THE ROLE OF ORGANIC MATTER IN THE MAINTENANCE OF SITE PRODUCTIVITY ON SANDY SOILS

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ABSTRACT

A comprehensive research programme is being undertaken in south-west Victoria to study the productivity of successive crops of radiata pine planted on infertile sandy soils low in organic matter. The research has concentrated first on identifying the important edaphic and environmental factors regulating growth in this locality and, secondly, on the effects of management practices on these factors. Results have been used to establish principles which need to be followed in order to maintain site productivity for radiata pine monocultures growing on such soils in low-rainfall regions. It has been shown that litter and logging residue remaining after clearfelling should not be burnt but left on-site so as to conserve organic matter and nutrients (especially nitrogen). The residue also acts as a surface mulch to conserve soil moisture.

INTRODUCTION

In recent times the ability of forest managers to maintain site productivity in radiata pine (*Pinus radiata* D.Don) monocultures has been challenged, particularly where plantations have been established on infertile, sandy soils low in organic matter (OM) such as those in the south-east of South Australia and neighbouring areas in Victoria. This followed reports of a substantial decline in productivity between first rotation (1R) and second rotation (2R) stands of radiata pine in the Mt Gambier region (Keeves, 1966). Whilst it has been claimed that radiata pine can, in fact, act as a soil improver (Will and Ballard, 1976), we are unaware of any studies which have carefully compared the growth of successive crops of radiata pine established on the one site using planting stock of comparable genetic and physiological quality and similar site preparation procedures to determine the magnitude of any decline and factors responsible for such a decline.

In 1975 a comprehensive research programme was initiated at Rennick in south-west Victoria to study this problem and pro-

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vide information to guide the development of silvicultural practices aimed at maintaining or possibly increasing productivity over successive rotations. This paper reviews the results of these studies and discusses their application to field practice.

THE STUDY AREA

Rennick is located in south-west Victoria and is within 25 km of the coast and 18 km of Mt Gambier. Over 100 000 ha of radiata pine plantations are growing on sandy soils of aeolian origin. Many soil types are represented and these have been described in detail by Stephens *et al.* (1941). The depth and fertility of the soils vary considerably and this variation is indicated by the growth of radiata pine. The sands are, however, relatively infertile by world standards for forest soils and contain very low OM levels in the surface horizons. For example, in a study comparing soil chemical properties under native eucalypt forest and mature radiata pine growing on Caroline sand which is a common soil type planted in this locality, it was found that the surface horizon (0-20 cm) only has around 1.6% OM, 0.03% total N, 40 ppm total P and 3 ppm water-soluble P (Hopmans *et al.*, 1979).

The area has a mean annual rainfall of around 800 mm with mean monthly rainfall being above 100 mm in mid-winter and less than 30 mm in mid-summer when maximum daily temperatures often exceed 30°C. Soil moisture availability, particularly during summer and autumn, is therefore one of the major factors regulating the early growth of radiata pine on these coarse-textured soils. The benefits of reduced competition for soil moisture through weed control during the establishment phase of radiata pine plantations in this locality have been clearly demonstrated by Woods (1976).

SITE PRODUCTIVITY STUDIES

An experiment was established in 1975 to compare the growth of 1R and 2R stands of radiata pine at Rennick. The study encompasses a range of site qualities and includes long-term comparisons of 1R and 2R growth on the *same* sites and an examination of growth on matched 1R and 2R sites in relation to edaphic, physiological and meteorological factors. This latter component of the study will provide interim evidence on the likely direction and magnitude of any change in productivity. A detailed account of the methods used to establish this study is given by Squire *et al.* (1979).

Briefly, plots were established in both low and high site quality 1R stands of 25- to 28-year-old radiata pine in the Rennick plantation. Stem analysis techniques were used to determine total underbark volume and height growth as functions of age before the stands were clearfelled and the 2R crop planted. Logging residue from the first crop was left unburnt and distributed uniformly over the plots. Every attempt was made to establish the 2R crop in exactly the same manner as the 1R crop. Seeds were collected from the plots before clearfelling and seedlings raised under cultural practices used in the late 1940s. Past practice was also followed during planting. This approach will enable valid comparisons of the productivity of 1R and 2R crops to be made as site factors and to some extent genetic influences have been taken into account and establishment and tending practices standardised. Climatic differences between rotations, particularly the amount and distribution of rainfall, could not, however, be eliminated but they are being measured.

Plots were also established on sites in adjacent native eucalypt forest. These 1R sites were matched with the above 2R sites using species composition and height of native vegetation, topographic position and soil profile characteristics. To simulate past practice, the native vegetation was hand-cleared, broadcast burnt and the plots pit-planted using seedlings raised as described earlier.

As the 1R and 2R crops develop, regular measurements are being made of shoot and root growth, weed competition, soil temperature and moisture, plant water status and nutrient uptake. Results for the first year after planting are discussed in detail by Squire *et al.* (1979). The most important findings were:

(1) Basal area (2.5 cm above ground) and height growth of trees on 2R plots of low and high site quality were substantially better than on matched 1R plots.
(2) Soil moisture levels in the zone containing most of the roots (0-45 cm) were far more favourable for tree growth on 2R than on 1R sites over the first summer to autumn period when the above growth differences were established.
(3) Pre-dawn measurements of leaf water potential showed that water stress was considerably higher in 1R than in 2R trees during the first summer after planting.
(4) Scrub competition was much higher on burnt 1R sites than on the unburnt 2R sites.
(5) Concentrations of nitrogen in the needles of trees on 2R sites were consistently higher than for 1R trees.

On the basis of these early results, Squire *et al.* (1979) postulated that better early growth on 2R sites was due to increased soil moisture availability through a surface mulch of litter and logging residue which reduced weed growth and evaporative losses. Squire *et al.* (1979) also suggested that more favourable surface soil moisture levels on 2R sites increased nitrogen availability through accelerated mineralisation of organic nitrogen.

THE IMPORTANCE OF NITROGEN, MOISTURE AND ORGANIC MATTER

Woods (1976) has shown that early growth of radiata pine in this locality can be substantially increased by eliminating weeds (and hence conserving moisture) and applying nitrogen during the establishment phase. In the study reported by Squire *et al.* (1979) there was evidence that soil moisture and nitrogen availability were key factors responsible for better early growth on 2R sites. To explore this further, incubation tests were carried out to study potential rates of ammonification and nitrification in the surface (0-3 cm) layer of Caroline sand (Hopmans *et al.*, 1980) Tests were conducted over a range of soil moisture contents and incubation periods and it was shown that *potential* ammonification rates are relatively high and strongly dependent upon moisture content. Despite a C/N ratio of 31 in the soil under radiata pine, up to 74 ppm ammonium was detected at a soil moisture content of 20% after 60 days' incubation compared with only 30 ppm at 5% moisture content. These results reinforced the hypothesis advanced by Squire *et al.* (1979) that litter and logging residue acted as a surface mulch to conserve soil moisture and increase nitrogen availability to radiata pine.

Until recently, current practice in this region has been to burn logging residue (and hence litter) following clearfelling of radiata pine crops, despite an early warning from Stephens and Bond (1957) that nitrogen losses through burning could lead to problems in maintaining soil fertility on these sandy soils. To determine the significance of nutrient losses (especially nitrogen) associated with the burning of litter and residue, a study was undertaken at Rennick and the results reported by Flinn *et al.* (1979). It was estimated that the combined losses of nitrogen from harvesting and burning represent around 28% of the total nitrogen in the pine ecosystem to a soil depth of 50 cm. Such a loss is serious in view of the low nitrogen status of these sandy soils and the possibility of further losses following burning through

leaching of nutrients down the soil profile and through soil and ash movement from the site by strong winds. Since inputs of nitrogen through rainfall and fixation are likely to only partially offset these losses, it was concluded by Flinn *et al.* (1979) that burning should be avoided if the productivity of these sites is to be maintained without substantial fertiliser additions.

Nutrients, however, are not the only loss when burning is practised. In the study reported by Flinn *et al.* (1979), an 84% loss in dry weight of logging residue and litter was recorded, and almost total loss of this organic material can be expected in hot broadcast or window burns. As noted previously, most of the soils planted to radiata pine in this locality have relatively low OM levels and it is well known that this soil property has a large bearing on the moisture and nutrient retention characteristics of sandy soils.

Agricultural experience shows that it is a very difficult and slow process to increase soil OM levels, and that there is a limit to the equilibrium level that can be attained depending on soil properties (particularly texture, aeration and fertility), climate (rainfall and temperature) and management effects such as fire and cultivation. However, it is very easy through mismanagement to rapidly reduce soil OM levels. Work by Flinn *et al.* (1979) in unthinned stands at Rennick indicates that around 80 t/ha of organic material remains on a site following clearfelling and harvesting. Higher volumes of logging residue have been recorded (*e.g.* 140 t/ha) where utilisation has been less intense owing to unfavourable marketing conditions. Although retention of this organic material between successive crops of radiata pine is likely to make only a small contribution towards increasing soil OM levels, it at least ensures that the relatively low levels existing at present should be maintained. Hot burns not only remove this source of OM but can significantly reduce OM levels in the surface horizon through direct combustion (Grier, 1975). Wildfires in this region during 1979 left a bleached surface soil where fire intensity was extreme, indicating direct and substantial losses of soil OM from this horizon which contains the greatest concentration of OM.

It is considered that conservation of OM through retention of litter and logging residue is vital to the maintenance of site productivity on these sandy soils. This retained organic material can also be used to advantage as a surface mulch to conserve soil moisture. Organic mulches are known to be very effective at reducing run-off of water (not a factor at Rennick) and evaporation

of moisture from the surface horizons of the soil. This provides a more even supply of moisture to plants. Ideally a mulch should not absorb significant quantities of water or consolidate into a tight surface which could reduce movement of oxygen into the soil and increase run-off. Observations indicate that litter and chipped logging residue have these desirable characteristics, and roots have been found to proliferate in this mulch in all of the studies at Rennick. The question remains, however, as to how to obtain this surface mulch under operational conditions so that sites can be planted at reasonable cost and movement of machinery is possible.

OPERATIONAL TRIALS

Flinn (1978) reported the results of a study at Rennick aimed at comparing alternative methods of establishing radiata pine on a former *P. pinaster* site. The three site preparation methods listed below were tested on an operational scale in combination with a range of fertiliser and weedicide treatments:

(1) Slash macerate and scalp along planting lines

(2) Broadcast burn and plough

(3) Windrow burn and plough.

Early growth was found to be markedly better on sites where residue was retained, and this was largely attributed to improved moisture availability through a partial mulching effect provided by the litter and logging residue. It was speculated that scalping which was necessary to expose planting lines reduced the effectiveness of the mulch and that later growth on unburnt sites will benefit through nutrients released from the organic remains. In the study a tractor-drawn spiked roller was used to achieve slash maceration, but this equipment was found to be less than ideal as the residue was only partially crushed which necessitated scalping along the planting lines before hand-planting. We believe that during attainment of a surface mulch, soil disturbance (*e.g.*, scalping) should be minimised so that weed growth is discouraged. A prototype machine with the capacity to reduce high volumes of logging residue to a surface mulch is currently being evaluated in Australia. The machine is being developed by a consortium consisting of Geoff Williames (Aust.) Pty Ltd (manufacturer), APM Forests Pty Ltd, Woods and Forests Department South Australia and Forests Commission Victoria.

CONCLUSIONS

Maintenance of site productivity is a fundamental responsibility of forest managers. In fragile ecosystems such as radiata pine plantations growing on infertile sandy soils low in OM, retention of litter and logging residue to conserve soil moisture, OM and site nutrients is likely to be the only reliable means by which site productivity can be maintained. It has been advocated that nutrients lost by harvesting and other management practices should be replaced by fertilisers (Will and Ballard, 1976; Adams, 1978). This measure, however, is not considered sufficient to sustain productivity on soils low in OM where it is essential to conserve organic material so that soil OM levels are at least stabilised. This can be achieved through retention of litter and logging residue following harvesting.

Results of the research programme at Rennick show that litter and logging residue remaining after clearfelling and harvesting can be left unburnt on the site and used as a surface mulch to conserve organic material, soil moisture and nutrients. Such a procedure will also reduce fertilizer and weedicide inputs. Though the same principles apply to more fertile sites, loss of organic material through burning is likely to be less important on soils with relatively high OM levels. The principle of a surface mulch containing significant quantities of nutrients could, however, be relevant on soils with a high phosphate retention capacity as roots may have direct access to P mineralised from the organic material before it is strongly adsorbed by the soil.

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