INFLUENCE OF STAND AND SITE ON RADIATA PINE LITTER IN SOUTH AUSTRALIA

R. G. FLORENCE and D. LAMB*

Department of Forestry,
Australian National University, Canberra

(Received for publication 18 October 1973)

ABSTRACT

Within plantations of radiata pine in the south-east of South Australia, variation in the soil type appears to have a greater effect on litter accumulation than variation in site productivity. Differences in litter accumulation are probably related to differences in rates of litter decomposition rather than litterfall. Relatively large accumulations of litter are found on most sand dune soils in the region, and this could contribute to problems of continuing site productivity on them.

INTRODUCTION

Since the early 1900s, plantation forests of radiata pine (*Pinus radiata* D. Don) have been established on the sand dune and related soils in the south-east of South Australia. Second rotation stands have been planted since 1940, and during the past decade it has become clear that their productivity is less than that of the first rotation stands on the same sites (Keeves, 1966). Florence (1967) and Bednall (1968) have discussed possible factors contributing to this decline. One hypothesis is that the rate of nutrient cycling within the pine stands is too slow to maintain indefinitely the early levels of wood production, and excessive quantities of nutrients may become immobilized in the litter layers of these stands.

The litter layer of a forest can contain a surprisingly large percentage of stand nutrients. For example, in a *Pinus nigra* forest, 52% of total stand nitrogen was held in the litter layer (Miller, 1969), and in a young unthinned *P. sylvestris* forest, 82% of stand nitrogen was in the litter layer (Ovington and Madgwick, 1959). While it is unlikely such a large fraction of total stand nitrogen would be immobilized in the litter layer of a highly productive forest, any unduly large accumulation of litter, and litter nutrients, could preclude continuing high levels of wood production, particularly where the soil nutrient store is small.

As part of an investigation of litter nutrient cycling in the South Australian plantations, this paper documents the weights of litter found on the forest floor, and describes the way a number of stand and site variables influence these accumulations, and the rate of accretion, by litterfall, to them.

* Present address: Department of Forests, Port Moresby, Papua New Guinea.

N.Z. J. For. Sci. 4 (3): 502-10

MATERIALS AND METHODS

Site Quality and Soils

Within the region, stand productivity is categorized on a stand volume basis within the range Site Quality (SQ) I to SQ VII, corresponding to the highest and lowest productivities respectively (Lewis, 1967).

The soils of the region were first described and mapped by Stephens *et al.* (1941) and their nomenclature will be followed here. Most soils are derived from calcareous beach sands and estuarine or lacustrine deposits and occur in a parallel series of Quarternary beach ridges. Deep podzolised sandy soils are found on the ridges (e.g. Nangwarry sand, Mt Burr sand), calcimorphic soils on occasional outcrops of Miocene limestone, and a complex of hydromorphic and calcimorphic soils on the flats between the ridges. Within these groups, variations occur in the depth to the clay horizon, colour, texture and structure. Soils transitional between the recognised types are common but not widespread.

In general, the nutrient status of the soils is poor. Stephens *et al.* (1941) found nitrogen levels in most of the sand podzols to range from less than 0.15% at the surface to about 0.05% in subsoils while phosphate concentratiosn commonly ranged from 0.02% total phosphorus at the surface to less than 0.001% in subsoils. Most soils have low water holding capacities and are subject to considerable moisture tensions in summer.

The Litter Sampling

Some effects on litter accumulation of differences in stand age, site quality and soil type were examined by sampling within 30 stands, as follows:

(i) Stand age: Samples were collected from an age sequence of stands towards the upper end of the productivity scale (SQII stands aged 11, 21, 30 and 37 years), and at the lower end of the economically productive scale (SQV stands aged 11, 19, 29 and 40 years). All SQV stands were on Mt Burr sand, and three of the SQII stands were on meadow podzolics. With the exception of the 40-year stand the SQV sequence, all sampled stands were unthinned.

(ii) Site quality: Four stands were sampled on Mt Burr sand and four on Nangwarry sand; for each soil type, sampling covered the site quality range SQII to SQV. Stands on Mt Burr sand were aged 30 years, and Nangwarry sand, 40 years. All stands had received the normal, relatively conservative, thinning applied in the region.

(iii) Soil type: Twelve additional stands were sampled to cover a range of soil conditions; these were about SQII in productivity and were within the age range 30-40 years. The soil types included the sand podzols, meadow podzolics, terra rossa soils, and soils transitional between sand podzols and terra rossa soils. All twelve stands had received normal thinning.

Sampling Procedure

The weight of litter at each site was measured at 50 random points within a 30 m square. Samples were taken by plunging a 10 cm tube through the litter into the mintral soil. The samples were separated into L and F + H layers, oven-dried at 80°C and weighed. Woody material greater than 5 cm diameter was excluded. As litter samples taken in this way have a variable quantity of sand included, sand contents were measured and oven-dried weights were adjusted to give the weight of organic matter at each site on a sand-free basis.

Litterfall

Litterfall was sampled at four sites, all about SQII, and carrying 30-year-old stands. At each site, monthly collections were taken from 15 trays, distributed within the same area sampled for litter accumulation. Each tray had an area of 0.37 m^2, wooden sides 10 cm deep, and a nylon mesh base. The litters were separated into woody (i.e. female cones and twigs larger than 5 mm diameter) and non-woody material (all other material), oven-dried and weighed. Collections were made over two years.

RESULTS

Accumulation of Litter on Different Sites

In radiata pine plantations, litter accumulates rapidly on the forest floor (Table 1). The rate of accumulation may be particularly fast on highly productive sites. At 11 years, 10 700 kg/ha were present on the SQII site and 6110 on the SQV site. At this age there was no clear differentiation into L and F-layers although this process had commenced. In the series examined, the SQII stand contained 32 200 kg/ha litter at 21 years, nearly double that of the SQV stand of comparable age. This large accumulation probably reflects the heavy litterfall associated with early crown closure and rapid rise of the green crown in an unthinned SQII stand. Beyond 20 years the weight of litter accumulated in a high quality stand may decline as litterfall stabilises. This apparently occurred in the series examined, where there was little difference between the accumulations at 30 and 40 years (22-24 000 kg/ha). On lower quality sites, the rise in green crown level may be slower, so that a more progressive increase in litter weight occurs. In the series examined, litter weight increased from 15 860 kg/ha at 19 years to 22 500 at 40 years. This latter weight is similar to that recorded for the SQII series at 30 and 40 years. Thus it seemed that by 30-40 years the weight of litter on the forest floor might be independent of site quality. To test this, litter accumulation was examined in a series of stands where stand age (30-40 years) and soil type (sand podzol) were held constant, and site quality was varied within the range of SQII to SQV.

TABLE 1—Litter accumulation in unthinned **P. radiata** stands of SQII and SQV on sand dune soils in South Australia. Figures in parentheses are standard errors of 50 samples.

Stand age (years)	Soil	Litter weight (kg/ha) L layer	F layer	Total
(i) Site Quality II				
11	meadow podzolic	—	—	10700 (520)
21	meadow podzolic	11700 (830)	20500 (1310)	32200 (1540)
30	meadow podzolic	10050 (830)	12590 (1640)	22640 (610)
37	modified Mt Burr sand	6040 (180)	18330 (940)	24370 (570)
(ii) Site Quality V				
11	Mt Burr sand	—	—	6110 (550)
19	Mt Burr sand	5520 (270)	10330 (540)	15860 (600)
29*	Mt Burr sand	6640 (240)	9580 (790)	16230 (850)
40**	Mt Burr sand	6530 (280)	15960 (740)	22500 (840)

* Site quality is between V and VI

** Lightly thinned, no unthinned stand available

Litter Accumulation and Site Quality

At 30 and 40 years, variation in site quality had no consistent influence on weight of litter accumulated on sand podzol soils (Table 2). All of the eight stands through the range had accumulations between 20 and 26 000 kg/ha, similar to weights previously recorded for stands of this age on sand podzols and meadow podzolics (Table 1).

TABLE 2—Influence of differences in site quality on the amounts of litter accumulated in 30- and 40-year-old stands of **P. radiata** on two sand podzol soils. Figures in parentheses are standard errors for 50 samples

Soil: Stand age:	Mt Burr sand 30 years	Nangwarry sand 40 years
SQII	26520 (560)	25130 (990)
SQIII	20210 (880)	22030 (710)
SQIV	24220 (760)	23100 (690)
SQV	24490 (990)	26110 (850)

The observation that litter accumulated is independent of site quality must be qualified to the extent that the litter accumulation on sand podzols and related soils may be significantly smaller in stands below Site Quality V. Thus, while the litter accumulations in stands on Mt Burr sand ranged between 20 000 and 26 000 kg/ha (Table 2), the 29-year stand on a Mt Burr sand in Table 1 had a litter accumulation of only 16 230 kg/ha; this stand is a permanent management plot and has a productivity rating between SQV and SQVI. Measurements and observations elsewhere support this qualification.

Litter accumulation could also be affected by variations in the timing and intensity of thinning. However, the broad similarities of litter weights at 30 and 40 years in unthinned stands (Table 1) and thinned stands (Table 2) suggested the conservative thinning regimes invariably applied in the late 1940s and 1950s may have had little effect on litter accumulation. To examine this further, weights of litter were sampled in thinned areas adjacent to the unthinned sample plots. Thinning had no significant effect on the weight of F-layer litter at any site, but total litter weight was significantly smaller at two thinned sites (20 and 30-year SQII stands). For the purposes of this study, it is accepted that conservative thinning regimes have little consistent effect on litter accumulated by age 30 to 40 years. Early and heavy thinning could influence litter accumulation, but it has not been possible to determine this in the study region.

Litter Accumulation and Soil Type

It has been shown that by 30-40 years the weight of litter accumulated in radiata pine plantations could be more or less independent of site quality over a broad site quality range. However, the supporting data were drawn only from stands growing on sand podzols and meadow podzolics. It was evident from field observation that litter accumulation was in fact considerably smaller in some healthy and vigorous stands, and that major variations in accumulation might be related to differences in soil type and other environmental factors, rather than to site quality *per se*. The third study was made to investigate this.

Where both the stand age range (30-40 years) and site quality (II or III +) were constant, there was a wide range in litter accumulation (Table 3). The greatest accumulations were found on sand podzols (up to 27 720 kg/ha), and the least on the soil referred to as having a "Nangwarry-Wandilo" profile. This latter stand had a litter accumulation of only 11 830 kg/ha. The stand is within the general area of occurrence of Nangwarry sand, but the soil has a variable depth of sand over a clay layer more typical of the humus podzol, Wandilo sand. The five stands growing on the terra rossa soil and terra rossa-influenced sands also had considerably smaller accumulations than most of the stands on sand podzol profiles. The range in accumulation for the terra rossa group was 15 270 to 19 190 kg/ha. The two stands on the meadow podzolic soils had accumulations of 19 550 and 22 640 kg/ha respectively. The one stand on a sand podzol soil not conforming to the general sand podzol pattern was a Nangwarry sand with a litter weight of 17 860 kg/ha. In this case, the crowns were sparse, only one- and two-year needles were retained, and these were short and chlorotic. Possibly, site or crown deterioration has occured here following early vigorous stand growth.

TABLE 3—Litter accumulation (kg/ha) in 30 to 40 year old stands of **Pinus radiata** growing on different soils in the south-east of South Australia. All stands are SQII or SQIII+. Figures in parentheses are standard errors for 50 samples

Soil type	L-layer	F-layer	Total litter
SAND PODZOLS			
Mt Burr sand	5920 (280)	21800 (1670)	27720 (420)
Mt Burr sand	3660 (130)	22860 (1120)	26520 (560)[1]
Nangwarry sand	7760 (380)	17370 (1070)	25130 (990)[1]
Mt Burr sand	6040 (180)	18330 (940)	24370 (570)[1]
Nangwarry sand	6710 (280)	16480 (900)	23190 (900)
Mt Burr sand	5050 (160)	16720 (1140)	21770 (580)
Nangwarry sand	4030 (150)	13830 (770)	17860 (380)
MEADOW PODZOLICS			
Sandy meadow podzolic	10050 (830)	12590 (1640)	22640 (610)
Wandilo sand	4810 (280)	14740 (1050)	19550 (540)
DEEP TERRA ROSSA and TERRA ROSSA-INFLUENCED SANDS			
T.R.-sand	3190 (150)	16000 (1000)	19120 (500)
T.R.-sand	4570 (200)	12870 (880)	17180 (450)
Deep terra rossa	4390 (200)	12360 (790)	16750 (510)
T.R.-sand	3940 (140)	12340 (750)	16270 (380)
T.R.-sand	4820 (240)	10450 (600)	15270 (320)
"NANGWARRY-WANDILO SAND"			
	6140 (360)	5820 (570)	11830 (340)

[1] Data drawn from Tables 1 and 2

In most stands, the F-layer constitutes the greater part of the total litter present, although there are exceptions to this. Where the F-layer only is considered, the effect of soil type on accumulation is just as pronounced. For example, the range in weight of F-layer litter is 16 480 to 22 860 kg/ha on most sand podzols, and 10 450 to 16 000 kg/ha on the terra rossa and transitional soils. The Nangwarry-Wandilo stand had only 5 820 kg/ha of F-layer material.

Over the range of soil types, the litter layer varies not only quantitatively, but qualitatively as well. At the typical sand podzol site, the L-layer is composed of bright, orange-brown, or yellow undecomposed whole needles, sharply differentiated from an F-layer of grey-brown, broken and decomposed needles matted by fungal hyphae. In contrast, it was sometimes difficult to determine a line of demarcation between L and F-layers when sampling litter on the deep terra rossa soil, on some of the transitional soils and on the Nangwarry-Wandilo soil. In these cases there is no matted F-layer or it has a patchy distribution. Rather, a loose layer of whole needles may grade into a layer of fragmented grey brown needles overlying the mineral soil. In effect, the litters on the sand podzols have definite mor-humus forms, while those lacking a well defined F-layer resemble mull-humus forms. It is important to note that the latter form has probably only a very limited occurrence in the plantations of the region.

Litterfall

There are two reasons why litter accumulation might vary widely in stands of similar age and site quality. There may be a smaller annual accretion in those stands with smaller accumulations, or the rate of litter decomposition in them may be faster. While it seemed more likely that differences in decomposition would account for the differences in accumulation, it was necessary to confirm this. In the first instance, this was done by examining the relationship between litterfall and litter accumulation. Later investigations were concerned with differences in litter as microbial substrates.

Litterfall was compared in adjacent stands growing respectively on a Mt Burr sand and a terra rossa-influenced Mt Burr sand. It was also compared on a Nangwarry sand and a nearby soil previously described as having a "Nangwarry-Wandilo" profile. In each situation the sand podzol site had a considerably greater litter accumulation than the associated "transitional" soil site (Table 4).

The annual litterfalls recorded in this study ranged from 3255 to 4195 kg/ha (Table 4), and are of the same order as the mean annual fall of 3390 kg/ha recorded by Pawsey (1959) over a 4-year-period at a Mt Burr sand site. They might be regarded, therefore, as typical litterfalls for this region.

The Nangwarry sand site had a significantly greater litterfall than the Nangwarry-Wandilo site in 1969, but over the two years of measurement litterfalls were closely similar at the two sites. The fall of non-woody litter (needles, male cones) was smaller

TABLE 4—Annual litterfall (kg/ha) in four 30-year old SQ II stands of **P. radiata**

Soil		Weight of litter on forest floor	Non-woody litterfall		Total litterfall		
			1969	1970	1969	1970	Mean
Nangwarry sand		17720	2743	3139	3788	3789	3788
"Nangwarry-Wandilo" profile		11830	3088	3919	3255	4125	3690
Mt Burr sand		28030	3485	3127	3954	3361	3657
Mt Burr sand-terra rossa transitional		15270	3739	3855	4079	4195	4137
Significance of difference	P = 0.05		246	190	493	353	
between sites:	P = 0.01		328	252	656	471	

at the Nangwarry sand site in both years. At the two sites based on Mt Burr sand, total litterfall over the two year period was greater on the transitional soil; it was substantially greater on the transitional soil in 1970. Thus there is no evidence that weight of litter on the forest floor is a function of weight of annual litterfall. Indeed litterfall, particularly non-woody litterfall, may be somewhat greater at sites with smaller litter accumulations.

The litterfall study has been too limited to rule out any possibility that litterfall and litter accumulation are related; for example, litterfalls could have differed markedly at younger ages on the different sites. However, on the evidence available it seems reasonable to infer that differences in accumulation are not related to litterfall, but are determined by differences in the rate of litter decomposition on the forest floor.

DISCUSSION

Litter accumulation and litter type appear to be strongly influenced by soil type, but the particular soil or litter properties responsible for this are not clear. In some cases they may be chemical, while in others the physical soil properties may be more important. For example, an accumulation of 16 750 kg/ha was recorded in a SQII stand on a deep terra rossa soil in a gentle lower slope position (Table 3) while an accumulation of 26 630 kg/ha was recorded on a shallow terra rossa soil in an upper slope position. The latter stand was assessed as SQIV. These two sites would differ primarily in soil depth and soil moisture status. Hence, soil moisture could be the factor influencing the relative size of the two litter accumulations. A similar pattern was found by Minderman (1960) in hardwood forests in Holland. A heavy mor humus occurred on coarse-textured soils at well drained sites but a more decomposed mull humus was found on finer-textured soils, or where the topography produced a moister site. He suggests a more favourable soil moisture status could prolong the period during which microbial activity occurred, leading to greater decomposition.

While soil moisture status could be a critical factor in litter accumulation at some sites, it probably does not account for differences in accumulation at all sites. For example, the soil surface at the Nangwarry-Wandilo site is not appreciably moister than adjoining Nangwarry sand sites and yet the difference in litter accumulation is very great indeed. Here, litter and soil nutrient levels may be of greater significance than soil moisture.

Any conclusions from this study on relationships between site quality, soil and litter accumulation are valid only if litter weight is more or less stable by 30-40 years, that is, if a dynamic equilibrium exists between litter accretion and litter decay. Some evidence suggests this is a reasonable working assumption. There were no consistent differences between accumulations at 30 and 40 years in the South Australian stands on sand dune soils and several studies elsewhere indicate a similar pattern. Forrest (1969) suggested the 17 000 kg/ha he recorded in a 12-year stand was the maximum likely to occur in the Tumut district, NSW, and Hamilton (1964) demonstrated an equilibrium after 35 years in plantations near Canberra. Kittredge (1940, 1955) showed litter accumulation in radiata pine plantations in USA approached an equilibrium after 30 years.

On the assumption of an equilibrium, the main conclusions from this investigation are—

(i) Within a single geographic region, or even a single forest, large differences in litter accumulation are found in radiata pine stands of similar age and site quality.
(ii) These differences probably reflect differences in the rate of organic matter decomposition, rather than differences in litterfall.
(iii) Stands having small litter accumulations and a mull-type humus are probably restricted in distribution, occurring only where soil and other environmental conditions are particularly favourable.
(iv) Stands having larger litter accumulations and distinctive mor-type humus are widespread, occurring on sand podzols, meadow podzolics, some terra rossa-influenced sands, and shallow terra rossa soils.
(v) On the sand podzols, variation in site quality has little effect on litter weight within the range SQII to SQV, where stands are in a healthy condition.

At the upper end of the litter accumulation range in South Australia (22-28 000 kg/ha), the amount of nutrients in the litter on the forest floor could be excessive in relation to site production in the first rotation. Olson (1963) demonstrates a broad correlation between productivity of forests and the rate of organic matter turnover; that is, in a steady state situation, the more productive the forest, the greater this rate must be. Although the productivity of radiata pine plantations in South Australia, in New Zealand, and at Tumut (NSW) can be considered as broadly comparable, the litter weights recorded in some New Zealand stands, and at Tumut, are considerably less than those recorded on the sand podzol soils in South Australia. Forrest (1969) estimated a maximum accumulation of 17 000 kg/ha at Tumut, and Will (1964) measured 13 000 kg/ha of litter in a 35-year-old stand in New Zealand. The level of accumulation on sand podzol sites in South Australia could indicate a rate of organic matter and nutrient cycling which is limiting continuing production, but it remains to be shown whether this is so and, if so, at what stage of stand development it becomes critical.

REFERENCES

BEDNALL, B. H. 1968: The problem of lower volumes associated with second rotations in **Pinus radiata** plantations in South Australia. **Woods and Forests Dept. South Australia Bull. 17.**

FLORENCE, R. G. 1967: Factors that may have a bearing upon the decline of productivity under forest monoculture. **Aust. For. 30:** 50-71.

FORREST, W. G. 1969: Variations in the accumulation, distribution and movement of mineral nutrients in radiata pine plantations. Ph.D. thesis, Aust. Nat. Univ., Canberra.

HAMILTON, C. D. 1964: The effect of Monterey pine on the properties of natural **Eucalyptus** forest and woodland soils. M.Sc. Thesis, Western Australia Univ., Perth.

KEEVES, A. 1966: Some evidence of loss of productivity with successive rotations of **Pinus radiata** in the southeast of South Australia. **Aust. For. 30:** 51-63.

KITTREDGE, J. 1940: A comparison of forest floors from plantations of the same age and environment. **J. For. 38:** 729-732.

——— 1955: Some characteristics of forest floors from a variety of forest types in California. **J. For. 53:** 645-647.

LEWIS, N. B. 1967: Economic aspects of agriculture and afforestation on comparable lands. **Aust. For. 31:** 3-9.

MILLER, H. G. 1969: Nitrogen nutrition of pines on the sands of Culbin Forest, Morayshire. **J. Sci. Food Agric. 20:** 417-9.

MINDERMAN, G. 1960: Mull and mor (Muller-Hesselman) in relation to soil water regime of a forest. **Plant and Soil 13:** 1-27.

PAWSEY, C. K. 1959: The seasonal fall of litter under Monterey pine. **Newsletter. Inst. For. Aust. 2 (4):** 16-17.

STEPHENS, C. C., CROCKER, R. L., BUTLER, B. and SMITH, R. 1941: A soil and land use survey of the hundreds of Riddoch, Hindmarsh, Grey, Young and Nangwarry, County Grey, South Australia. **Coun. Sci. Indust. Res. Bull. 142.**

OLSON, J. S. 1963: Energy storage and the balance of producers and decomposers in ecological systems. **Ecology 44:** 322-332.

OVINGTON, J. D. and MADGWICK, H. A. I. 1959: Distribution of organic matter and plant nutrients in a plantation of Scots pine. **For. Sci. 5:** 344-355.

WILL, G. M. 1964: Dry matter production and nutrient uptake by **Pinus radiata** in New Zealand. **Commonw. For. Rev. 43:** 57-70.