Production, Accumulation and Nutrient Content of Sitka Spruce Litterfall

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Abstract
Litterfall measurement in three stands of Sitka spruce showed that on average 5,500 kg/ha was shed per annum. This contained 72 kg of nitrogen, 5 kg of phospharus and 14 kg of potassium. Because litter production exceeds decomposition large amounts accumulate. On average the litter layers had a D.M. content of 50,000 kg/ha containing 915 kg of nitrogen, 50 kg of phosphorous and 130 kg of potassium. The high figures for production and accumulation, and the variation between sites, appeared to be related to crop density.

Introduction

THE maintenance of satisfactory tree growth where fertilisers are not applied is ultimately dependent on the recycling of essential nutrient elements. Although throughfall and stemflow contribute to nutrient cycling, litterfall is by far the most important factor involved in the release of nutrients from trees. Work by Ovington (1961) on Scots pine *(Pinus Sylvestris* L.), Cole *et al* (1967) and Abee and Lavender (1972) on Douglas fir *(Pseudotsuga menziesii* (Mirbel) Franco), Mahendroppa and Ogden (1973) on Black spruce *(Picea mariana* (Miller) Britton, Sterns and Poggengerg) and Miller, Cooper and Miller (1976) on Corsican pine *(Pinus nigra* Arnold) showed that on average 87, 70 and 40% of the nitrogen (N), phosphorus (P) and potassium (K) reaching the forest floor each year was contained in the litter.

Due to the high content of cellulose and lignin in leaf tissue, the biologically impoverished nature of many forest soils and the close spacing of trees in many man-made forest crops, the decomposition of coniferous litter tends to proceed rather slowly, leading in many areas to the accumulation of large quantities of organic matter on the forest floor. The object of the study reported here was to measure the dry matter and the N, P and K contents of the litter shed over a twelve month period by representative polestage crops of Sitka spruce *(Picea sitchensis* (Bong) Carr.) and to determine the amounts of those elements in the forest floor.

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Site Description

The dry matter and N, P, K contents of the litterfall and the forest floor were measured in three polestage crops of Sitka spruce (Table 1). The crops varied in age from 34 to 47 years and were located in separate State forests in County Wicklow.

Based on forest management tables (Bradley, Christie and Johnston, 1966), the Glenmalure crop was approximately 164% overstocked, the Glenealy crop 16% overstocked and the Ballinglen crop 9% overstocked. The Ballinglen and Glenealy crops had been thinned heavily in 1973 and would have been considerably overstocked before then. The Glenmalure stand had never been thinned. The plantations were established by pit-planting on unploughed and unfertilised land. The soil at the Glenmalure site varies between a peaty podzolised gley and a blanket peat (peat depth approximately 80 cm) the parent material being mainly mica schist with a small proportion of granite. The soils at the other two sites are both Brown Podzolic but the drift at Glenealy is essentially a mixture of Cambrian shale and slate with a high proportion of quartzite whereas that at Ballinglen is comprised mainly of Ordovician shale with a significant mixture of mica schist and slate and some quartzite. The three soils are strongly acid in reaction with pH values in the top 25 cm varying between 3.8 and 5.1. Mean annual rainfall varies from 1800 mm at Glenmalure to 1025 mm at the other two sites. Mean annual temperature is approximately 10°C.

TABLE 1

Elevation, age and growth parameters for the three stands.

Forest	Elevation (m)	Age (yrs.)	Top Ht. (m)	Yield Class m^3/ha	Basal Area m^2/ha	No. Stems/ ha
Glenmalure	350	34	15.9	14	74.7	3760
Glenealy	200	39	15.7	12	35.5	1216
Ballinglen	300	47	24.6	18	38.8	583

Experimental

Three plots, 25x25 m, were selected at random within each crop for measurement of the dry matter and nutrient content of the litterfall and of the forest floor. Within each plot fifteen sampling points were selected at random. The depths of the forest floors were measured and samples taken at the end of November 1974.

The material collected included L, F and H layers only as defined by Hoover and Lunt (1952). All branch, twig and coarse (greater than 25 mm diameter) root materials, although strictly speaking part of the forest floor, were excluded. To facilitate sampling a stiff section of P.V.C. piping 10 cm in diameter and 8 cm deep was pressed firmly into the forest floor. A sharp knife was used to cut through the layers of organic matter around the edge of the ring and the sample was then carefully removed. Each sample was placed in a sealed P.V.C. bag and transferred to the laboratory within 24 hours.

The measurement of litterfall commenced at the end of November, 1974, after the forest floors had been sampled, and continued for a period of twelve months. The litter was collected in P.V.C. plant pots (top internal diameter 25.4 cm, height 22 cm). Fine polypropylene netting was placed at the bottom of the pots to filter litter from rainwater. Fifteen pots were placed at random within each plot (total collection surface, 0.76 m^2 per site). The litter was harvested every two months and transferred to the laboratory in paper bags.

All samples of the forest floor were dried for 48 hours at 90°C and weighed. Samples were then bulked by crops prior to analysis of duplicate subsamples for organic carbon and nutrient contents using standard chemical methods. pH was determined on the bulked samples before drying using a 1:1 water sample ratio. In addition, ten samples from each crop were carefully separated to find the proportions of needles, root, bark and other material. Litterfall from each collector in each sample period was dried at 90°C, weighed and then bulked by crops for analysis of nutrient content. Dry weights for litter and forest floor are expressed on a 105°C basis.

Results

Litter Production

The quantity of litterfall and its absolute nutrient content (Table 2) both follow the pattern of stocking density, being greatest at Glenmalure and least at Ballinglen. Although significant quantities of litter fell throughout the year at each site, the months of June and July had by far the highest fall of the six sampling periods (Table 3, Fig. 1). This may be a reflection of the unusually low rainfall and high temperatures recorded in Ireland for that period in 1975. There was a general tendency for the figures for P and K (% DM) to be highest in April-May and lowest in October-November (Table 3). The high April-May figures may be due to leaching of nutrients from the newly formed foliage onto the older needles, whereas the drop in the October-November data could be due to translocation to other parts of the tree prior to senescence or to leaching out by rainwater. Both of these processes are known to take place in trees (Tamm, 1951; Madgwick and Ovington, 1959; Tukey, 1970). Alternatively, the high April-May data may represent movement of these elements from roots and stem to shoots prior to bud-break (Miller, 1977, personal communication), the low figures for October-November being the reverse. It is apparent from Figure 2 that the variation in nutrient concentration of the litterfall throughout the year follows very similar patterns for the three sites. Similar patterns were found by Wright (1957) for N, P and K in Norway spruce, and by Miller *et al* (1976), for N concentration in Corsican pine.

TABLE 2

Mean dry matter and N, P and K contents of litterfall (kg/ha/annum)

Forest	DM	SE*	N	P	K
Glenmalure	8860	204	117.6	7.8	21.9
Glenealy	4040	138	54.2	4.1	13.6
Ballinglen	3850	55	45.0	2.3	7.4

*Standard error of the mean.

Although the values in Table 2 are generally higher than those cited in the literature they are quite comparable with the figures given by Wright (1957). The dry matter, N and K contents given by Owen (1964), for Sitka spruce are considerably lower than those reported here; his data for P are quite comparable. All data for the Glenmalure plots are extremely high when compared with those in the literature. Apart from the figures by Spain (1973) for Douglas fir in Australia, the N data here are considerably higher than those reported in the literature.

Litter Accumulation

The forest floor samples were all extremely acid (Table 4) with pH values varying between 3.7 and 4.5, the average being 4.1. The Glenmalure forest floor was more acid than that at the other two sites. Organic carbon contents were high, averaging 48.4%, resulting in high carbon/nutrient ratios.

The figures for dry matter and nutrient contents of the forest floors in Table 4 are in general considerably higher than those cited for conifers by other workers, with the exception of the data for 100 year old Douglas fir given by Youngberg (1966). It should be borne in mind however that in the present study all branch twig and coarse root material was excluded from the samples. A feature of the composition of the forest floors (Table 5) is the occurrence of many small (less than 2.5 mm diameter) tree roots. Mycorrhizal fungi were also observed but not quantified. The average dry matter content of the small roots for the three sites was 1450 kg/ha.

TABLE 3

Bi-monthly dry matter and nutrient contents, per cent of dry weight and absolute quantities (kg/ha), of litterfall at the three forests. Each figure represents a mean of three plots.

Collection Period	Forest	kg/ha	DM (SE)	%Tot	%DM	N kg/ha	%DM	P kg/ha	%DM	K kg/ha
Dec-Jan	Glenmalure	1100	280	12.4	1.32	14.5	.09	1.0	.23	2.5
	Glenealy	440	200	11.2	1.39	6.1	.10	0.4	.36	1.5
	Ballinglen	300	120	7.5	0.94	2.8	.06	0.2	.12	0.3
Feb-Mar	Glenmalure	999	210	11.3	1.39	13.8	.08	0.8	.22	2.1
	Glenealy	150	70	3.8	1.39	2.1	.10	0.1	.31	0.4
	Ballinglen	340	120	8.6	1.16	3.9	.08	0.2	.16	0.5
Apr-May	Glenmalure	1400	240	15.8	1.37	19.2	.10	1.4	.36	5.1
	Glenealy	710	180	18.1	1.49	10.5	.13	0.9	.57	4.0
	Ballinglen	430	100	10.8	1.23	5.2	.09	0.3	.28	1.2
Jun-Jul	Glenmalure	2630	510	29.7	1.28	33.6	.08	2.1	.23	6.0
	Glenealy	1700	380	41.7	1.32	22.4	.11	1.8	.30	5.1
	Ballinglen	2280	450	57.7	1.14	26.0	.08	1.8	.21	4.8
Aug-Sept	Glenmalure	1660	380	18.8	1.46	24.2	.09	1.4	.24	4.9
	Glenealy	390	140	9.9	1.46	5.7	.10	0.4	.28	1.1
	Ballinglen	390	120	9.8	1.42	5.5	.09	0.3	.13	0.5
Oct-Nov	Glenmalure	1040	300	11.7	1.10	11.4	.06	0.6	.13	1.3
	Glenealy	530	200	13.5	1.12	5.9	.07	0.3	.16	0.8
	Ballinglen	210	50	5.3	1.42	3.0	.09	0.1	.12	0.2
Annual Total	Glenmalure	8829				116.7		7.3		21.9
	Glenealy	3920				52.7		3.9		12.8
	Ballinglen	3950				46.4		2.9		7.5

Discussion

The results show that the rate of litter accumulation beneath polestage crops of Sitka spruce far exceeds its rate of decomposition. If the forest floors beneath the crops had reached a stage of equilibrium, or as Reiners and Reiners (1970) term it a "steady state", the input of organic matter and nutrients to the forest floor would equal the output. However these crops of Sitka spruce, with the possible exception of the Ballinglen stand, have not yet reached this stage and work by Page (1968) would suggest that they are unlikely to do so until they are 55 to 60 years old.

The wide variation between sites both with regard to litterfall and forest floor characteristics raises the question as to why such large differences exist. It is probable that the main factor contributing to the wide variation in both litterfall and forest floor characteristics is crop density. The Glenmalure stand had both the highest litterfall and the greatest quantity of organic matter present in its forest floor whereas the Ballinglen site, which was also the most productive, had the smallest amounts. Although the Glenmalure stand was the

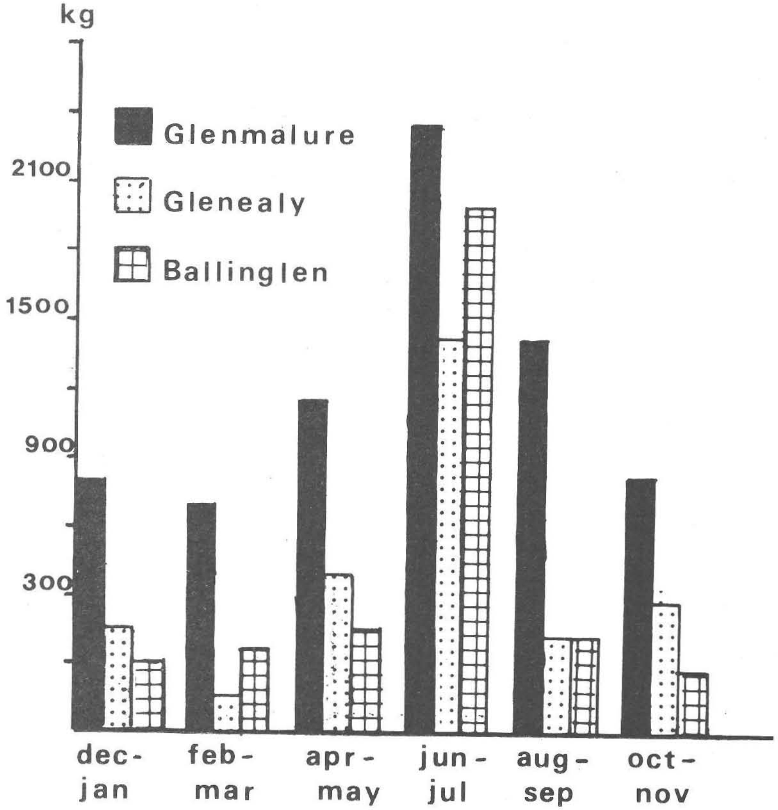

Figure 1. Seasonal variation in Sitka spruce litterfall. (kg ha^{-1}, D.M.

younger of the two it was also the most overstocked. While the confounding effect of age on stand density makes it impossible to isolate the significance of either factor, crop density is very likely the over-riding one. Wright (1957) working in a Norway spruce *(Picea abies* (L.) karsten) thinning experiment showed that forest floors beneath heavily thinned crops contained 66% less organic matter compared with lightly thinned plots, twenty five years after the treatments were imposed. Although he found that thinning resulted in a slight reduction in litterfall, Wright attributed the large decrease in litter accumulation on the forest floor to a considerable increase in its rate of decomposition following thinning operations.

Results from research on spacing experiments carried out in Sitka spruce in Ireland have been published by Jack (1971) and Gallagher (1973). From these it appears that growth was not affected, at least on the better sites, at spacing up to 2.4 metres but production is severely reduced with further increases in initial spacing. However, a balance would have to be found between the beneficial effects of a faster circulation of nutrients and the straightforward adverse effects of a heavy reduction in stocking on increment, a balance that would probably vary with the nutrient capital of the site.

In the context of the overall nutrient budget, both the quantities of nutrients being shed annually in the litterfall and the amounts immobilised in the forest floors are substantial. More detailed studies at the Glenmalure site (Carey, 1977a) showed that 45% of the N and 35% of the P present in the ecosystem were in the forest floor. The quantity of K present in the forest floor on the other hand represents

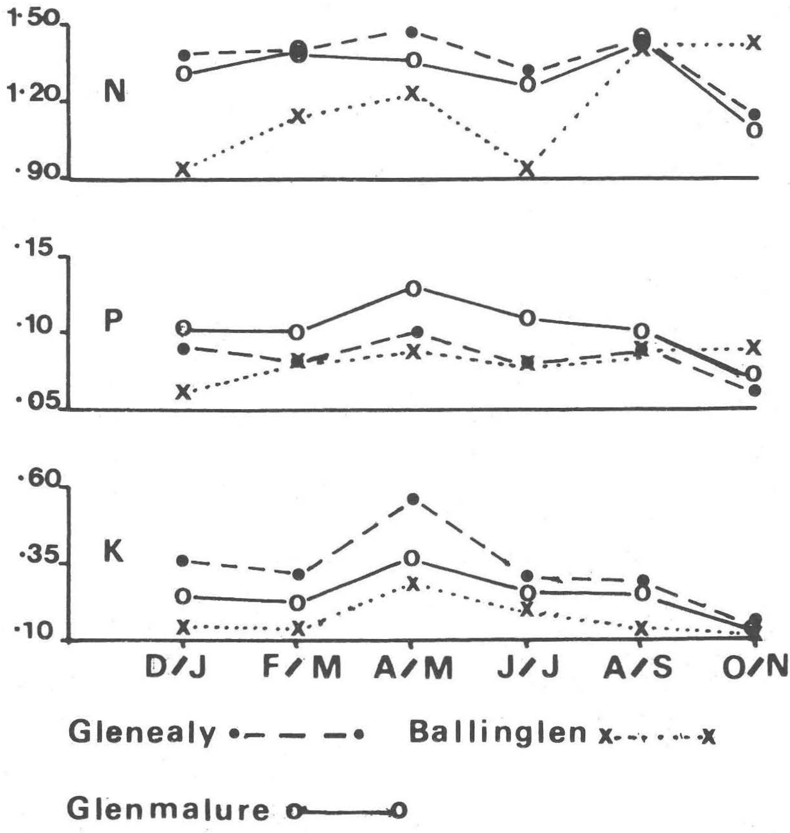

Figure 2. Seasonal variation in the N, P and K concentration of Sitka spruce litterfall (% D.M.).

only 7% of the total present in the system. This nutrient is held in inorganic form whereas most of the nitrogen and phosphorus are organically bound. Further studies also indicated that the quantities of nutrients reaching the forest floor in the litter represented the greater proportion of the annual uptake by the crops concerned. This suggested that the nutrient requirements could be almost totally satisfied through recycling, but that the process was being interrupted by the slow rate of decomposition (Carey 1977b).

The accumulation of litter and the immobilisation of nutrients within the forest floor will be of practical significance only when the supply of nutrients is incapable of satisfying the demands of the crops. Although there are indications of impending deficiency in some crops, recent work by O'Carroll, Dillon and Carey (1976) suggests that these are by no means widespread under Irish conditions. Under these circumstances, the accumulation of litter on some sites might offer certain advantages, serving as a reservoir of nutrients for future forest rotations. However, on nutrient-poor sites, the immobilisation of nutrients in the forest floor may have serious consequences for tree nutrition and fertiliser inputs might be required to sustain growth.

TABLE 4

Depth, pH, organic carbon (% D.M.) dry matter content, and concentration and mass of nitrogen, phosphorus and potassium in the forest floors

Site	Glenmalure	Glenealy	Ballinglen
Depth (cm)	6.0	4.8	3.6
pH	3.7	4.4	4.4
Organic carbon (%)	53.7	47.8	43.8
D.M. (tonnes/ha	55.46	50.65	45.67
Standard error	7.42	8.60	13.15
N% D.M.	2.04	1.63	1.73
kg/ha	1131	825	790
P % D.M.	.09	.09	.11
kg/ha	49	47	51
K % D.M.	.06	.28	.47
kg/ha	33	142	216
C/N	26	29	25
C/P	596	531	398
C/K	895	170	93

The occurrence of many fine mycorrhizal roots within the forest floor suggests that the trees are obtaining some of their nutrient supply directly from these layers as has been suggested by Gessel *et al* (1973). Further research is required in order to establish the extent to which Sitka spruce obtains N and the other essential nutrients directly from the forest floor. Results from such studies would provide the forest manager with a greater understanding of the nutrient cycle in forest crops and of the extent to which it can be manipulated in the interests of greater wood production.

TABLE 5

Composition of the forest floors (kg/ha)

Forest	Small roots	Twigs	Bark	Needles and non identifiable material
Ballinglen	950	180	220	44,320
Glenealy	2,080	2,220	20	45,580
Glenmalure	1,320	1,100	—	54,040

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