Influence of Soil and Site Factors on the Productivity and Drought Susceptibility of Pinus radiata in the Blackwood Valley Region of Western Australia

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Abstract

Following the drought years of 1986 - 87 extensive mortality occurred in Pinus radiata (D.Don) plantations in the Blackwood Valley region of WA. A survey of the plantations was carried out in spring 1988 to determine whether tree deaths were associated with specific soil, site and plantation factors and, if so, to recommend site specifications for future plantations as well as determining the plantation density (as basal area) that various sites can carry during similar drought conditions.

The occurrence of drought death was related to soil depth, the position in the landscape, aspect and the initial basal area of the stand prior to the drought. Site index (top height at 30 yrs) was also related to the same site factors that influenced tree mortality. The slowest growing and most drought prone sites were on shallow soils on upper slopes and ridges facing north east and the fastest growing, least drought prone sites were on the lower slopes with deep soils.

Introduction

The Pinus radiata plantations in the Blackwood Valley cover 13,700 ha. This represents 26 percent of the area of publicly owned and managed pines in WA. (Department of Conservation and Land Management, 1987). The majority of the area (85%) was planted between 1960 and 1980.

The soils of the Blackwood Valley region range from the deeply weathered lateritic gravels and earths on the old Darling Plateau to the younger, finer textured and more fertile soils associated with the crystalline rocks exposed by the re-working of the drainage lines. On the valley sides the more shallow, younger soils overlie either a saprolite layer or the exposed crystalline rocks (Finkl 1971). Most of the P.radiata plantations in this region are located on the younger soils found in the valleys.

The climate is characterized by cool moist winters and warm to hot, dry summers. Mean annual rainfall varies from 850 to 1080 mm with 90% falling in the seven months between April and October. Thus tree growth and survival during summer depends on stored moisture. The last 20 years has been a period of relatively low rainfall in the Blackwood Valley. However, at none of the five recording centres, for which long term rainfall records were available, was the rainfall in either 1986 or 1987 the lowest on record. The two year period 1986-87 had the lowest cumulative rainfall for any two consecutive years. Consecutive dry years are reasonably common in the region as "dry periods" of between two and five years have occurred four times since 1950. Thus dry periods are reasonably frequent events in the Blackwood Valley.

Droughts in 1968 and 1969 and a series of dry years in the mid 1970's resulted in extensive tip death and some tree death in the plantations in the Blackwood Valley. The introduction of a silvicultural system based on early commercial thinning of the plantations was expected to solve most of the drought problems in this area. However, following the extremely dry winters of 1986 and 1987, during which annual rainfall was between 200 and 300 mm below average, extensive mortality occurred in the P.radiata plantations in the Blackwood Valley region.

Prior to establishment of the plantations soil surveys were carried out to determine the suitability of the soils for P. radiata plantations. The suitability of the soils was determined by their texture, geological origin and depth (to a maximum of 1 metre). The mortality following the 1986-87 drought indicated that the original soil classification system had been too optimistic on some sites.

A survey of the plantations was carried out in spring 1988 to determine whether tree deaths were associated with specific soil, site, and plantation factors and, if so, to recommend site selection guide-lines for future plantations.

Materials and Methods

A survey of 253 temporary plots ranging in age from 9 to 30 years was carried out in the Blackwood Valley plantations during spring 1988. A stratified random sampling technique was used, with sampling areas selected on the basis of plantation age and severity of impact. Plots were randomly located within the selected areas. At each plot, the soil profile to a depth of two metres was described and landform parameters (aspect, position in the landscape, slope type and slope angle) were determined after McDonald et al. (1984). Five landscape positions were recorded in the survey (crest, upper slope, mid slope, lower slope, valley). Due to the small number of plots that fell into the crest and valley positions these categories were combined with the upper slope and lower slope categories respectively, thus creating three categories of landscape positions (upper, mid and lower slope).

Tree and plantation parameters (stocking, top height [Ht of the tallest 50 trees/ha], diameter at breast height over bark [DBHOB], crown health) were measured. For each tree, crown health was classified into one of four categories: healthy; tip death; more than half crown dead; dead. Thus for each plot the proportion of the basal area that was healthy, drought affected or dead was determined.

The data were analysed firstly by one way analysis of variance with the dependent variables being the proportion of the basal area in a plot that remained alive (defined as live trees and trees with tip death) or the proportion of the basal area that was severely affected (defined as dead and half dead trees). A multiple regression model was constructed to allow the prediction of the likelihood of the drought susceptibility of sites. The dependent variable in the regression model was top height. All independent variables included in the regression models were significant at the $P<0.05$ level.

Results and Discussion

Influence of Site Factors on Tree Mortality

The three site factors that had a significant impact on the occurrence of symptoms were soil depth (depth to either saprolite or rock), position in the landscape (upper, mid, lower) and aspect. Although these factors are interactive, for simplicity, the main effects will be presented independently.

Soil depth

When live basal area (trees with only tip death and live trees) was plotted against soil depth it was apparent that as soil depth increased the maximum basal area that was carried on a site increased (Fig. 1). A boundary line analysis indicates that the maximum basal area remaining after the drought increased from 20 to 48 m2ha-1 as soil depth increased from 0.5 to 2.0 m. However, for any soil depth there were a number of instances where the live basal area was considerably less than the maximum. Reasons for the scatter of data below the maximum may be: the interactive effect of other site factors reducing the maximum basal area that can be carried at any soil depth; the occurrence of "over kill" where plots above the carrying capacity of the site "over thin" when exposed to severe drought stress; plots may not yet have reached their maximum carrying capacity.

As soil depth presumably provides an indicator of the maximum quantity of water available to the trees, it was thought that examining the depth to heavy clay may provide an indicator of rooting depth and available soil volume. When live basal area was plotted against depth to heavy clay (Fig. 2) no relationship was obvious, indicating that soil texture did not provide a guide to penetration by P.radiata roots

Landscape position

The proportion of affected basal area increases from the lower to the upper landscape position (Table 1). Even without taking the interactive effects of soil depth, aspect, and initial basal area into account the overall effect of landscape position was significant at P<0.08. Presumably the effect of landscape position is related to drainage with the upper slope being a water shedding zone and the lower slope being a water gaining zone, but there may also be a microclimate effect, with the upper slopes being more exposed and the lower slopes more protected.

Aspect

Various divisions of aspect were tried to determine whether aspect had an influence on the pattern of drought impact. A "moving mean" of the percentage of basal area affected, was calculated by swinging a 90o segment at 45o intervals. The resulting moving mean is shown in Figure 4 for both the severely affected category (dead and trees with intermediate symptoms) and the all affected category (dead, intermediate and tip dead trees).

A greater proportion of the basal area was affected on north easterly aspects. The worst affected zone was a 90o sector from 335o to 65o. The mean percentage of the basal area that was severely affected in this sector was 24.9 compared with 16.9 in the remaining 270o sector, and this difference was significant at P<0.02. It is also apparent from Figure 3 that a similar proportion of the basal area had tip death in all the sectors. The greater incidence of severely affected trees on north east slopes is probably not related to soil depth as there was no difference in mean soil depth between the north east sector and the remaining sector.

Aspect also had a significant effect on top height and site index, this suggested that the drier environment on the north east slopes has had a long term influence on tree growth, not just an acute effect during dry periods. The most common effect of aspect on tree growth occurs via higher solar radiation on north and west aspects (southern hemisphere) and south west aspects (northern hemisphere) (Einspahr and McComb 1951). The greater incidence of symptoms in the north east sector suggests that a factor other than radiation is involved, possibly the desiccating effect of the prevailing east winds during summer, or possibly a rain shadow effect, since winter rain drives in from the south west.

Windroses for the period November to April for Kirup (Fig. 4) show an overall summer pattern of east, south east winds in the morning and westerly sea breezes in the afternoon. The most obvious feature being the stronger winds and greater frequency of north east winds during the summer of 1987-88. Thus the two year dry period was characterised by low winter rainfall, dry summers and stronger than normal east to north east winds.

Predicting which Sites are Susceptible to Drought Stress

To predict the likelihood of drought impact we first predicted site index and then examined the relationship between initial basal area and surviving basal area in each site index class.

Relationship between height growth age and site factors

Although, there was a strong relationship between age and top height, there was still considerable variation that was not explained by age alone. Part of this variation was attributable to the same environmental factors that influenced the occurrence of drought death. The regressions between top height and age, soil depth, and aspect for each landscape position accounted for between 84 and 86 percent of the variation. The relationship was not improved by adding slope to the equations, presumably because the main effect of slope in decreasing water availability is taken into account by soil depth and position in landscape. Aspect was a significant contributing factor only in the upper slope position. The increase in productivity with increasing soil depth is similar to that reported for radiata pine in New Zealand by Jackson and Gifford (1974).The equations which link the elements of the model are:

Equation 1: Upper slopes and ridges

1n(TopHt)=3.46+.0798*soil depth+.000911*aspect - 8.01/age

N=110
R2(adj)=0.83
F=183.82 P<0.001
s=.08962

Equation 2: Mid slopes

1n(Top Ht) = 3.64 + 0.0761 * soil depth - 9.89/age

N=123
R2(adj)=0.85
F=338.24 P<0.001
s=.09232

Equation 3: Lower slopes and gullies

1n(Top Ht) = 3.73 + 0.0583 * soil depth - 9.19/age

N=52
R2(adj)= 0.84
F=134.43 P<0.001
s=.08618

Note: Soil depth (m); Aspect is the departure in degrees azimuth from a bearing of 200

Defining site index as the predicted top height of the trees on a site at age 30 years, and given a soil depth ranging from 0.3 to over 2.0 metres, we find that the upper slopes and ridges have a theoretical site index range from roughly 26 to 33 metres at age 30, depending on soil depth and aspect; midslopes from 30 to 33 metres depending on soil depth, and lower slopes and gullies over 34 metres. These site indices can be conveniently split for management purposes into four site classes (Table 2).

The relationship between the initial basal area and surviving basal area for the four site classes is shown in Figure 6. Progressing from site class I to site class IV the amount of basal area lost during the drought increased. For site class 1 there was no apparent limit on the basal area that could be carried, while for site class 4 any area with an initial basal area above 30m2ha-1 would lose a large proportion of its basal area. While not providing a precise indication of the amount of basal area that will be lost in similar drought conditions, the site classes provide a good guide to the likely success or failure of the plantations.

Conclusions and Implications

Soil depth (defined as depth to rock or saprolite), position in the landscape, aspect and plantation density (defined as basal area per hectare) were the only factors that had a significant effect on the occurrence of tree death or partial crown death.

The same site factors that influenced the occurrence of drought deaths were related to height growth. Regression models describing height growth based on age, soil depth, landscape position and aspect were developed. Thus sites can be classified prior to planting on the basis of their productivity and drought susceptibility. Early thinning reduces the impact of drought on the plantations, by reducing the initial basal area of the stands. However, on the more drought prone sites, thinning will not totally prevent drought deaths. To minimise the impact of droughts, thinning should be concentrated on the more drought prone sites.

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Table 1. Influence of position in the landscape on the mean percentage of the basal area that was severely affected by drought (dead and half dead trees).

Trend was tested by regression: F=5.15; P<0.03

Landscape position	Sample size	Mean percentage affected	Standard error
Upper	95	22.4	2.9
Mid	112	18.2	2.0
Lower	45	12.6	2.8

Table 2. Site class limits and main location of site classes .

Note: * indicates main location for each site class

Site class	1	2	3	4
Top height (at 30yrs)	>34m	32-34m	30-32m	<30m
Upper	no	yes	yes	yes*
Mid	no	yes*	yes*	yes
Lower	yes*	yes	yes	no