NUTRIENT LOSSES FROM LITTERBAGS CONTAINING PINUS RADIATA LITTER: INFLUENCES OF THINNING, CLEARFELLING, AND UREA FERTILISER

G. M. WILL, P. D. HODGKISS and H. A. I. MADGWICK

Forest Research Institute, New Zealand Forest Service,
Private Bag, Rotorua, New Zealand

(Received for publication 30 March 1983; revision 29 September 1983)

ABSTRACT

A 4-year study using nylon mesh bags in a **Pinus radiata** D. Don stand showed that tree canopy density had little or no effect on litter decomposition rate or loss of nutrients. The application of urea at 200 kg N/ha raised the nitrogen concentration in the litter by 0.5%; even though this higher margin was consistently maintained throughout the study, decomposition rate and nutrient release were unaffected.

During the study relative rates of loss of dry weight and nutrients from litterbags were nitrogen < manganese = calcium = zinc = magnesium < dry weight < phosphorus < boron < potassium. There was little or no loss of nitrogen during the first 97 weeks; this was followed by a small release. In sharp contrast there were substantial losses of phosphorus and potassium within 9 weeks, and potassium continued to be lost until 90% had been released after about a year.

INTRODUCTION

In the past, widespread attention and concern have been given to soil "deterioration" and productivity declines in pine stands in Europe. Most, if not all, of such declines are now known to be due to practices that removed nutrients from the site – foremost among these was litter removal (Stone 1973). Greater recognition is now being given to the importance of the role of litter in nutrient cycling in the world's forests. Recently Weber & Van Cleve (1981) examined an ecosystem under arctic conditions, Jorgensen *et al.* (1980) looked at a temperate pine forest, and Swift *et al.* (1981) studied a tropical situation.

In Australia and New Zealand *Pinus radiata*, in fast-growing plantations, is by far the major softwood forest species. In both countries fertilisers are applied routinely on many soils and there are extensive programmes to study the cycling and conservation of nutrients. In Australia nutrient content of and release from *P. radiata* litter have been studied by Feller (1978), Lamb (1975, 1976), Florence & Lamb (1974), and Raison (quoted by Waring 1980).

In New Zealand there is growing awareness of the importance of litter as a major nutrient pool in *P. radiata* forests – particularly for nitrogen. Webber & Madgwick (1983) pointed out that the above-ground biomass of a mature stand contains about 400 kg N/ha, half of which is removed in a conventional harvest: in contrast the litter in a first-rotation stand contains about 300 kg N/ha and in second-rotation stands the amount may exceed 500 kg N/ha. Even for potassium, a very mobile element in the ecosystem, the litter layer contains the equivalent of 17% of the total amount in a mature crop of trees.

Recognising the importance of litter as a nutrient pool, the present study was undertaken to examine the effects of different forest management practices on the loss of macro- and micro-nutrients from decomposing litter. Although the technique of using litter bags is recognised to have limitations, it was considered to be the only practical way of carrying out the study.

MATERIALS AND METHODS

Field Sites and Treatments

Pinus radiata needle litter-fall is continuous throughout the year with maxima in the spring and autumn (Will 1959). For this study a bulk collection of freshly fallen litter was made immediately after a storm in the autumn of 1973. Needles were removed by hand from the forest floor. Only those that had just reached a yellowish brown, senescent condition were collected; both green needles brought down by the storm and darker brown needles which had fallen earlier were rejected. The litter sample was air dried and well mixed, and then 30-g portions (27 g oven-dry) were placed in 20 × 30-cm nylon mesh (1-mm) bags.

The litter bags were placed on the forest floor in Cpt 69 Kaingaroa Forest in an area adjoining the location of a previous litter decomposition study (Will 1967). It is a highly productive site; the soil is Kaingaroa silty sand, a yellow-brown pumice soil with adequate nutrition and rooting depth for vigorous tree growth. The mean annual temperature is 10.7°C and annual rainfall about 1470 mm evenly distributed throughout the year. Fuller climatic details have been given in descriptions of a nearby lysimeter study (Will 1977; Knight & Will 1977).

Litter bags were placed at three sites:

(1) A second-rotation 14-year-old *P. radiata* stand with closed canopy – approximately 1000 stems/ha;

(2) Same as (1) but recently thinned to 250 stems/ha;

(3) A recently clearfelled *P. radiata* area.

At each site at least 15 bags were placed in each of six groups, each group within an area of 3 × 3 m. At all sites three of the six groups were placed on the undisturbed litter or soil surface and left untreated and undisturbed; at Sites 1 and 2 the other three groups were treated with urea 5 weeks after the experiment began. Urea was evenly applied to the 3 × 3-m area at a rate equivalent to 200 kg N/ha. At Site 3, three groups of bags were placed partially under the ground surface to simulate litter that had been "disturbed" during logging.

Ground minimum thermometers were installed at each site and read at weekly intervals.

Sampling Times

At Site 1 one bag was removed from each group after 3 weeks and again just before the fertiliser application at 5 weeks. Thereafter one bag was removed from each group at all sites after 9, 19, 31, 45, 58, 71, 84, 97, 110, 123, and 218 weeks.

Dry Weights and Chemical Analyses

All collected litter bags were oven dried and the weight of the litter remaining in each bag was determined. Samples from each bag were then ground and analysed for nitrogen, phosphorus, potassium, calcium, magnesium, boron, manganese, and zinc. Copper was not determined as the area had been sprayed with copper oxychloride to control Dothistroma needle blight.

Nitrogen was determined colorimetrically by Autoanalyser after semi-micro Kjeldahl digestion using a selenium catalyst. All other elements were determined after dry ashing and solution in dilute hydrochloric acid. Phosphorus and boron were determined colorimetrically and potassium, calcium, magnesium, manganese, and zinc by atomic absorption spectrophotometry.

RESULTS AND DISCUSSION

Mean nutrient concentrations and contents of the litter at the beginning of the observation period are given in Table 1.

TABLE 1—Concentrations and weight of eight elements in the litter at start of study

Element	Concentration	Weight per bag (mg)
	(%)	
Nitrogen	0.69	186
Phosphorus	0.098	26
Potassium	0.40	108
Calcium	0.42	113
Magnesium	0.07	19
	(ppm)	
Boron	14	0.38
Manganese	550	14.9
Zinc	47	1.27

For all treatments, litter decomposition proceeded at about the same rate so that after 2 years approximately half of the litter by weight had disappeared (Fig. 1); decomposition at the clearfelled site tended to be slightly slower than at the other sites.

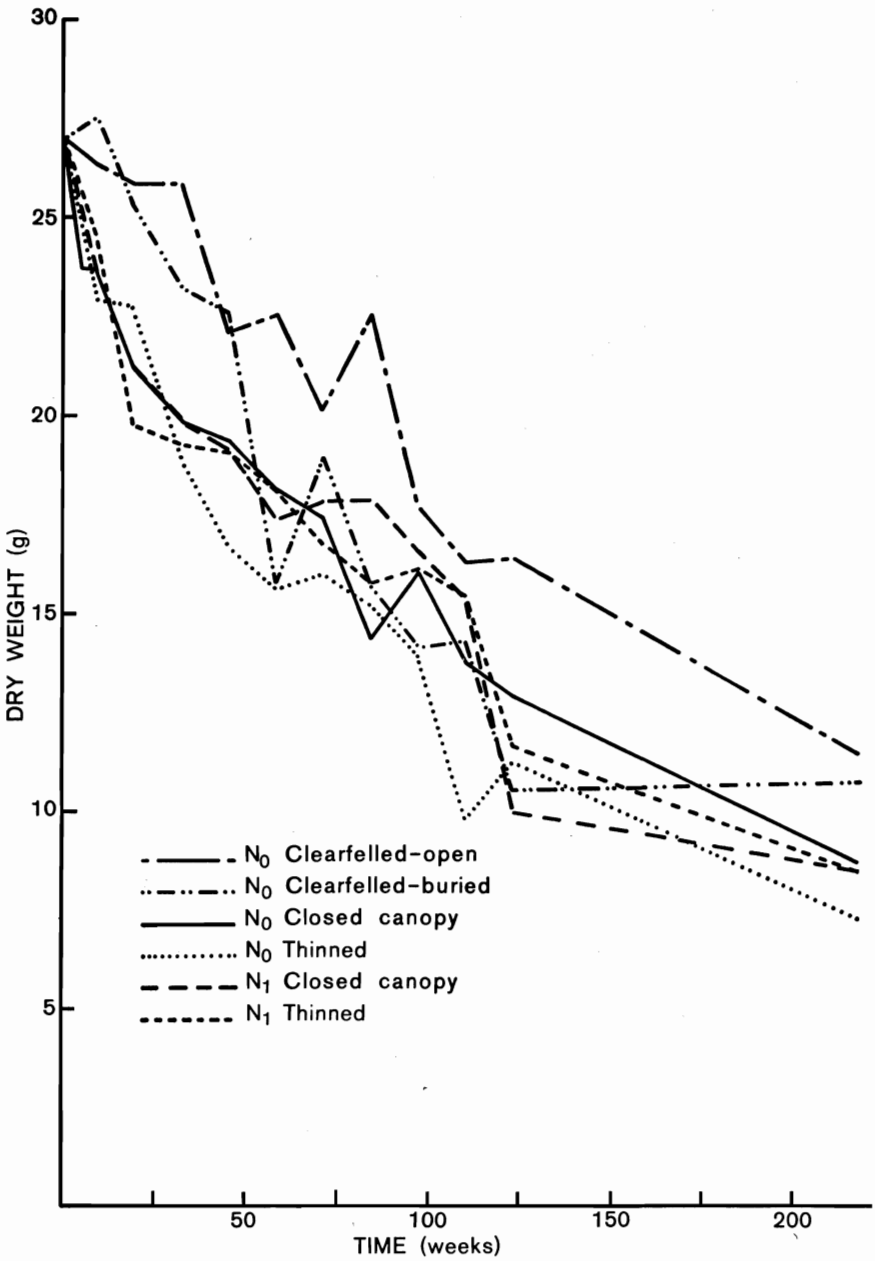

FIG. 1—Changes in mean weights of litter remaining in litter bags.

The dry weight remaining in each litter bag was related to time by the simple exponential model:

$$W_t = W_0 \, e^{-kt}$$

where W_t is the weight at time t, t is time in weeks since the beginning of observations, and k is a measure of the rate of loss (Wieder & Lang 1982). Separate regressions were calculated for each site using regressions of time on logarithm W (Table 2). There was a slight suggestion that these regressions over-estimated loss during the first year but attempts to fit double exponentials (Wieder & Lang 1982) of the form

$$W_t = A \, e^{-k_1} + (W_0 - A) \, e^{-k_2 t}$$

where A and $(W_0 - A)$ are two hypothetical fractions with separate loss rates of k_1 and k_2 respectively, yielded values of k_2 which were not significantly different from zero.

TABLE 2—Estimated decay constants (k) for each treatment using the simple exponential model $W_t = W_0 \, e^{-kt}$ where W_t is the weight of litter remaining at time t and t is measured in weeks

Treatment	k	Standard error
Control	4.97×10^{-3}	0.28×10^{-3}
Plus urea	5.29×10^{-3}	0.56×10^{-3}
Thinned	6.46×10^{-3}	0.81×10^{-3}
Thinned + urea	4.96×10^{-3}	0.47×10^{-3}
Clearfelled - open	4.31×10^{-3}	0.40×10^{-3}
Clearfelled - buried	5.66×10^{-3}	0.86×10^{-3}

There was no apparent consistent effect of site or treatment on the value of the loss rate, k.

Comparable, simple, mathematical models for changes in nutrient concentrations or total nutrient contents with time were not available. Consequently, changes in nutrient concentrations with time were examined using regressions involving time and dummy variables to represent treatments.

The correlation matrix showed the following significant relationships ($r > 0.60$).

(1) With increasing time:
   (i) Percentage of nitrogen increased ($r = +0.70$)
   (ii) Percentage of phosphorus increased ($r = +0.70$)

(2) The application of urea increased the percentage of nitrogen ($r = +0.63$)

(3) Percentage of nitrogen was related to concentration of manganese ($r = +0.69$)

(4) Concentrations of calcium, magnesium, manganese, and zinc were all related to each other, except for magnesium–manganese.

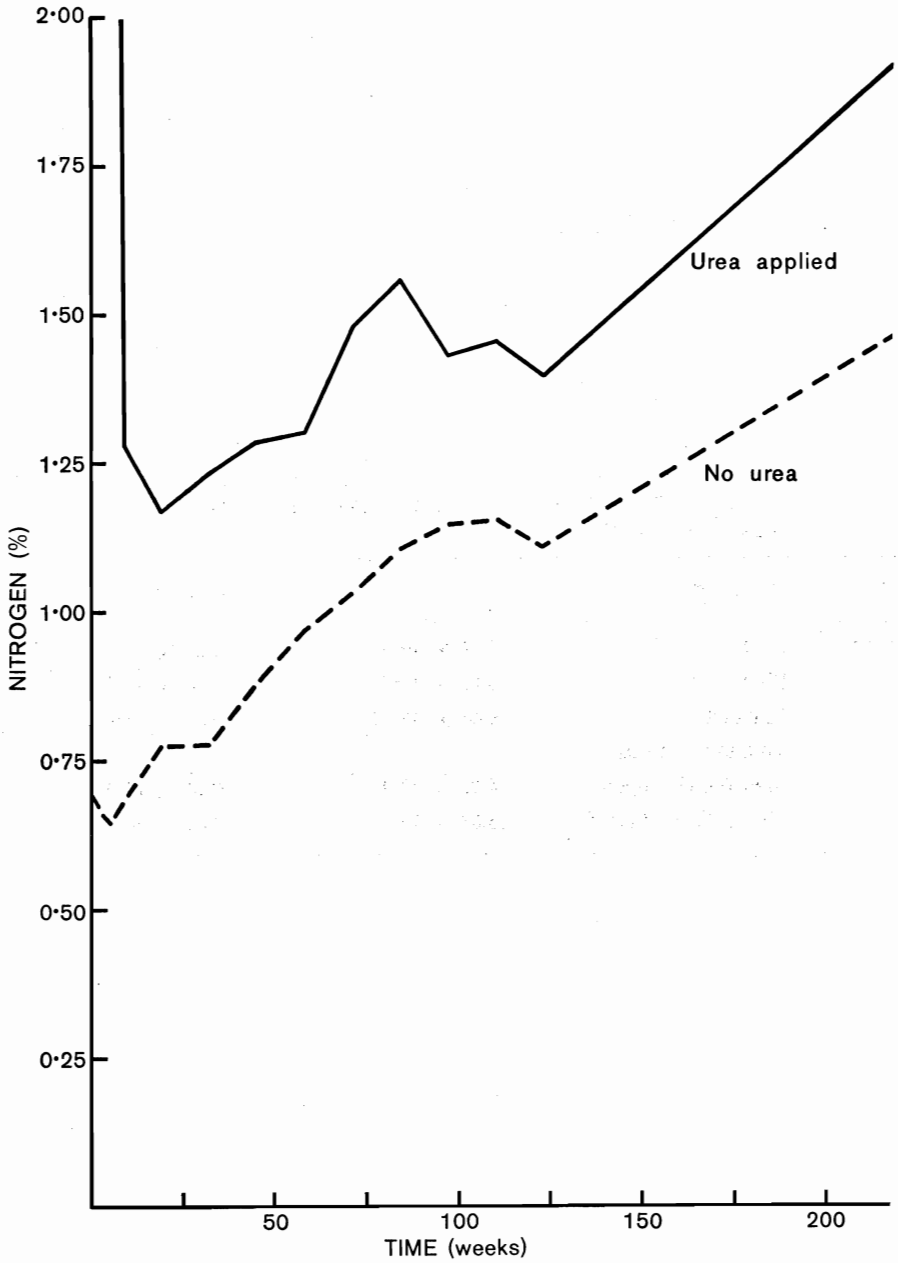

FIG. 2—Changes in nitrogen concentration in decomposing litter with time.

As the only statistically significant effects of treatment on nutrient concentrations were changes in levels of nitrogen as a response to fertiliser additions, the data presented in Fig. 2–5 are average values of nitrogen by fertiliser treatment and over-all averages for other elements.

For nitrogen (Fig. 2), where there was a significant difference in concentration due to urea application, mean figures are presented for (a) all untreated groups and (b) all urea-treated groups. The untreated litter increased steadily in percentage of nitrogen with time, regardless of thinning or location in the clearfelled area. Where urea was applied there was a rapid leaching of the greater part of the nitrogen but sufficient was retained to permanently raise the concentration in the litter by about 0.5%. It should be noted that during the 4 years of the experiment (1) both treated and untreated litter increased in percentage of nitrogen at similar rates, and (2) the urea-treated litter consistently maintained the 0.5% higher level of nitrogen.

Changes in concentrations of nutrients other than nitrogen followed a range of different patterns (Fig. 3). Potassium, phosphorus, and boron all decreased in concentration during the first few weeks of exposure and for potassium this decline continued for at least 58 weeks. The same three elements increased in concentration towards the end of the 4-year period, with the most consistent and continuous increase recorded for phosphorus. By the last observation phosphorus concentration was at a level almost equal to the initial concentration; as already noted, this increase had a statistically significant relationship to the loss of dry weight during decomposition.

Calcium, magnesium, manganese, and zinc concentrations all tended to increase over the first 123 weeks: only manganese increased between 123 and 218 weeks, all others decreased.

While nutrient concentrations are valuable figures in themselves, it is when they are combined with weight figures to give total contents that they are most relevant to nutrient cycling. The total quantities of nitrogen in the bags were relatively constant over the initial 97 weeks; those untreated remained at the starting value, while those treated with urea remained at the level at which they stabilised within 19 weeks of treatment (Fig. 4). It seems that, under the conditions of this experiment, untreated *P. radiata* litter loses little nitrogen during the first 2 years of decomposition on the forest floor. After an initial rapid period of stabilisation, the same observation applies to litter to which urea has been applied. After 2 years there is some loss of nitrogen.

The total content of all other nutrient elements examined decreased with time but with some large differences in rate, the order of relative decrease being $Ca = Mg = Mn = Zn < P < B < K$ (Fig. 5). Thus the elements calcium, magnesium, manganese, and zinc decreased by about half after 4 years while about 90% of the potassium disappeared in approximately 1 year. These absolute and relative decreases are similar to those found in the earlier study at a nearby site (Will 1967) but quite different from the relative loss rates reported for *P. sylvestris* L. litter in central Sweden (Staaf & Berg 1982) where no substantial initial losses of phosphorus and potassium occurred.

GENERAL DISCUSSION

A number of authors have criticised the use of litter bags for studying decomposition (*see* Wieder & Lang 1982) but it is still a widely used technique. It has limitations which should be recognised but in the absence of a practical alternative we feel it is a technique that has value, particularly in comparative studies covering the early stages of decomposition.

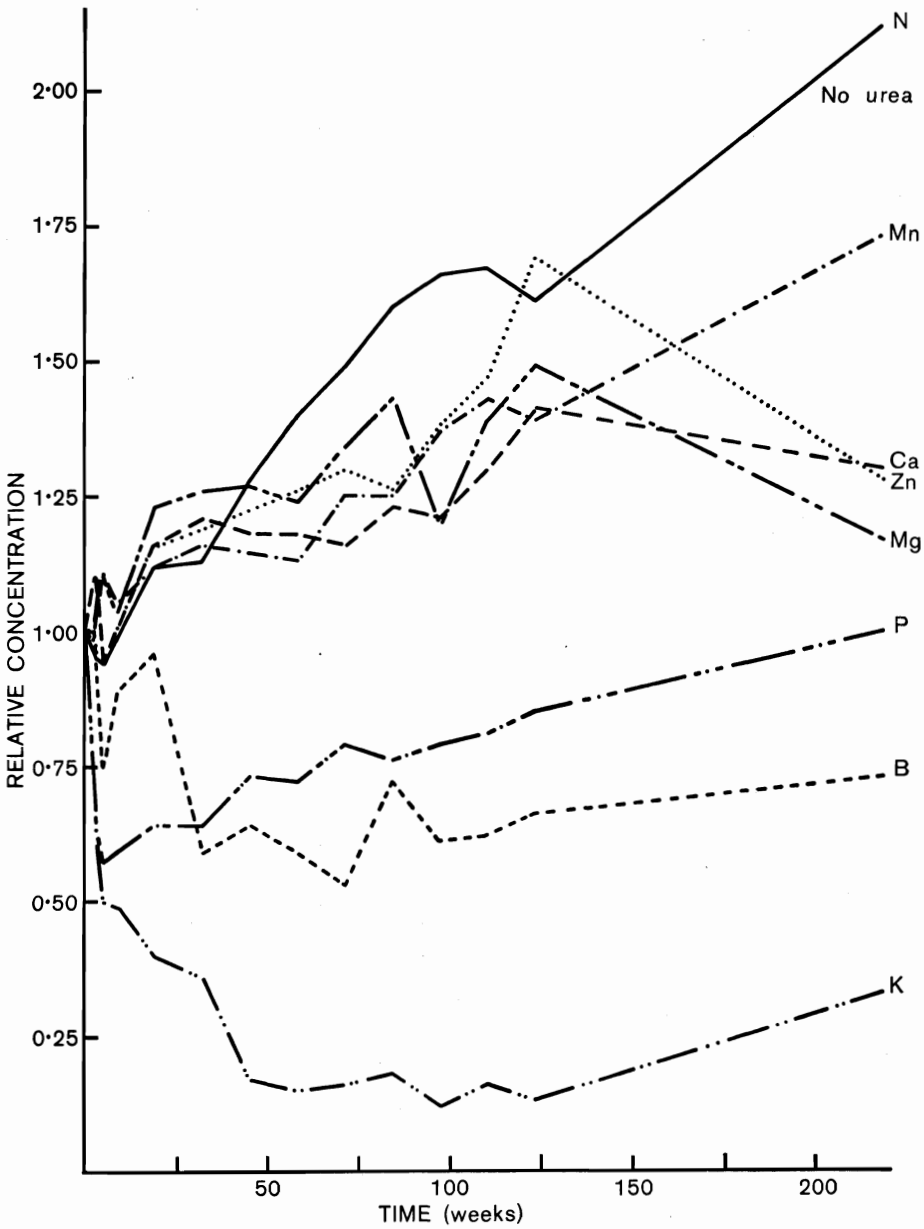

FIG. 3—Relative changes in nutrient concentrations in decomposing litter with time.

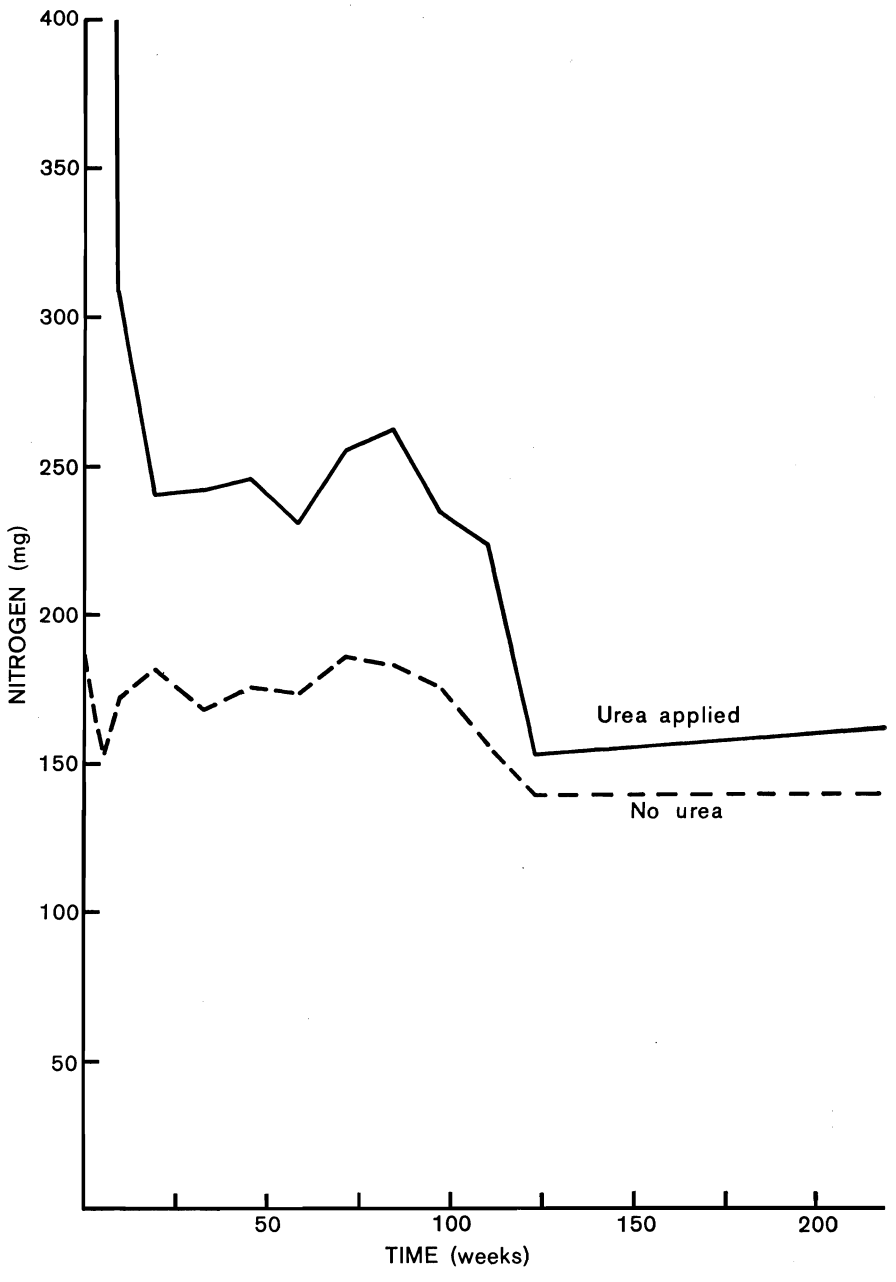

FIG. 4—Changes in total nitrogen content of decomposing litter with time.

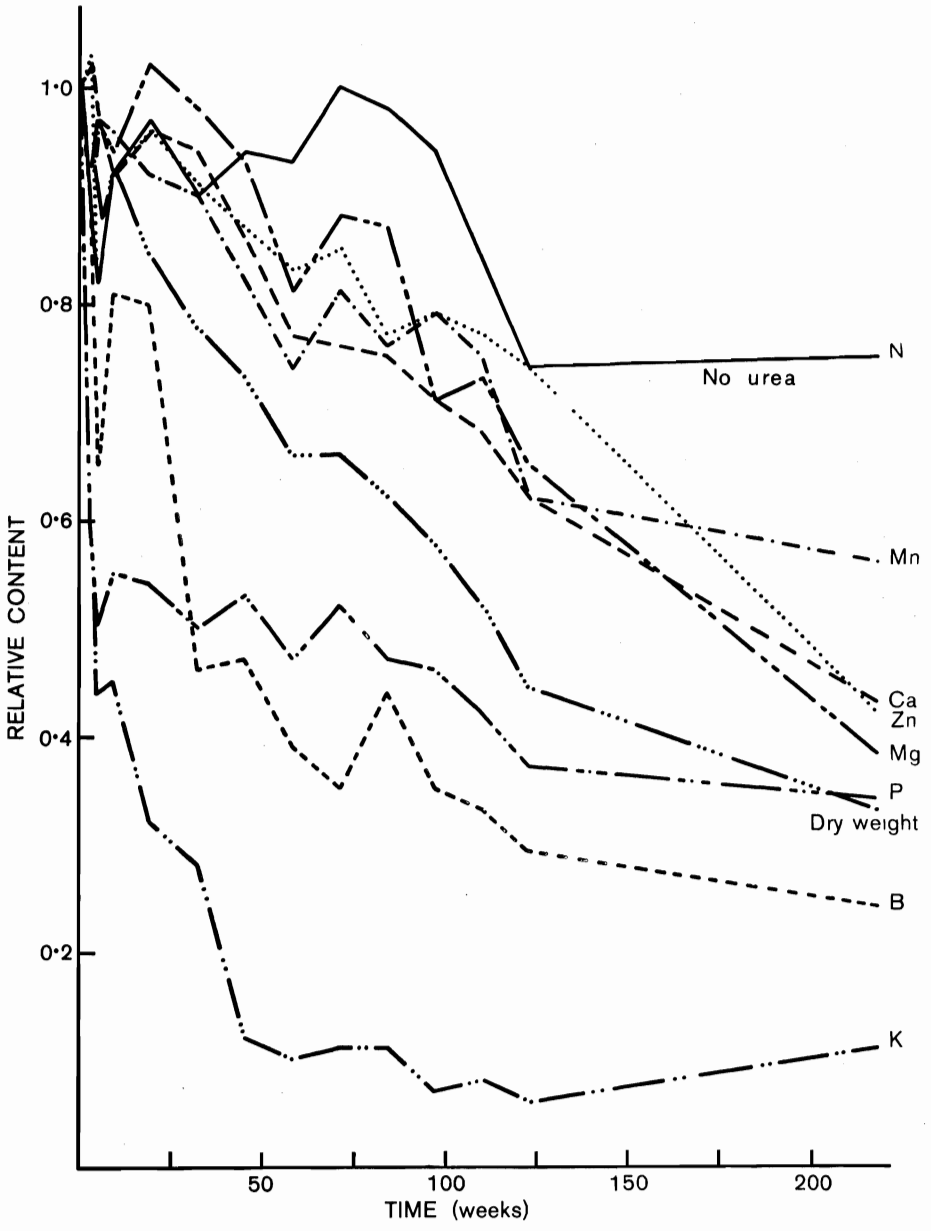

FIG. 5—Relative changes in total nutrient contents in decomposing litter with time.

In an earlier study (Will 1967) the exclusion of larger fauna by the bags resulted in greatly reduced physical breakdown of needles but similar changes in chemical composition occurred. Our mean value of the decay constant $k = 5.3 \times 10^{-3}$ is considerably lower than that which may be calculated for unconfined *P. radiata* litter from the report by Gadgil & Gadgil (1978), namely $k = 16 \times 10^{-3}$. However, M. L. Carey (pers. comm.) has found that accumulated litter layers in nine, first-crop, 16- to 20-year-old *P. radiata* stands in Kaingaroa and Tasman Forests contained an average of 18 tonnes organic matter/ha which, with annual litter-fall inputs of about 5 tonnes/ha fairly evenly distributed through the year (Will 1959), suggests a decay constant close to 5×10^{-3}. This agreement with our litter bag value may well be fortuitous given the simplistic nature of the exponential decay model used. There is no obvious explanation why, in this study, clearfelling had no significant effect on the rate of decomposition, while in their field and laboratory studies, Gadgil & Gadgil (1978) found a marked effect which they attributed to biological (mycorrhizal roots) rather than physical (microclimate) changes.

Gill & Lavender (1983) have shown that litter bags can be used to detect changes in decay constants for needle litter exposed at different sites and with applied nitrogen compounds. The failure of our experiment to detect similar effects suggests that, under our conditions, some factor other than nitrogen or degree of shade was limiting the rate of decomposition. That nitrogen was not limiting is further suggested because, even in litter without fertiliser applied, there was a doubling of nitrogen concentration over the life of the experiment while the decay constant remained stable after the first few weeks.

Our litter samples followed the pattern of nitrogen conservation frequently described in the literature and summarised by Aber & Melillo (1980) in the equation:

$$\% \text{ remaining} = a - b\ (\% \text{ N concentration in residue})$$

where a and b are constants. Aber & Melillo (1980) gave 33 values of b obtained for leaves (mostly hardwoods) under forest conditions, ranging from 11.5 to 161.1 with a median of 38.9. The mean value for our data was 57.2, with treatment and percentage nitrogen concentration accounting for 61% of the variation in percentage of litter remaining in the litter bags. Using Aber & Melillo's definition of the transition from "litter" to "soil" as the point where net nitrogen immobilisation changes to net mineralisation, our unfertilised material exhibited the transition after about 75 weeks (Fig. 4).

In agriculture C/N ratios are often used as indicators of decomposition and nitrogen-release potentials. However, Jorgensen *et al.* (1980) found that, in a temperate pine forest, nitrogen release was not well related to C/N ratio and this present study also shows that decomposition rate was unaffected by a considerable decrease in C/N ratio brought about by urea application. What factors, then, do influence decomposition rates? This study suggests that, in some circumstances, reduction in canopy by thinning or felling, and the resulting limited changes in temperature and moisture conditions, have no significant effect. Monthly means of weekly ground minimum temperatures (Fig. 6) show that there were only minor differences due to thinning. The markedly lower

minima on the clearfelled site probably indicate greater extremes rather than an over-all lower mean temperature. Whatever the changes in temperature conditions and associated moisture status, there was no substantial change in decomposition rate.

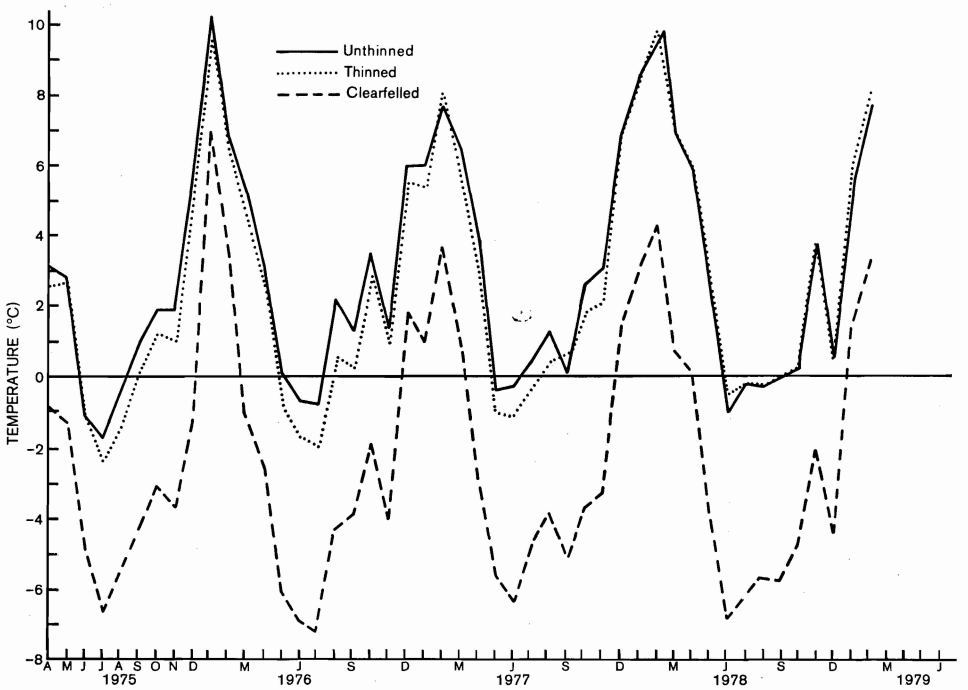

FIG. 6—Mean monthly ground minimum temperatures at litter decomposition test sites.

Lamb (1975, 1976) and Florence & Lamb (1974) reported differences in rate of decomposition with soil type, possibly through differences in polyphenol-protein complexes. Fogel & Cromack (1977) have suggested that the lignin content of *Pseudotsuga menziesii* (Mirb.) Franco litter affects decomposition. For *P. sylvestris* litter Berg, Hannus, Popoff & Theander (1982) found lignin decomposition rate to be slower than that of other organic compounds but Berg, Wessen & Ekbolm (1982) reported that initial nitrogen content influences lignin decomposition. Bosatta & Staaf (1982) have developed a model in which rate of decomposition and initial nitrogen concentration are major factors determining retention and release of nitrogen; in this present study an artificially induced higher initial nitrogen concentration had little effect on the release of nitrogen once the excess had been leached within a few weeks. Gadgil & Gadgil (1975, 1978) showed the importance of mycorrhizal fungi; however, the relative roles of and interactions between the physical environment, microbiological factors, and litter chemical composition (both organic and inorganic) need further investigation and clarification to resolve the apparent contradictions between existing results.

There was a steady increase in percentage of nitrogen in the litter, similar to that found by Versfeld (1981) in *P. radiata* litter in South Africa, but there was no marked import of nitrogen as was noted in a previous study (Will 1967). It seems, therefore, that nitrogen accumulating mechanism(s) operating during the previous study were not present during this study period.

Some of the nitrogen applied as urea fertiliser was retained for almost the whole of the study period (*see* Fig. 4) but this was only approximately 10% of the total applied. The remainder would have leached through to the older litter and mineral soil. The study by Worsnop & Will (1980) suggested that at least 50% of fertiliser nitrogen reaches the mineral soil within a week of application; presumably tree roots have ready access to that reaching the mineral soil plus that retained in the more decomposed litter which is exploited by roots. Where understorey or ground vegetation is present much less of the applied nitrogen may be available to trees; Weber & Van Cleve (1981) reported that 28 months after application 90% of the nitrogen applied was present in a moss layer.

The litter layer appears to contain a remarkably stable pool of nitrogen which reacts little, if at all, to imposed silvicultural treatment such as thinning. However, thinning and the replanting of clearfelled land impose major increases in the demand for nitrogen by tree crops (Webber 1978). A knowledge of the dynamics of nitrogen in the litter layer, including quantitative assessment of inputs and outputs, is crucial to good forestry practice. Such knowledge should lead to ecologically sound methods for manipulating forest litter layers to affect the availability of this nitrogen pool to the tree crop.

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