INFLUENCE OF MOISTURE RELATIONSHIPS ON THINNING PRACTICE

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ABSTRACT

In south-western Australia, which possesses a strongly seasonal, Mediterranean type of climate, moisture availability is a very strong determinant of pine growth potential. This is in turn determined by the depth and moisture-holding capacity of the soil, which limits the magnitude of moisture storage during the winter, and by the density of the stand, which controls the rate of exhaustion of the stored water during the spring and summer growing season. In stands which do not tap the regional groundwater table, the volume production is largely independent of density within a very wide range of basal area levels. By contrast, diameter growth is very strongly influenced by stand density. In dense stands, all readily available moisture is exhausted by November and diameter increment ceases. In heavily thinned open stands moisture availability and diameter growth continue until the following March or April. Application of fertilisers must be preceded by reduction in stand density to be effective. Success of density reduction by thinning is dependent on subsequent control of pine coppicing and of weeds.

Moisture limitations manifest themselves, in order of increasing intensity, firstly in depression of diameter growth, secondly in predisposition to attack by **Ips grandicolis**, and finally in direct drought deaths. Prevention of this can be achieved either by early non-commercial thinning, or by planting of genetically improved stock at wider spacing.

INTRODUCTION

The chief contribution that Western Australia can make to the discussion of thinning is its experience in, and its experimentation with, the effect of moisture availability on growth and survival of pine stands. This has been necessitated by the strongly seasonal, Mediterranean-type of climate of the main pine-growing regions.

Brief Historical Review

The earliest documented case of interaction between stand density and moisture availability dates back to the early 1950s, when moderately extensive dying of *Pinus pinaster* trees was reported from a portion of the Sommerville plantation near Perth. Investigation (Hopkins, pers. comm.) revealed that death tended to be associated with the presence of limestone pinnacles in the subsoil. It was suggested that as death occurred mainly in stands reaching canopy closure, on shallower-than-usual soils, and as it became manifest at the end of the dry summer period, the most likely cause was drought. Due to preoccupation with nutritional problems at the time, the suggestion that thinning might alleviate the problem was not followed up. However, thinning

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experiments and moisture studies were initiated by Hopkins and these formed the basis of subsequent studies.

Site studies by Havel (1968) identified drought prone sites in terms of indicator species and associated environmental conditions. The sites most prone to drought death combined relative shallowness of soil and good capacity to retain applied phosphate. Most of the plots occurred in the northern portion of the Swan Coastal Plain, where annual rainfall was lowest (less than 750 mm) and drought probability and evapotranspiration highest. The first and most serious mortality occurred when below-average rainfall coincided with canopy closure. The deaths invariably occurred in the centre of the plot and never on the periphery. Preliminary investigations utilising a neutron probe established that on the drought-prone sites the exhaustion of moisture during summer was more thorough, and its replenishment less complete, under dense stand of pine (*P. pinaster*) of basal area 23 m^2/ha than they were under adjoining native woodland of 14 m^2/ha, which was presumably in balance with the long term site potential. A poorer stand of pine, on deeper, more leached sand, which had a basal area of 16 m^2/ha, had a moisture regime comparable to that of the native woodland referred to earlier, and did not suffer from drought deaths.

Concurrently (1966-67) with the deaths recorded in *Pinus pinaster* stands on the northern coastal plain by Havel (op. cit.), deaths were also reported from *Pinus radiata* plantations in the valleys of the Darling Range, and in particular in the Blackwood Valley at Nannup. These became very serious by 1969 (when a dry year coincided with canopy closure over an extensive area of plantations) and have persisted since. The deaths became associated with attack by *Ips grandicolis,* which appeared to finish off trees already affected by severe moisture stress. The deaths were not restricted to any particular size class, though the impact on the select, pruned dominants was slightly lower than on co-dominants and suppressed trees.

It was at this stage that, through a combination of factors, the so-called Silviculture 70 was adopted for the management of young pine plantations. The essence of this system (Forests Dept. of W.A., 1973) is relatively early non-commercial thinning, by which the initial stocking (1704 stems/ha for *P. radiata,* 1988 stems/ha for *P. pinaster*) is reduced to 740 stems/ha at age 5 and 6 respectively. This is followed by further reduction to 200 stems/ha at age 11 for *P. radiata* and to 247 stems/ha at age 14 for the slower growing *P. pinaster.* The factors influencing the adoption of this radical approach were:

1. availability of silvicultural data from local studies,
2. availability of economic data from New Zealand studies,
3. realisation of the connection between stand density, moisture exhaustion and drought deaths,
4. poor marketing prospects for, and low returns from, small-dimension logs derived from first commercial thinning.

EXPERIMENTAL

Combined Thinning and Hydrology Studies in Pinus pinaster

(a) *Design*

Two large thinning experiments were established on the northern coastal plain at Yanchep and Gnangara concurrently with site studies, during 1965 and 1966

(Hopkins, 1971). Initially they were primarily designed to relate increment to stand density, expressed in terms of basal area. Subsequently, detailed hydrological studies were grafted on to this basic design as the desirability and feasibility of this was established by preliminary studies described earlier. The levels at which stand density was to be maintained by periodic thinnings were 37, 24, 16, 11 and 7 m^2/ha, that is progressive reduction by 33.3%. In fact, the full range could only be applied on deep, leached, moist sands at Gnangara. On the drier, weakly-leached sands at Yanchep, the highest basal area level could not be applied, as drought deaths had already occurred at 24 m^2/ha. The design was therefore initially a 5 × 10 randomised block design at Gnangara, and 4 × 10 at Yanchep.

By 1970, remeasurement confirmed that differences between adjacent blocks were so slight that a further factor could be introduced. A treatment involving the application of superphosphate with zinc and copper (0.5 t/ha) and sulphate of ammonia (0.25 t/ha) was introduced in 1971, altering the design to 5 × 2 × 5 and 4 × 2 × 5 factorials respectively.

The response of the stands was assessed by two-yearly remeasurement of diameter and height, from which were also derived basal area and volume increments. Continuous measurement of diameter growth was carried out on select stems by dendrometers. The hydrological studies involved gravimetric soil sampling to 3.3 m by Veihmeyer tubes, bi-monthly measurement of soil moisture to 7 m by neutron probe, measurement of throughfall by combination of fixed and moving raingauges, and the measurement of stem flow by special stem flow gauges. Of these, only the neutron probe measurements were carried out beyond the initial calibration period of 2 years.

The establishment of the Gnangara plots, and the initial silvicultural findings, have been described by Hopkins (1971). For the sake of brevity, the subsequent findings have been summarised by means of diagrams and tables.

(b) *Relationship between Pine Growth and Water Availability*

Figures 1 and 2 represent respectively the wetting and drying phase of the annual soil moisture cycle, for native woodland and low and high density good-quality *P. pinaster* stands at Yanchep. The high density stand suffered from drought deaths in 1966.

The points particularly worth noting are almost identical patterns under open native woodland and low-density pine stands. By comparison, under the densely stocked pine stands the wetting is slightly delayed and soil drying is greatly accelerated — the moisture is exhausted down to 7 m by mid-November as compared with March under the more open stands.

Figures 3 and 4 demonstrate how this is reflected in girth increment of final crop (250 trees/ha) in pine stands of low and high density. The cessation of girth increment is not related to monthly rainfall, but to exhaustion of soil moisture, which occurred in this particular year in mid-November on densely stocked stands and in March in stands of low stocking (Fig. 2). The corresponding girth increments on trees monitored by dendrometers during the period September 1970 to September 1971 were 12 mm and 39 mm respectively.

The differences in average diameter increment for all trees in stands of varying density are quite consistent (Fig. 5) though they are subject to climatic influences and

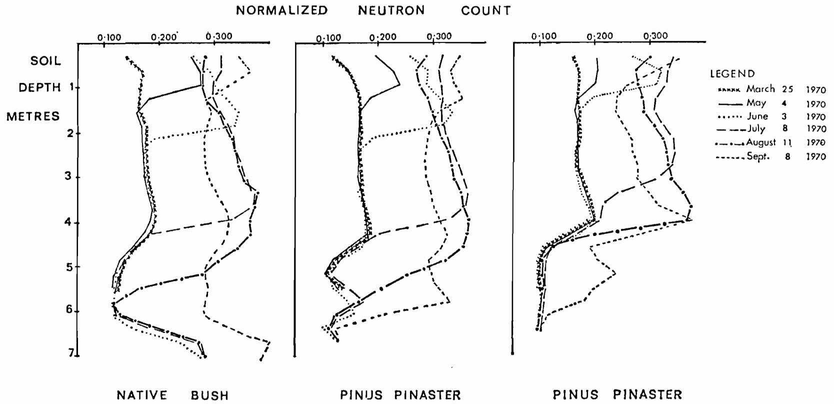


FIG. 1—Build-up of soil moisture under native woodland and pine stands of density 7.1 m²/ha (centre) and 24.6 m²/ha (right) at Yanchep, W.A. Normalised neutron count reflects the amount of water held in the soil. Moisture levels in March approximate wilting point.

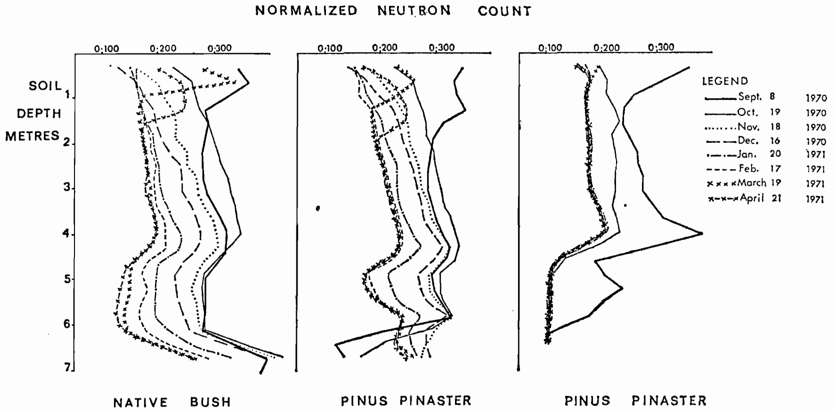


FIG. 2—Exhaustion of soil moisture (see Fig. 1).

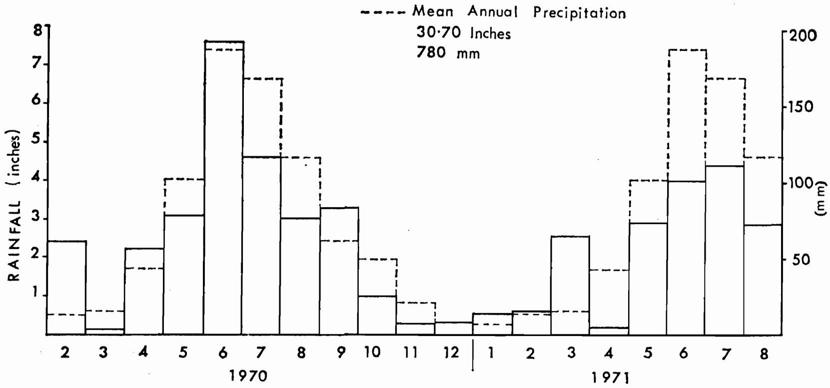


FIG. 3—Rainfall patterns at Yanchep. Mean annual precipitation and actual rainfall 1971-2, corresponding to dendrometer measurements in Fig. 4 and neutron probe measurements in Figs. 1 & 2.

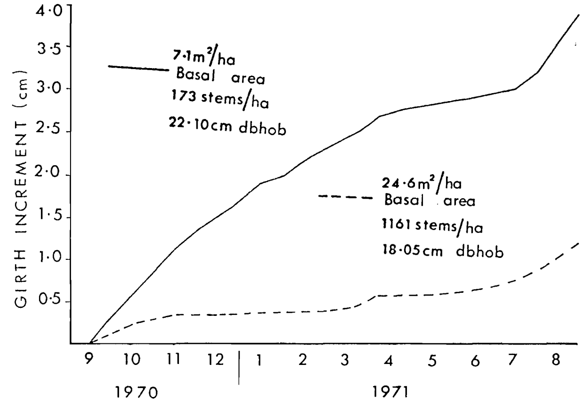


FIG. 4—Cumulative girth increment in densely and lightly stocked pine stands at Yanchep, over period covered by soil moisture measurement (Figs. 1 & 2) and precipitation recording (Fig. 3).

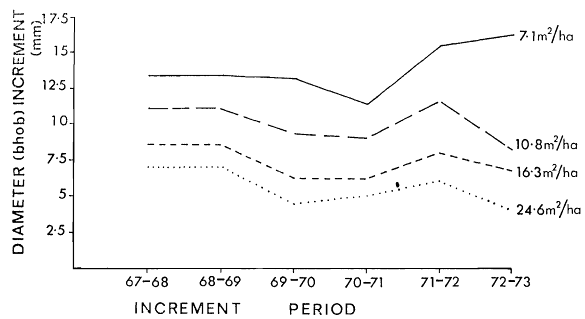


FIG. 5—Diameter increment in stands of varying density, recorded at Yanchep over a span of six years (age 14.5 to 20.5).

to the effects of fertilisation. They tend to be greatest during periods of below average rainfall (69-70 and 71-72) and following fertilisation. The effect of fertilisation will be discussed later.

The long-term effect of stand density on diameter increment is shown in Fig. 6, which also incorporates the effect of site. It indicates that the benefit from thinning is greatest on shallower soils with higher phosphate-holding capacity (I) on which the pine stand has the greatest capacity to exceed available moisture. On the deeper, more leached soils (IV), the benefit of thinning is reduced by lower growth potential and greater persistence of competing shrubs.

Whilst the dimension of the final crop is an important consideration both from the point of view of harvesting costs and the price/size differential, its beneficial effect could be offset by losses in the total wood production.

Volume production for the period 16.5 to 20.5 years in the Yanchep stand is shown in Figure 7. It indicates that the volume produced on this site is largely independent

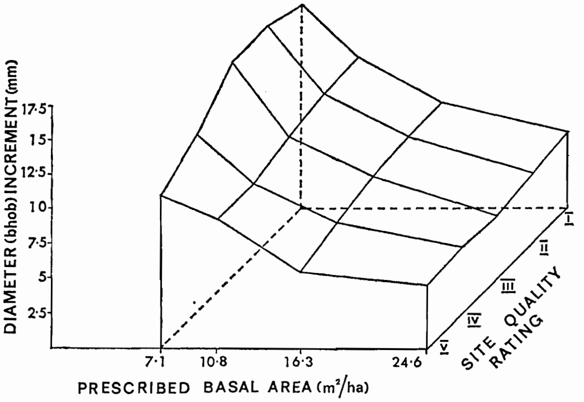


FIG. 6—Diameter increment in relation to site and stand density, recorded at Yanchep over a period of 4 years (age 16.5 to 20.5).

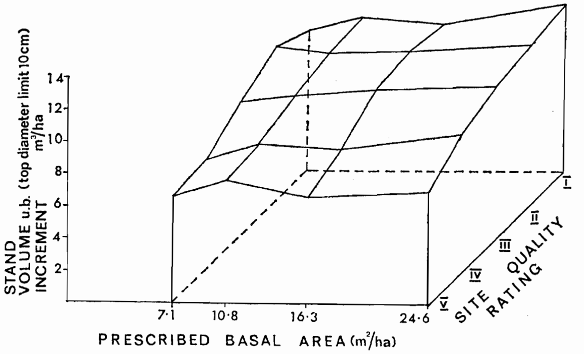


FIG. 7—Volume increment. **See** Fig. 6.

of stocking. There is just so much water available at the beginning of the growing season, and it is this that determines the amount of wood that can be produced. It can either be put rapidly on a large number of smaller trees during the period August to November or slowly on a small number of large trees during the period August to March. This hypothesis is supported by Fig. 8, which compares total volume increment over three growing periods. During the good growing period prior to the extreme drought in 1969, the more heavily stocked stands produced a greater volume than the very lightly stocked stands, but since then the difference has been negligible.

The situation in the Gnangara stand is somewhat different. Here the gradient of diameter increment still corresponds to the gradient of decreasing stand density (Fig. 9) but total volume production is positively related to stand density on the better quality sites (Fig. 10 and Table 1). These are characterised by an extensive regional ground water table accessible to the trees at the moderate depth of 4 metres (site I). On the drier sites at Gnangara (site V), the differences in volume production are much smaller,

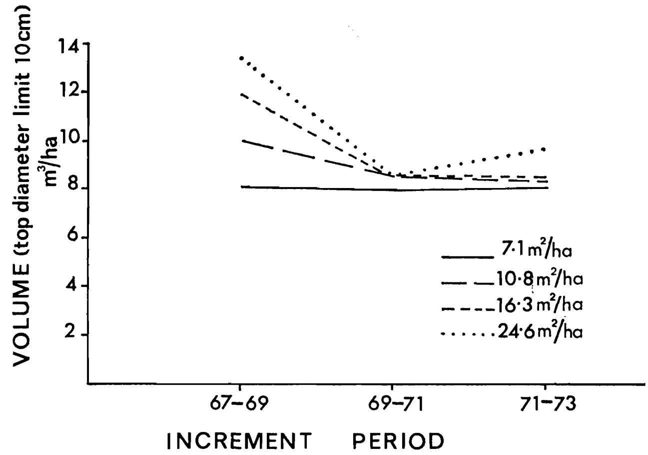
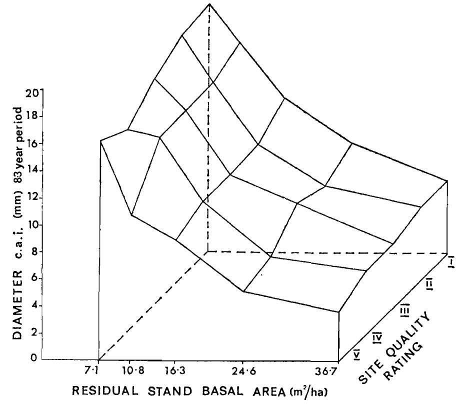


FIG. 8—Periodic volume increment in stands of varying density. See Fig. 6.



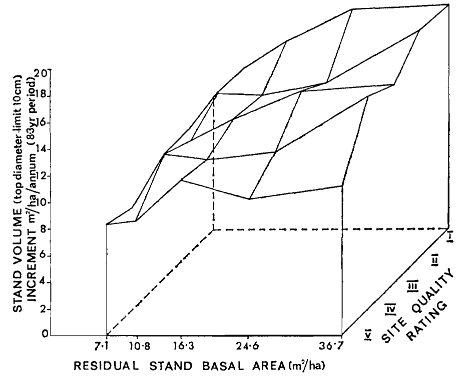


FIG. 9—Diameter increment

FIG. 10—Volume increment

Each shown in relation to stand density and site quality, recorded at Gnangara over a period of 8 years (age 19.2-27.5). (Erratum: Volume in m³ not m².)

(c) *Effect of Site and Stand Density on Pine Growth*

The effect of site can also be illustrated from the so-called Free Growth experiment, which is situated in a transition zone between Gnangara and Yanchep. The area is characterised by major site variations, in both the availability of moisture and the capacity to retain phosphate. The essence of the experiment is an early progressive reduction of the original stocking from approximately 2200 stem/ha to 1480, 1240, 990, 740, 495 and 247 stems/ha respectively. The two extreme sites within the experiments are high ridges with weakly leached subsoil and swampy depressions with highly

TABLE 1—Current annual increment for **Pinus pinaster** stands in relation to stand density and site quality

Residual Basal Area	SITE QUALITY RATING I			II			III			IV			V			Mean for given stocking density		
	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c
36.7	1421	2.11	853	1569	2.19	927	1792	1.97	1026	1779	2.08	1124	1878	1.57	1285	1693	1.98	1038
24.6	964	2.07	519	1001	1.79	544	1124	2.02	556	1087	1.53	630	1458	1.58	766	1124	1.80	605
16.3	593	1.79	272	655	1.68	309	717	1.67	358	618	1.57	309	890	1.71	395	692	1.68	334
10.8	346	1.50	148	395	1.56	173	334	1.42	148	432	1.03	99	531	1.33	222	408	1.48	173
7.1	222	1.24	99	235	1.19	86	247	1.18	99	259	1.03	99	284	1.17	99	247	1.16	99
Mean for given site quality	704	1.74	383	766	1.68	408	840	1.65	432	840	1.56	470	1013	1.47	556	828	1.62	445

a. Stocking (stems/ha) in 1965
b. Increment of basal area over bark in m^2/ha/yr
c. Stocking (stems/ha) in 1974

Experiment from 1965 (tree age 19.2) to 1974 (tree age 27.5). Values from the Gnangara experiment (covering all site qualities) are means from two plots.

leached, acid organic soils. At the time of the original site studies (Havel, 1968) it was noted that both effects were comparable in size, in the former case, due to good retention of applied phosphate and in the latter due to high, in fact excessive, availability of moisture. The growth on these sites has been traced for two stand densities (1480 and 740 stems/ha) over the period 1962 to 1975. In 1965 the mean diameters were comparable between sites, but were approximately 15 mm smaller for the more densely stocked stands. Since then the diameter differential has widened between densely and lightly stocked stands on the dry ridge sites, but has hardly altered on the originally excessively wet sites. On the other hand, the diameter increment of the wet leached sites has progressively outstripped that on the dry, weakly leached sites irrespective of density (Fig. 11).

The basal area of the plots, which was initially very similar (4.8 to 5.1 m^2/ha in 1962), has progressively diverged (Fig. 12). It is by far the highest (35 m^2/ha) in the densely stocked stands on initially excessively wet sites which have now dried to such a degree that they probably represent the optimum site for the area. It is also worth noting what was formerly the best site, resulting from an unusual combination of weakly leached soil and initially optimum moisture availability, is the only one on which a number of deaths have occurred during the drought period, presumably because its very high density outstripped the moisture reserves of the site.

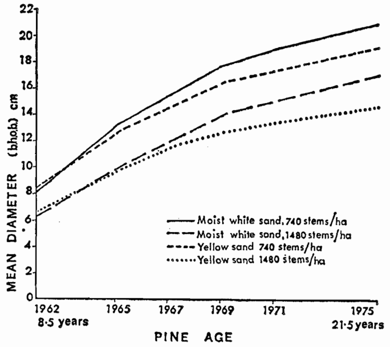


FIG. 11—Cumulative changes in mean diameter of stands in relation to site and stand density, recorded in transition zone over a period of 13 years.

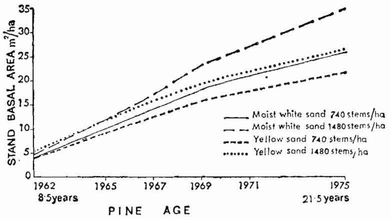


FIG. 12—Cumulative changes in stand basal area, **see** Fig. 11.

(d) *Effect of Fertilisation and Stand Density on Pine Growth*

In the Yanchep experiment it is also possible to evaluate the interaction between stand density, moisture availability and response to fertiliser application (Fig. 13). The response of the heavily stocked stands in terms of girth increment of final crop trees is minimal and is completely overshadowed by the effect of stand density. The obvious conclusion is that on this site the chief limiting factor is the availability of moisture rather than nutrients. Under these conditions it is essential that the application of fertilisers be preceded by thinning.

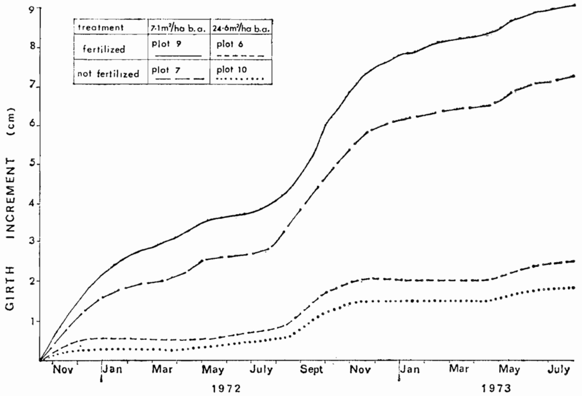


FIG. 13—Cumulative girth increment following fertilisation, Yanchep.

(e) *Effect of Competition on Growth and Water Usage of Pine Stands*

The adoption of Silviculture 70 on a broad scale has not been without problems. At the time of early thinning, the stands usually have not closed adequately to ensure the suppression of competing shrubs and the death of lower branches. As a result, there is a tendency for the green branches remaining on the stumps of culled trees to resume growth, and for the competing shrubs to regain vitality. The net result of this may be partial negation of the aim of the thinning, that is, the concentration of the growing potential on a smaller number of trees including those that will make up the final crop. To clarify this, an experiment was established in which the removal of shrub competition and competition by pine coppice, singly and in combination, have been compared with a control. Early dendrometer measurements over six months growing period (Fig. 14) indicates that the competition from pine coppice is more serious than

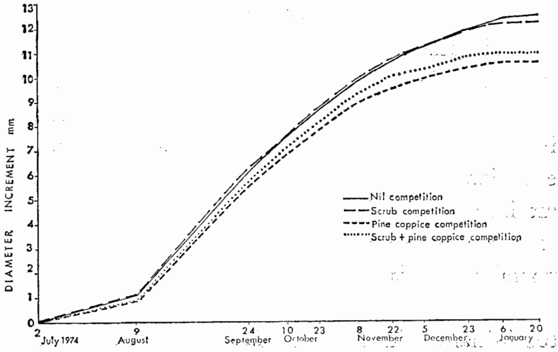


FIG. 14—Cumulative diameter increment in relation to control of competing vegetation, Yanchep.

competition from the shrubs. This could mean that either the shrubs are less efficient in terms of soil exploration and water use, or that this negative aspect is partially compensated for by addition of nitrogen, as the main species (*Jacksonia stenbergiana*) is a nitrogen-fixing legume. Soil moisture depletion curves (Fig. 15) would seem to indicate that the former is the case.

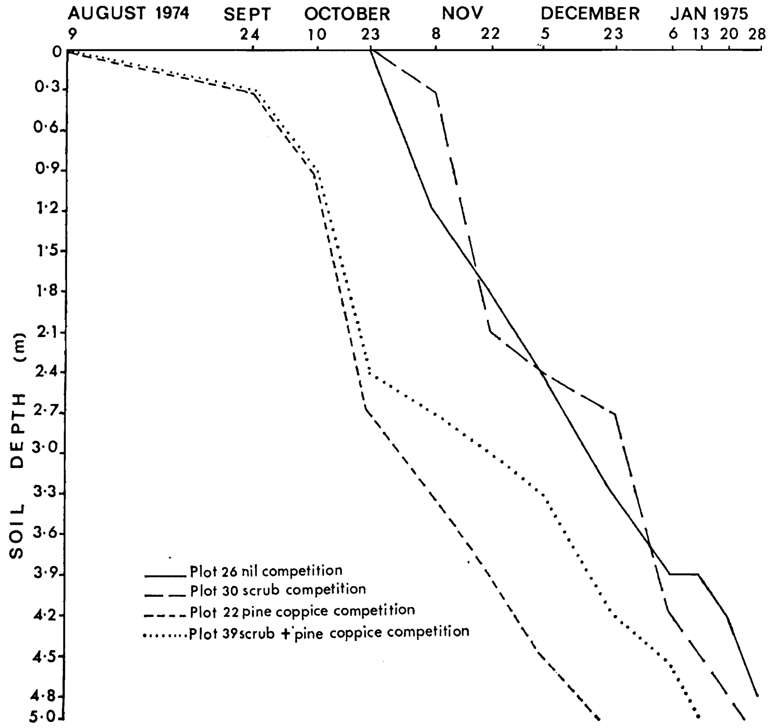


FIG. 15—Soil moisture depletion in relation to control of competing vegetation, Yanchep.

Drought Problems in Pinus radiata

The wealth of hydrological data available for *Pinus pinaster* cannot be matched for *P. radiata.* The bulk of *P. radiata* plantations in Western Australia have been established on the moderately fertile soils of the main river valleys in the south-western portion of the state. The chief reason for this is the strong geomorphological control of soil distribution in the region. Almost the entire plateau surface between the rivers is covered by deep but infertile lateritic soils, and it is only where erosion has stripped these old soils that newer, more fertile soils have developed. As a result, the more fertile soils are generally associated with steeper slopes, and frequently are shallow and stony.

The areas planted initially with *Pinus radiata* carried native forest, but in the 1960s considerable areas of marginal grazing country were repurchased by the department and planted. This land had already been partially or fully cleared some decades earlier, and its initial fertility was further raised by application of superphosphate to improved pastures containing nitrogen-fixing legumes. The combination of steep topography and shallow, fertile soils set up a situation in which the unbalance between nutrient-based growth potential and moisture availability was at a maximum. The initial growth rates were particularly rapid but soon after the stands reached canopy closure (usually at age 9 or 10), drought deaths occurred, even in years in which rainfall was not particularly low. Although the drought deaths occurrence was worst on shallow, stony sites with a north-western exposure, it was not restricted to these sites.

An attempt was made in 1969 to establish a combined thinning-hydrology investigation on these drought-prone sites, but due to competition for limited labour resources with routine logging operations, the experimental thinning was delayed so much that drought deaths destroyed the comparability of the plots and the experiment was abandoned. The adoption of Silviculture 70 and the inability of the department to purchase further worthwhile areas of this type of land took away the *raison d'etre* for any further work along these lines. This was particularly so as the thinning aspect of the problem has already been adequately covered (McKinnell, 1971) and the routine operation which undermined the experiment at least had established that stands thinned prior to moisture withdrawal were not affected by drought. Today, the problem is virtually something of the past, as most stands have been either already affected by it, or their predisposition to it has been removed by early non-commercial thinning according to Silviculture 70 prescriptions. The results reported by McKinnell support the findings made for *P. pinaster,* namely that in a Mediterranean climate on sites with limited water availability, the volume increment is largely independent of stand density. The logical outcome of this is that as the minimum size specifications are increased, so is the profitability of heavy thinning. Even where smaller dimension logs are saleable, early thinning is worthwhile as an insurance against periodic drought losses of potential final-crop trees.

IMPLICATIONS OF THE RESEARCH FINDINGS

The chief idea put forward on the preceding pages is that in a Mediterranean climate, particularly on certain sites, moisture availability is the chief factor limiting the productivity of pine plantations. On such sites it is highly desirable to ensure that the density of stands does not exceed the potential of the site to supply moisture. Even in its mildest form, moisture deficit results in deflection of growth potential from final crop trees to trees that will ultimately be removed as small, low value logs. In a more severe form it leads to dead-topping and reduction of resin-pressure, which opens the stands to attack by insect pests. In its most extreme form, it causes the death of the trees directly.

There are two alternative ways of preventing this. The non-commercial thinning embodied in the Silviculture 70 prescriptions is one. Consideration should be given to site conditions when applying it. Drought-prone sites with fertile but shallow soils should obviously be given first priority. Next in priority are dry, less fertile sites on which drought deaths may not occur, but thinning ensures concentration of growth potential on final crop trees. Lowest in priority are excessively wet sites where early thinnings are not necessary, and may in fact be undesirable in that they reduce the total volume increment without markedly increasing the size of the final crop trees.

The other alternative is a reduction in the number of trees initially planted. This is only feasible if the basis for final crop selection is not destroyed in the process. As such it is not feasible in plantations raised from run-of-the-mill seed, but is with genetically improved seed. With *P. pinaster,* all seed is currently derived from seed orchards. Progeny trials have indicated that seed orchard stock produced 85% of stems of acceptable form, as compared with 53% for routine seed. The corresponding proportion of trees of outstanding form, suitable for final crop, is 15% and 7% respectively. This means that it is possible to reduce the initial stocking from 2250 stems/ha to 1150 stems/ha, and to increase the spacing from 2.5 m × 2 m to 3.5 m × 2.5 m, and still have an expectation of 124 stems/ha of outstanding form. The advantages of this are lower nursery costs and planting cost and postponement of thinning. The latter will in turn result in a lower thinning cost and may even eliminate non-commercial thinning altogether, particularly as the better form is associated with increment increases of 24% for height, 47% for basal area and 68% for volume.

Where early non-commercial thinning is applied it is necessary to ensure that the benefits are not negated by coppicing and resurgence of weed competition. On dry sites, thinning is an essential prerequisite to fertilisation.

CONCLUSIONS

Clearly the ideas put forward in this paper are not universally applicable. Work by Bell and Gatenby (1969) and Smith *et al.* (1973) clearly indicates that the exhaustion and replenishment of soil moisture under pine stands in uniform rainfall regions is far more complex. Studies by Shepherd and Forrest (1973) have shown that in a region in which moisture is not the main limiting factor the mean diameter of the stand is inversely proportional to stand density, but the volume production increases with increase in stand basal area up to a basal area of 23 m^2/ha. It is to be expected that under these conditions the effect of soil moisture on pine growth will likewise be less clear cut than in the case of the strongly seasonal climate of Western Australia. However, past experiences in the Australian Capital Territory and Victoria indicate that the drought problem is not peculiar to Western Australia.

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