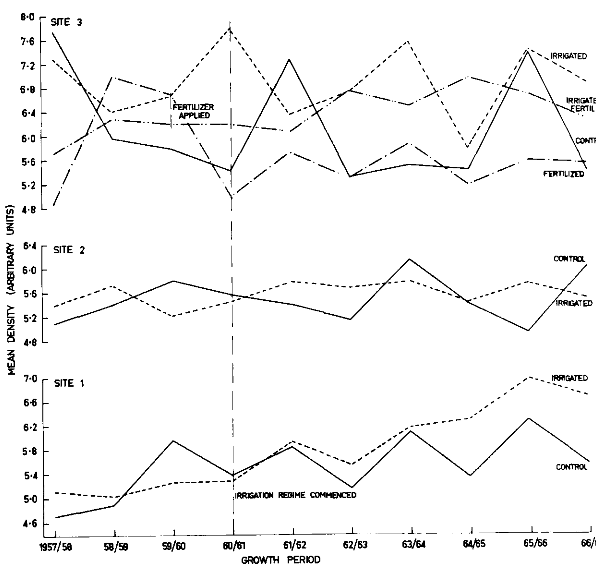


Figure 9. — The variation in average density from 1957 to 67 for groups of *Pinus radiata* from three sites at Mt. Crawford showing the influence of irrigation and fertilizer treatment.

Table 3. — The means of average tracheid length (mm) through the latewood of successive years from 1957 to 1967 for groups of *Pinus radiata* trees from Mt. Crawford.

Growth period	Site 1				Site 2		Site 3			
	Control	Fertilized	Irrigated	Fertilized and Irrigated	Control	Irrigated	Control	Fertilized	Irrigated	Fertilized and Irrigated
1957/58	3.70	3.58	3.48	3.69	4.31	4.33	4.37	4.43	3.98	4.02
1958/59	3.72	3.65	3.55	3.84	4.32	4.35	4.50	4.37	4.04	3.98
1959/60	3.92	3.83	3.62	3.82	4.21	4.28	4.44	4.38	4.04	4.02
1960/61	4.04	3.92	3.79	4.00	4.38	4.39	4.62	4.55	4.20	4.10
1961/62	4.20	3.99	3.99	4.04	4.45	4.49	4.79	4.66	4.43	4.17
1962/63	4.05	4.06	3.88	4.16	4.36	4.39	4.53	4.46	4.21	4.03
1963/64	3.65	4.03	3.56	3.92	4.57	4.44	4.57	4.50	4.23	4.07
1964/65	4.01	4.17	3.59	4.02	4.60	4.56	4.69	4.61	4.34	4.14
1965/66	4.26	4.23	3.98	4.26	4.68	4.60	4.75	4.59	4.35	4.15
1966/67	4.47	4.30	4.02	4.28	4.83	4.68	4.57	4.48	4.33	4.26

the present study on the basis that it was an easily identified reproduceable portion of the growth ring. For this characteristic the means for the various tree groups have been set out in *Table 3*. These data show that the average tracheid lengths of the material from the three sites were not modified by the irrigation treatment. No significant change was discernable as a result of applying fertilizer to the trees at site 3. As some confirmation of these findings which are based on sampling of the late wood, two control and two irrigated trees from site 2 were further investigated by sampling the whole growth ring. The data so obtained representing the ten year period under review, show that no significant change in average tracheid length could be ascribed to the irrigation treatment.

5. Conclusions

It has been seen that provided the soil nutrient level is not a limiting factor the maintenance of appropriate soil moisture conditions by supplementary watering can result in sizeable increases in the stem diameter growth of *Pinus radiata* trees. The present study was concerned with one particular irrigation regime. It is interesting to speculate however whether the economics in this case may not have been improved, by omitting irrigation during January and February because of adverse atmospheric moisture conditions, by commencing the programme in November, and by regulating the amount of supplementary water during and after periods of heavy rain so that soil moisture is not increased beyond that required for optimum growth.

The present investigation has revealed changes in ring texture and mean density which were attributable to the irrigation treatment. The proportion of "late wood" has increased from a mean value of 20.4 to 34.3 per cent. and from 18.9 to 28.0 per cent., and mean density has increased by 8.1 and 2.0 per cent. at sites 1 and 2 respectively. This may or may not be advantageous. The proportion of "late" wood for the control trees is remarkably close to the estimates of conventional late wood previously obtained for populations of *Pinus radiata* from South Australia (Nicholls and Dadswell, 1965), and such a proportion was judged by Watson (1962) to have little influence on papermaking properties. Although an increase to 30 per cent. may not come within this category it may not be disadvantageous in a mixed furnish and would contribute to an improvement in tear factor. The increase in density is certainly not adverse and represents an increase in dry matter yield. Increased density is also associated with improved strength properties in sawn timber.

Acknowledgements

The author wishes to thank the Conservator, Woods and Forest Department who supplied the specimens for examination in this study. He also thanks members of the staff of the Department who were associated with the collection of the specimens and the forwarding of meteorological data.

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Summary

Specimens from 32 trees of *Pinus radiata* from three sites at Mt. Crawford South Australia have been examined. Densitometric information and results for average tracheid length were collected from the last ten successive growth rings in each tree. These data were analysed to show the effect of supplementary watering and fertilizer treatment.

Sizeable increases in stem diameter growth were attributable to the irrigation programme. The proportion of thick-walled cells associated with summer and autumn growth was increased from approximately 20 per cent. to 30 per cent. Average tracheid length was not affected by supplementary watering.

The changes in wood quality are not regarded as adverse and therefore the effect of the irrigation programme is to increase the amount of acceptable wood.

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Clonal Repeatabilities and Clone-Site Interactions in Pinus radiata

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Introduction

This paper covers some results of a 12-year-old clonal replication trial with *Pinus radiata* in which clones were replicated within and between four different sites. It is concerned with growth vigour in general, the frequency of branch clusters on the stem, and tree form and stem straightness. Several clonal replication trials with *Pinus radiata* have been reported (Fielding, 1953; Fielding and Brown, 1961; Nicholls, 1967; Pawsey, 1960) which have demonstrated considerable variation between clones for a wide range of characters. In none of these trials, however, was the replication extended to more than one site.

Clonal replication trials can give estimates of the magnitudes of total genetic and environmental variation, from which predictions may be made of the genetic gain to be expected from improvement programmes based on vegetative propagation. If such trials are extended to several sites they can give estimates of clone-site interactions, and will help to ascertain the range of sites over which a selection of clonal or seedling stock can be profitably planted.

Procedure

Establishment and Design of Trial

The trial was initiated and established by G. C. Weston. In 1950 open-pollinated seed was sown from nine parent trees, which had been chosen for a variety of distinctive morphological features. In 1953 two seedlings were chosen from each of the nine progenies for replication as being representative of their respective progenies. It is clear, then, that the 18 clones are far from being a random population sample.

From 6 to 25 plantable cuttings (ramets) were obtained from each of these seedlings, giving a total of 224. They were planted out in 1955 at 9 ft × 9 ft spacing on four sites: Glenbervie, Whakarewarewa (Whaka), Gwavas and Berwick. Where there were too few ramets of a clone to permit replication within all four sites it was omitted from one of the sites. As far as possible equal numbers of ramets of a clone were planted on each site where it was represented, and with this restriction the ramets were allocated at random to the respective sites. The unbalanced structure was accentuated by some mortality and by the partial felling of the Whaka plot (Clones 59 to 63 inclusive) in 1961. The lack of complete surround plantings, the suppression of some trees, and the lack of a randomised layout at Whaka, further complicate the analysis and interpretation of data.

Particulars of the Sites

Glenbervie State Forest, Lat.: 35° 35'; Alt.: C 500'; Rainfall: c 65 in.; Slope c 20°; Aspect: N, sheltered; Soil: clay, shallowly rooted with tree growth indicating a fertility gradient within plot.
Whaka State Forest, Lat.: 38°; Alt.: 950'; Rainfall: c 55 in.; Flat ground slightly exposed; Soil: pumice, sandy loam, freely rooted.
Gwavas State Forest, Lat.: 39° 15'; Alt.: c 1200'; Rainfall: c 50 in. (probable evapo-transpiration deficit in summer); Slope 15—20°; Aspect: NE, exposed; Soil: gravelly sandy loam, freely rooted.
Berwick State Forest, Lat.: 46°; Alt.: 200'; Rainfall: c 28 in.; Slope c 20°; Aspect: N, sheltered; Soil: loess — derived clay loam, with good root penetration in spite of compactness. Two of the last three seasons had been abnormally dry on this site.

The soil in the Glenbervie plot is representative of clay soils in that district which have previously carried kauri (*Agathis*) forest and which are known to be of low fertility. Results of foliage analyses and fertilizer trials (Weston, 1956) indicate that low phosphate status is by far the most important factor which limits the growth of *P. radiata* on such sites. The other soils in this trial are generally considered to be of high fertility for growing conifers.

Measurement of Trial

In the winter and early spring of 1967 all plots were felled and measured in detail. In connection with this paper the following observations were recorded for each tree:

(1) Total height (to top of annual growth stage, summer 1967).
(2) Breast height diameter over bark (d.b.h.o.b.).
(3) Any growth abnormality.
(4) Incidence of forking.
(5) Visual assessment of stem straightness.
(6) Total number of branch clusters on main stem.

The visual assessment for stem straightness was made by three independent observers, using a 1 to 9 scale, 1 being extremely straight and 9 extremely crooked. Sinuosity or "crook" or "kink" was the only form of crookedness considered; butt sweep, bole sweep, and lean were ignored as far as possible (cf. Shelbourne and Stonecypher, in press; Bannister, MS in preparation).

For purposes of counting branch clusters, cones or aborted female strobili were treated as branches (cf. Bannister, 1962).