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ORGANIC MATTER CHANGES IN AN AGE SERIES OF *PINUS RADIATA* PLANTATIONS

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INTRODUCTION

Radiata or Monterey pine (*Pinus radiata* D. Don) has been successfully introduced into Australia and is the species most extensively planted in Australian commercial forestry. By 1968 nearly 300 000 ha of forest plantations had been established and of these about 70% were *P. radiata*. Sometimes large gains in wood production have been obtained by applying fertilizers and about 10% of the pine plantations have been treated with inorganic fertilizers (notably superphosphate but also zinc and potassium salts). The original plantations of this species may be more productive than succeeding second rotation plantations in some locations (Keeves 1966). Because of the economic consequences of any decline in wood production and the increasing use of fertilizers, interest is growing in obtaining data on the ecological dynamics of pine plantations particularly with respect to productivity (both economic and biological), the accumulation of organic matter and nutrient flow.

Ideally, progressive changes in stand dynamics should be based on records obtained over a complete rotation at the same spot but this requires long term investigation. Alternatively, an age sequence of stands may be studied within a general area of similar environment and management history and the series regarded as representing the development of an individual stand. The second alternative was adopted to evaluate aspects of *P. radiata* plantation dynamics in a major pine forest at Tumut, New South Wales, Australia. This paper is concerned with the plant organic matter system and a later paper will deal with plant nutrients.

FOREST AREA AND STUDY PLOTS

Single plots either 0·101 or 0·081 ha, were marked out in each of five stands at the Billapaloola Plantation, Tumut. All plots were on the eastern aspect of a prominent north–south ridge running centrally through the plantation so that ecological conditions were essentially similar.

The mean annual rainfall for the area is 145 cm with a lowest mean monthly rainfall in summer of 8 cm. The mean temperature of the hottest month is 20° C and of the coldest 4° C. Snow falls in most winters and may lie for 2 months and cause some damage to trees.

All plots have red earth soils derived *in situ* from granite parent material, granite boulders in various stages of degradation occur occasionally on the surface and through the profile. The soils are at least 75 cm deep to the underlying decomposing granite country rock with some gradational change down the profile (Northcote 1965, 1966), the A horizons being sandy–sandy loams whilst the B horizons are finer-grained sandy

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loams–loams. There is no evidence that nutrient deficiency seriously limits tree growth at the plots and the slight variation in soil nutrient status between plots seems insufficient to cause significant differences in the growth and nutrient contents of the trees (Forrest 1969).

Forest records indicate the original vegetation was broadly similar over the plantation area where the plots were located but detailed records do not exist for individual plots. The original vegetation was old, mature forest of *Eucalyptus viminalis*, *E. dalrympleana*, *E. radiata* and *E. dives*. Forest management has been the same in every plot, the original eucalypt forest having been cleared before pine planting and any woody regrowth after planting removed to prevent competition with the pines. All pine seedlings planted were raised at one of three local nurseries and were probably of similar stock, originating from seed collected off trees felled in second thinning operations in local pre-1939 plantations. At Tumut the plantation trees are generally pruned to about 3 m above ground when 8 years old and the oldest plots, 12 and 9 years old, were so pruned in 1962 and 1965 respectively.

Details of the five study plots and tree size are given in Table 1, the regular increase in tree growth parameters indicates the plots probably represent an acceptable age sequence.

Table 1. *Plot and tree data*

Plot no.	5	4	3	2	1
Plot age (years)	3	5	7	9	12
Tree stems ha^{-1}	1483	1492	1458	1470	1560
Average diameter at breast height (cm)	–	3·9	12·3	14·5	16·0
Basal area (m^2 ha^{-1})	–	2·0	16·0	25·0	32·9
Average height (m)	1·4	3·1	7·9	12·1	15·6
Bole weight of smallest sample tree (kg)	0·1	0·3	4·2	15·2	21·2
Total weight of smallest sample tree (kg)	0·2	0·6	6·9	21·3	25·0
Bole weight of largest sample tree (kg)	0·4	3·0	26·5	63·0	96·9
Total stem of largest sample tree (kg)	1·2	7·9	56·9	84·9	131·8
Average bole weight for sample trees (kg)	0·267	1·51	15·18	35·76	55·80
Average total weight for sample trees (kg)	0·767	3·56	31·93	48·83	73·85

SAMPLING METHODS

The height and bole diameter at breast height of all trees in the plots were measured just prior to sampling. The tree bole diameter range for each plot was divided into five classes of progressively larger diameter such that equal numbers of trees were in each class. From each class two trees were randomly selected for harvesting and weighing, making ten per plot. The statistical validity of this sampling procedure for *Pinus radiata* plantations has been examined in detail (Ovington, Forrest & Armstrong 1967). All weights given in this paper were obtained by oven-drying to a constant weight at 85° C and weight values are expressed as kilograms per hectare.

Harvesting of sample trees commenced in June 1966, one or two trees being taken from each plot at roughly weekly intervals over the dormant period. The trees were cut at ground level and by mid-August nine trees per plot had been collected. Heavy rain and snow delayed the collection of the tenth tree for several weeks, by which time substantial growth had taken place. Consequently only nine trees were used to estimate stand weights. Within a week from collection all material had been oven dried, losses in dry weight through respiration would be negligible during the waiting period for drying because of the short time involved and storage at a low temperature (Forrest 1968).

After cutting each tree at ground level, all previous winter resting nodes were identified as far down the tree as possible (fully for trees in plots 3, 4 and 5, and at least for the five previous years for the older trees of plots 1 and 2). The boles were cut at each winter node to give successive vertical age-strata. For each age-stratum of every tree the whole of each major plant component (branches, leaves, cones, etc.) was weighed as a separate unit, the number of units increasing with tree age, size and the confidence with which the age-strata could be identified. For instance, each tree of plot 1 (12 years old) was divided into as many as 35 units. No tree roots were collected.

Ground vegetation and litter samples from the plots were collected immediately before felling of the sample trees commenced. Twenty quadrats, 25 × 25 cm square, were located randomly in each plot and within every quadrat the ground vegetation was carefully clipped to ground level and subdivided into species groups. The litter layer was then collected from within the quadrat frame and subdivided into two major categories, relatively undecomposed (L layer) and well decomposed (F and H layers). Further subdivision of the F and H layers proved impracticable but for the L layer pine leaves and branches were separated from other dead vegetation and all were weighed separately after oven drying.

DETERMINATION OF STAND WEIGHTS

Numerous relationships between sample tree weights and linear dimensions, including direct multivariate and transformed variable relationships, were examined for each plot. The following equation was selected to calculate tree and stand dry weights for plots 1–4 because of its consistently greatest significance:

$$\log_e \text{weight} = a+b \log_e (\text{BA} \times \text{Ht})$$

where BA = bole cross sectional area at breast height (130 cm) and Ht = top height of the tree. The equation could not be used for plot 5 because many trees had not reached breast height. Since there was a curvilinear relationship between tree weight and height, weight being related significantly to $\log_e$ Ht, the stand weights for this plot were determined using the equation weight $= a+b \log_e$ Ht.

All weight determinations were significant at the P = 0·01 level except for female cones in plots 1 and 2 and for leaves borne on the main stem in plots 1–4 where the equations were not significant for plots 1 and 2 but significant at $P = 0{\cdot}1$ for plot 3 and at $P = 0{\cdot}05$ for plot 4. The weights of female cones and leaves carried on the main stem represent only a small proportion of the total tree weight (less than 1%) and any errors introduced through including them in the total stand weights would be relatively unimportant.

The weights of all trees (or their component parts) were calculated for each plot using the appropriate regression equation obtained from the sample trees and the known linear dimensions of all trees. The individual tree or component weights were summed (Table 2), the slight discrepancy between total tree weights obtained by summing tree components and by summing total tree weights arises largely through the poor size–weight relationships for minor components and the rounding off of component values. When comparisons of the total weight of the trees on an area basis are made the results obtained by the second method are used since they are the more accurate. Confidence limits for the weight determinations were calculated using a modification of the method developed by Williams (1959) to allow for log: log transformation in the regression.

The ground vegetation and litter weights per hectare were calculated from the average for the twenty random quadrats.

TREE WEIGHTS

Tree size varied considerably at each plot despite the uniformity of site and treatment. The sample trees do not necessarily include the complete size range present, yet in individual plots the largest sample trees were between four and thirteen times the weight of the smallest trees, the greatest percentage difference occurring in the 5-year-old plot (Table 1).

Table 2. *Oven-dry weights of above-ground material* (10^3 *kg* ha^{-1})

	Stand age (years)				
Trees					
Branches minus leaves	0·2	1·2	14·9	9·9	18·7
Branch leaves	0·4	1·9	11·2	8·4	9·2
Bole leaves	0·1	0·2	0·4	0·4	0·3
Bole bark	0·1	0·3	2·7	5·6	8·8
Bole wood	0·3	2·1	21·1	48·2	80·7
Female cones	0	0	0·4	0·5	0·7
Total by summing above components	1·1	5·7	50·7	73·0	118·4
Total by summing total tree weights	1·2	5·6	50·7	73·4	118·8
95% confidence limits for total weights	1·1–1·2	5·3–6·0	47·1–54·7	67·7–79·6	113·2–124·6
Ground flora					
Native grasses	4·8	4·4	1·0	0	0
Bracken	0·1	0·3	0·8	1·2	0·4
Broadleaved plants	0·2	0·1	0	0	0
Total	5·1	4·8	1·8	1·2	0·4
S.E. for total	±1·0	±1·3	±0·2	±0·3	±0·2
Litter					
Pine leaves	0·4*	1·8*	4·7*	2·6	4·9
Pine branches	0	0	0	2·8	1·3
F and H	0	0	0	8·9	10·8
Total	0·4	1·8	4·7	14·3	17·0
S.E. for total	±0·2	±0·2	±0·7	±1·2	±1·0
Above-ground plant organic matter					
Total	6·7	12·2	57·2	88·9	136·2

*Inclusive of ground flora litter.

Over the 9-year period covered by the plots, the average weight of sample trees increased from 1 to 75 kg but the largest sample trees in the oldest plot were almost double this weight. Besides differing in size, the sample trees differed markedly in the relative proportions of their components depending mainly on age and vigour. Whilst all tree components tend to increase in weight as trees age, the overall rates of increase for tree boles were greater than for leaves or branches. In the younger plots the average relative proportions for all trees of boles : leaves : branches were 2 : 3 : 1 with very little variation between trees, whereas in the oldest plot the corresponding proportions varied greatly between trees but with an average of 10 : 1 : 2. In individual plots the dominant trees were not only taller but had greater amounts of leaves and branches than other trees. As the plantations age the leaves and branches of dominant trees increasingly represent a greater proportion of the leaf and branch biomass so that the relative competitive ability of the dominants probably increases progressively as they mature.

The divergence in rates of development between individual trees probably arises from physiological limitations on dominant tree size and the capacity of suppressed trees to persist whilst making little or no growth. No deaths from suppression were evident in the study plots but several of the smaller trees were moribund. In similar stands described by Spurr (1962), forty of the original 1525 trees planted ha^{-1} died by age 12 years but afterwards mortality was more rapid and 360 trees ha^{-1} died in the following 6 years.

Table 3. *Annual change in organic matter (oven-dry weight* (10^3 *kg ha*$^{-1}$) *negative values underlined; above ground material only*)

Stand age (years)	0–3	3–5	5–7		7–9	9–12
Tree branches	0·05	0·52	6·87		2·50	2·94
Tree leaves	0·17	0·79	4·79		1·48	0·30
Tree bole bark	0·02	0·12	1·21		1·43	1·09
Tree bole wood	0·10	0·86	9·51		13·57	10·85
Tree female cones	0	0	0·17		0·07	0·07
Total for trees	0·34	2·28	22·55		11·34	15·12
Native grasses	1·60	0·19	1·72		0·50	0
Bracken	0·04	0·09	0·27		0·16	0·25
Broadleaved plants	0·05	0·03	0·05	Pruning begins	0	0
Total for ground flora	1·68	0·12	1·48		0·35	0·25
Pine leaves litter (L)	0·14	0·72	1·45		0·70	0·77
Pine branches litter (L)	0	0	0		1·42	0·51
Amorphous litter (F & H)	0	0	0		4·45	0·64
Total litter	0·14	0·72	1·45		4·82	0·90
Total organic matter above ground	2·17	2·88	22·50		15·81	15·76

PLOT WEIGHTS

As the plantations age the organic matter above ground builds up progressively and by 12 years amounts to over 130 000 kg ha^{-1} (Table 2), trees constituting 87% of the total (66% bole material). The pattern and rate of accumulation of organic matter of the various categories changes considerably with time (Table 3). Thus, as true forest conditions develop and the tree mass becomes the dominant component of the organic matter, consequential changes occur in the ground flora both in terms of weight per unit area and species present.

The bulk of tree foliage is on the branches, after canopy closure the leaves on the main stem being less than 5% of the leaf mass. During the early plantation establishment period the build up of tree foliage is slow but about 5 years after planting, when the tree crowns expand rapidly both vertically and laterally, the annual increment in foliage is nearly 5000 kg ha^{-1}. Afterwards lateral crown expansion is restricted by between-tree competition and the canopy dies from below upwards so that the increment in foliage weight decreases. By 7 years of age the total weight of tree foliage is nearly 12 000 kg ha^{-1}, at the end of the tenth year most new leaves produced during the seventh year after planting are shed. Thereafter the weight of tree leaves present, at just less than 10 000 kg ha^{-1}, is fairly constant from year to year and the annual formation and shedding of tree leaves are roughly in balance each amounting to about 3000 kg ha^{-1}. This relatively constant foliage weight in the older stands with a close canopy is at the upper limit of the range 2·8–10·5 thousand kg ha^{-1} given by Tadaki (1966) for seventeen pine forests around the world and is about the value (9000 kg ha^{-1}) for *Pinus radiata* in New Zealand (Will 1964).

The pattern of branch (exclusive of leaves) accumulation is similar to that for leaves except that after 9 years branch accumulation continues at a large rate. Since Monterey pine is not self-pruning at Tumut, the lower branches progressively die and decay, and the two most important factors affecting the amount of branches on the trees are (1) pruning by foresters and (2) decay whilst still on the tree. In plot 1, the oldest plot and which had been pruned, all branches were living (i.e. carrying green leaves) at the time of tree sampling but 1 year later the lowest whorl branches of most trees were dead. Consequently, the living branch weight of nearly 19 000 kg ha^{-1} in this plot is probably close to the maximum weight of live branches in *P. radiata* stands in this locality at this spacing. In older plantations decrement by death, but not necessarily shedding, would presumably counter balance the production of new living branches and growth of older living branches. The maximum weight of branches on an area basis at Tumut is much greater than recorded in New Zealand (Will 1964). The New Zealand stands had many more trees (2644 stems ha^{-1}) and Satoo (1967) has shown for stands of *P. densiflora* overall branch weight decreases markedly with increased stand density, particularly through the range 1000–4000 trees ha^{-1}.

The amount of bole material in the plantations increases continually to represent a greater proportion of the biomass, the rate of accumulation being small initially but becoming rapid after the fifth year with a peak value at 7–9 years and averaging about 13 500 kg ha^{-1} annum^{-1} from 7 to 12 years. Initially bark constitutes about 19% of the bole material but the proportion decreases progressively to about 9% at 12 years.

Root weights were not determined in these plots but root studies in an 8 year old *P. radiata* stand at Canberra some 200 km distant showed the weight of roots greater than 0·5 cm diameter to be about 15% of the total tree weight (Ovington *et al.* 1967). If the proportions of tree components are similar at the two locations, the weight of large roots in the oldest Tumut plantations would be about 22 500 kg ha^{-1}.

Native grasses and other plants of the original sclerophyll forest survive pre-planting clearing and burning mainly because of their capacity to regenerate from subterranean organs. With the removal of the natural tree cover the ground vegetation takes full advantage both of the release from overstorey competition and protection from grazing so that the ground flora above ground amounts to over 5000 kg ha^{-1} 3 years after clearing. As the tree crowns meet, the grass vegetation is killed out and bracken replaces the grasses which are virtually absent by the ninth year. Whilst bracken appears more tolerant than the grasses to competition from the trees, it never attains the same abundance on a weight/area basis. At 12 years only 400 kg ha^{-1} of understorey vegetation are present, an amount which seems typical for the older closed canopy stands at Tumut. Whilst the rapid disappearance of the grasses and to a lesser extent of bracken may result from competition for light, water and nutrients it is probably hastened by the smothering action of the pine leaf fall which is substantial after 7 years.

The type and distribution of litter over the forest floor varies greatly according to the nature of the vegetation cover. Initially litter is patchily distributed and consists of fragmented remnants of grass tussocks, bracken, woody plants and occasional pine needles. There is little accumulation of amorphous organic matter and apparently organic matter is rapidly incorporated into the mineral soil. As the annual fall of pine needles increases, a characteristic pine litter is formed, first around the tree boles but later completely covering the ground. In the two oldest plots two distinct layers of litter can be distinguished, a lower layer (F and H) of amorphous material and an upper layer (L) of relatively fresh material (mainly pine needles shed when 3 and 4 years old but in plot 2 with an admixture of younger leaves and branch wood resulting from pruning at 8 years). Whilst the amorphous material is largely a mixture of pine and non-pine vegetation, pine foliage constitutes a greater proportion as the plantations age. At its maximum development litter on the mineral soil amounts to 17 000 kg ha^{-1}. This material accumulates most rapidly from 7 to 9 years but from 9 to 10 years the rate of build up of litter is small and litter accumulation and reduction become about equal in magnitude at 12 years. Many stands up to 35 years old were examined in the Tumut forest area and the litter was never thicker than in the 12-year-old plot so that 17 000 kg ha^{-1} seems to represent the maximum for the species at Tumut.

At this balance stage the ratio of fresh : amorphous litter weights is about 1 : 2. The litter layer is equivalent in weight to about 5 or 6 years of litter fall.

Whilst organic matter accumulates above ground throughout the 12 years the peak rate of accumulation occurs relatively early, i.e. between 5 and 7 years of age. This is much earlier than for those pine plantations in temperate regions of the northern hemisphere for which records are available and reflects the relatively rapid occupation of the site and fast growth rate of *P. radiata* which make it a very productive species.

DISCUSSION

Changes in plant biomass provide some measure, though inevitably incomplete, of the dynamic processes involved in plant organic systems and the relationships between the different kinds of organic matter present. Basically, three processes are involved: (1) the net production of organic matter (i.e. by plants with chlorophyll and exclusive of their use of photosynthate in respiration), (2) the retention and dispersal of plant organic matter within the ecosystem and (3) loss of plant organic matter, largely through decomposition but also in other ways as when pollen is dispersed by wind. The patterns and magnitudes of plant organic systems plus associated characteristics such as nutrient flow, have been suggested as a means to improve ecosystem classification (Basilevich & Rodin 1964). Whilst insufficient data of forest dynamics are available generally, the data for the *Pinus radiata* pine plantations can be used to supplement existing information and to illustrate certain facets of forest stand dynamics.

If the study plots represent the progressive development of a single stand, production of organic matter (exclusive of respiration loss and roots) can be calculated (Table 4) from the biomass data. This can then be checked and supplemented by other data. For example, the production of tree leaves has been estimated from measurements of leaf weights present at certain ages and by assuming an average leaf life of 3 years. When these estimates are compared with values for leaf fall obtained from trays placed on the forest floor to collect litter falling from the trees, the two are reasonably close. Thus the production of new leaves for plantations 3 and 10 years old were 156 and 3210 kg ha^{-1} compared with the relevant values of 194 and 3930 kg ha^{-1} for litter fall at plantation ages 6 and 13 years. Similarly, the weight of branch material removed by pruning of the older plots has been estimated from a knowledge of the amount and distribution of branch weight in the younger plots.

In general such estimates underestimate net production by trees because of failure to take into account losses caused by factors such as the attack of plant pests and diseases, bark-shedding and the fall of male cones and pollen. In the pine stands these probably represent an appreciable, but not a major, section of the organic system. For instance, the annual fall of male cones into litter trays in the 5 and 12 year old plots were respectively 23 and 470 kg ha^{-1} (about one-tenth of the annual litter fall). Field examination of tree leaves suggested the loss of leaf material through animals and diseases was small in the pine stands studied.

Greatest difficulty is encountered in quantifying the role of the ground vegetation in stand dynamics since sampling was only done on one occasion at the end of the growing period. Kazmierczakowa (1967) has demonstrated the error likely to be introduced through not studying the phenologies of the plant species present by sampling through the year, but, from her investigation and the relative simplicty of the ground flora in the pine stands, it seems reasonable to assume all understorey vegetation above ground at the end of the year is replaced and decomposed in the next year. A further assumption made in our calculations is that all the above-ground parts of the ground flora were destroyed

Table 4. *Total plant organic production, movement and decomposition (oven-dry weight kg ha*$^{-1}$*)*

Period (years)	0–3	0–5	0–7	0–9	0–12
Pine production (above ground)					
Leaves	0·5	2·3	12·7	19·7	29·3
Branches	0·2	1·2	14·9	20·8	29·6
Boles	0·4	2·4	23·8	53·8	89·5
Female cones	0	0	0·4	0·5	0·7
Male cones	0	0·1	0·7	2·0	4·2
Total of above	1·1	6·0	52·5	96·8	153·3
Pine litter fall					
Leaves	0	0·2	0·8	10·4	16·7
Branches	0	0	0	11·0	11·0
Male cones	0	0·1	0·7	2·0	4·2
Total of above	0	0·3	1·5	23·4	31·9
Ground flora production (above ground)	10·1	19·9	25·0	27·7	29·6
Ground flora litter fall	5·0	15·1	23·2	26·5	29·2
Total litter fall	5·0	15·4	24·7	49·9	61·1
Litter decomposed on ground	4·6	13·6	20·0	35·1	44·1

by clearing and burning prior to tree planting. Usually some patches of vegetation survive but the error in making this assumption is probably not great judging from general experience of clearing operations. The first assumption may lead to some underestimation and the second to overestimation of primary production.

Over the 12 year period, the annual net production of above-ground material amounts to just over 15 000 kg ha^{-1}, about 83% being primary production by trees. The overall annual litter fall from both trees and ground flora is 5000 kg ha^{-1}, litter decomposition amounting to more than 3500 kg ha^{-1} annually. Over the 12 years annual production always exceeds decomposition so that plant organic matter continuously accumulates above ground, either as living or dead material, the average annual rate of accumulation being about 11 400 kg ha^{-1}.

The maximum value, almost 26 000 kg ha^{-1} for the combined annual production of above-ground material by trees (90%) and ground flora (10%) occurs from 5 to 7 years after planting (Table 5) when the tree crowns are expanding rapidly to give complete coverage and just before the branches of the lowermost whorls die as the canopy as a whole is raised further above ground level. This is also the period of greatest annual accumulation of organic matter (22 500 kg ha^{-1}). Changes in litter decomposition do not parallel but tend to follow changes in organic production and accumulation. The peak rate of litter breakdown on the forest floor is from 7 to 9 years with an annual value of 7600 kg ha^{-1} and is associated with the heavy fall of pine needles in these years. In terms of organic matter production the Tumut plantations are placing greatest demands on the site from 5 to 7 years after planting and, as will be discussed in a later paper, this and the breakdown of nutrient-rich ground flora material is of great significance to mineral nutrient availability.

Comparisons of forests as productive systems often pay little regard to the successional stages of particular forests. These results support previous studies (Ovington 1957) in demonstrating the fallacy of such an approach. Clearly as plantations or natural stands mature, great changes can occur in the rates of production, retention and decomposition of plant organic matter. Initially the ground flora is the main primary producer but is replaced by the trees which change in form as they become more productive and occupy the site more fully. Of particular significance are changes in the tree canopy which as the tree crowns meet, becomes deeper, raised higher above ground level and dies below. The

Table 5. *Stand dynamics (oven-dry weight (kg ha^{-1} annum^{-1}))*

Period (years)	0–3	3–5	5–7	7–9	9–12
Above-ground material produced by trees	0·4	2·5	23·3	22·2	18·8
Above-ground material produced by ground flora	3·4	4·9	2·6	1·4	0·6
Total production of above-ground plant organic matter	3·8	7·4	25·9	23·6	19·4
Accumulation of organic matter above ground	2·2	2·8	22·5	15·9	15·8
Decomposition of above-ground organic matter	1·6	4·6	3·4	7·7	3·6

peak production of organic matter by the *P. radiata* plantations is reached about 6 years of age when on average the trees are about 6 m tall and death of the lower branches is occurring. The comparable average tree height at which maximum production on an area basis occurs for closed canopy plantations of *P. sylvestris* (Ovington 1957, 1959) is remarkably similar being about 7 m. Whereas *P. radiata* reaches this height and maximum production at about 6 years of age at Tumut, the Scots pine plantations in a colder, temperate climate take about 21 years and their peak annual production is about 75% that of that of the radiata pine stands.

The production of organic matter by the trees is not closely related to the weight of leaves present. Estimates of unit weight of organic matter produced per unit weight of leaves present in the previous years are 4, 8, 2, 2 and 2 for stands 4, 6, 8, 10 and 12 years of age respectively. Presumably in the early years the pine leaves as a whole are more favourably placed environmentally for high rates of photosynthesis than in later years when the tree crowns completely cover the ground and when the lower and inner leaves are shaded. Additionally in older plantations there may be growth restrictions caused by shortages of nutrients and water.

Denmead (1968) using micrometeorological techniques in a broadly similar *P. radiata* plantation some 200 km from Tumut stresses the relatively high efficiency with which radiata pine uses solar radiation in dry matter production and gives a maximum daily production of 410 kg of dry matter ha^{-1}. This is more than adequate to give the production values obtained by biomass study. If we assume root production is half that of shoot production, then to attain the peak annual production of organic matter, the Tumut plantations would only need to operate at half their maximum efficiency for about 200 days of the year.

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SUMMARY

Above-ground biomass data for trees, ground flora and litter are given for an age series of *Pinus radiata* plantations at Tumut, New South Wales, Australia. The weights of trees in the stands were determined using regression equations relating tree weight to trunk diameter and length. From the biomass data the production, retention and decomposition of organic matter were calculated and compared with values obtained for other pine stands, *P. radiata* is considered to be a very efficient producer of organic matter. Peak production of organic matter occurs relatively early (5–7 years) after planting reflecting the rapidity with which maximum leaf weight is achieved.

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