ing. III. In *Pinus radiata* D. DON. C.S.I.R.O. Aust., Div. For. Prod. Tech. Pap. No. 37, 1965. — PAUL, B. H., and MARTS, R. O.: Controlling the proportion of summerwood in longleaf pine. U.S. For. Prod., Madison. Rpt. No. 1988, 1954. — PAWSEY, C. K.: Timber sampling from standing trees. Aust. For. Res. 1 (3): 33—36 (1965). — PAILLIPS, E. W. J.: The beta ray method of determining the density of wood and the proportion of summer wood. J. Inst. Wood Sci. 5: 16—28 (1960). — POLGE, H.: Study of wood density variations by densitometric analysis of X-ray negatives of samgles taken with a Pressler auger. I.U.F.R.O. Proc. of meeting of Sect. 41, Melbourne, 1965. — POLGE, H.: Utilisation des spectres de diffraction des rayons X pour les etudes de qualite du bois. Thesis for Dr. of App. Sci. Univ. of Nancy, 1966. — POLGE, H., and KELLER, R.: Influence de l'approvisionnement en eau sur la structure interne des accroissements annuels. Ann. Sci. forest. 25 (3): 125—133 (1968). — SHEPHERD, K. R.: Growth patterns and growth substances in Radiata pine (*Pinus radiata* D. DON). Univ. of Melb. Ph. D. Thesis, 1965. — SKENE, D. S.: The period of time taken by cambial derivatives to grow and differentiate into tracheids in *Pinus radiata* D. Don. Ann. Bot. 33 (130): 253—262 (1969). — SMITH, DIANA, M., and WILSIE, MARY C.: Some anatomical responses of loblolly pine to soil-water deficiencies. Tappi 44: 179—185 (1961). — WATSON, A. J., and DADSWELL, H. E.: Influence of fibre morphology on paper properties. Pt. 11. Early wood and late wood. Appita 15 (6): 116—128 (1962). — ZAHNER, R.: Internal moisture stress and wood formation in conifers. For. Prod. J. 13 (6): 240—246 (1963).

Clonal Repeatabilities and Clone-Site Interactions in Pinus radiata

By R. D. BURDON

Forest Research Institute, Rotorua, New Zealand

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 X 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 restrictіcn the ramets were allocated at random to the respective sites. The unbalanced structure was aecentuated 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).

Analysis *of* Results

Analyses of variance were performed for each metric character, site by site. Combined analyses for all four sites were not attempted because of the unbalanced structure of the experiment and also the obvious magnitude of the clone-site interactions; these factors could have made the analyses difficult and then only of limited value when completed. The test for the significance of differences between clones is automatically a test for clonal repeatability. Repeatability is given by the ratio $V_c/(V_c + V_E)$ where V_c is the variance between clones and V_E is the variance between ramets of clones, within one site. In this trial repeatability cannot be regarded as a broad-sense heritability, because the clones are few in number and are not a random selection from the population. The components of variance are calculated from the analysis of variance (see SNEDECOR, 1956, 10.6). The square root of V_E gives a pooled standard deviation of ramets within clones, although this must be treated with some caution because of some undoubted heteroscedasticity, or differences in between-ramet variance, among clones.

For stem straightness, which was assessed by three independent observers, the analysis is more complex. If the scores for the ramets are summed over the three observers, and no account taken of the observers in the analysis of variance, the expected mean square for within-clone variation is equal to $3V_{R:C} + V_{OR:C}$, where $V_{R:C}$ is the variance between ramets within clones and $V_{OR:C}$ is the residual variance. In this event a repeatability estimate is of the form $3V_C/(3V_C + 3V_{R:C} + V_{OR:C})$. However there are indications that $V_{OR:C}$ can be treated purely as observer error (BANNISTER, MS in preparation); so when account is taken of observer effects in the analysis $V_{OR:C}$ can be partitioned off, and an adjusted estimate of repeatability may be obtained by treating it as the ratio $V_C/(V_C + V_{R:C})$. The analysis of subjective assessments for straightness is being treated comprehensively by BANNISTER and will not be considered in further detail here.

Results for the different characters are tabulated as arithmetical means for each clone on each site, the number of ramets being listed in brackets. Because of the unbalanced structure of the experiment and the large clone-site interactions no satisfactory expression of site means can be obtained. However, listing the values for individual clones in order of ranking does permit some overall comparison between sites. Individual clone-site interactions or comparisons between particular clones can be roughly evaluated on inspection by considering the pooled standard deviations ($\sqrt{V_E}$) in conjunction with the numbers of ramets involved.

Certain ramets were discarded from the analyses. For assessing height and diameter growth all dead trees were omitted and also any trees in which suppression had resulted from slow establishment. In assessing height growth trees which had been affected by appreciable leader breakage were discarded if possible. Where the calculated mean height is necessarily an underestimate of the growth potential of a clone through wind breakage, leader dieback or suppression, a plus sign is written beside the figure.

Results and Discussion

Growth Vigour

Results for height and diameter growth are presented in Tables *1 and* 2. The effects of sites, clones within sites and clone-site interactions are large.

At Glenbervie the reduction in growth was caused almost certainly by phosphorus deficiency, of which the spindly, thin-crowned appearance of the trees, some leader dieback, some mortality without crown suppression, and the occasional individual showing needle fusion, are typical stand symptoms (WESTON, 1956). Foliar analyses, which are still in progress give very strong support to this view.*) Growth at Gwavas was probably restricted by several factors, including summer drought, winter temperatures and exposure. At Berwick it appears to have been limited mainly by summer drought and winter temperatures. On the whole, height growth at Berwick was about 10 ft less than at Gwavas and a preliminary study of successive annual height increments predicts this difference resulted entirely from a combination of slow initial growth and the effects of two particularly dry seasons.

The clonal repeatabilities for height were generally higher than those for diameter, particularly at Whaka and Gwavas where the within-clone variance for diameter was inflated by edge' effects. At Glenbervie the within-clone variances for height and diameter growth were doubtless inflated by the fertility gradient within the plot; that for height was further inflated by some leader dieback. Glenbervie and Whaka showed much greater between-clone variances than the other sites. At Whaka this resulted largely from the partial suppression of clones 67 and 70. From a study of the establishment records there was no indication that clonal differences had resulted from initial ramet size effects.

It must be emphasised that height and diameter growth are two aspects of overall vigour, which itself is a somewhat indeterminate character. When comparing sites, or clones within a site, diameter growth appears to give a clearer indication of poor vigour than does height growth, even though height growth is far less influenced by edge effects. The general untkriftiness of the trees at Glenbervie was reflected more in stem diameter than in total heights. In comparing clones within sites, differences in height growth can often reflect habit of growth rather than overall clonal vigour; e. g., clones 65, 66 and 69 were undoubtedly tall-growing, while clones 64, 71 and 72 were relatively squat, at least up till the age of felling.

The clone-site interactions were very striking and they mainly reflected the inability of certain clones to thrive at Glenbervie. With the evidence from foliar analyses that Iow soil phosphate status is by far the main factor to limit growth on this site, it is almost certain that these clones performed poorly because of a greater susceptibility to phosphorus deficiency. All clones showed more or less normal vigour at Gwavas and Berwick, but at Glenbervie there were several namely 59, 60, 61, 62, 67, and possibly 69, in which diameter growth was severely depressed. All three ramets of clone 66 which had been planted there died naturally, although one which survived for several years had made reasonably rapid growth. At Whaka clones 67, 68 and 70 all showed poor diameter growth, although height growth was normal in clone 68. Unfortunately, the other clones which performed poorly at Glenbervie were not represented at Whaka.

That most of the clone-site interactions for vigour have, in this trial, arisen from clonal differences in ability to tolerate low available phosphate is evident. At Whaka, clones 67 and 68 showed evidence of phosphate deficiency, which was rather unexpected; however, on this site boron

*) They will be reported in another paper together with the results of soil analysis.