Biomass, Nutrient Content and Distribution in a Stand of Sitka Spruce*

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ABSTRACT

The annual uptake of nitrogen, phosphorus and potassium by an unthinned 33 year old crop of Sitka spruce was estimated by destructive sampling of eight trees. Extrapolation of their nutrient contents to the total crop gave estimates of 81kg N, 4kg P and 15kg K. Although the stemwood and bark accounted for half of the total dry matter production they only contained 17, 14 and 36 *per cent* of the total quantities of N, P and K present in the crop and forest floor, the main bulk of the nutrients being in the needles and branches.

INTRODUCTION

The rising cost of fertilisers in recent years, together with the extension of afforestation on to increasingly difficult site types, and a trend towards more complete-tree harvesting systems (Young 1974, Keays and Hatton 1976), has focused attention on both the biomass production and nutrient accumulation patterns within forest crops. Although results from many studies have been published none of these refer to Sitka spruce (*Picea sitchensis* (Bong) Carr.), a native of Western North America and now the most important forest tree in Ireland (Purcell 1977) and Britain (Pearse 1976). This study was carried out in a polestage crop of Sitka spruce. The objècts were:

1. to measure the total dry matter (DM) production by the crop and to determine its distribution between the different crop components;
2. to measure the total nitrogen (N), phosphorus (P) and potassium (K) contents of the crop and to determine their distribution patterns;

* Based on part of a larger study carried out by the Senior Author at University College Dublin, Ireland.

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3 to estimate the gross annual production of organic matter and the gross annual uptake of N, P and K;

4 to quantify the extra drain on the nutrient budgets that would result through the implementation of more complete tree harvesting systems.

METHODS

Field

The crop was planted in 1941 at Glenmalure forest (National Grid ref. Glenmalure T 06 94) on a soil transitional between a peaty gley and a blanket peat — peat depth 80cm — over shallow glacial drift comprised of mica schist and granite. No cultivation or fertiliser treatments were imposed on the site other than the fact that the trees were planted on mounds. No silvicultural operations had been carried out apart from brashing of dead branches in 1973 which were left on the forest floor. As a result the crop was considerably overstocked (Table 1) relative to the normal management tables for the species (Bradley, Christie and Johnston, 1966).

Table 1 — Crop and site characteristics.

Age	Top Ht.	Yield Class	Basal Area	Stems	Elevation	Mean Annual rainfall	Mean Annual temperature
(Yrs)	(m)	m3 ha^{-1}	m2 ha^{-1}	ha^{-1}	(m)	(mm)	^{o}C
33	15.9	14	74.7	3,760	350	1,800	10

Eight trees were selected at random for destructive sampling using the following procedure: three square 0.1ha plots were located randomly within the stand which had a total area of 7ha. The diameter at 1.30m from the base of all trees (a small proportion of which was dead) in the three plots was measured to the nearest 0.1cm. The total population for the plots, 735 trees (diameter range 7.0-28.9cm), was divided into eight equal number classes based on the diameter distribution and the sample trees were randomly allocated within these, the only restriction being that at least two samples should fall on each plot. Each sample tree was felled on to a large P.V.C. sheet and separated into the following components for determination of fresh weights and subsampling for moisture content and chemical analyses; dead branches (including bark), live coarse branches, live fine branches, bole timber and bark and coarse and fine roots (greater and less than 1cm diameter), the stump being included with the coarse root fraction. That part of the

Table 2 — Concentrations of N, P and K in the different components on each sample tree. (% D M).

Tree Component		1	2	3	4	5	6	7	8	$\bar{X}$	Std. Error
		Sample tree number									
Dead branches	N	.80	.84	.76	.87	.87	.87	1.00	1.06	.88	.035
	P	.0560	.0500	.0545	.0585	.0480	.0520	.0550	.050	.0522	.0012
	K	.067	.050	.050	.060	.050	.055	.092	.045	.059	.005
Live coarse branchwood	N	.11	.11	.13	.16	.13	.13	.13	.14	.13	.005
	P	.0090	.0082	.0130	.0207	.0115	.0110	.0147	.0125	.0125	.0013
	K	.075	.067	.095	.100	.050	.085	.107	.090	.084	.006
Live coarse branch bark	N	.98	.92	1.32	1.25	1.07	1.08	1.01	1.31	1.12	.054
	P	.0900	.1000	.1600	.1100	.110	.1400	.1500	.1400	.1237	.0090
	K	.390	.545	.725	.480	.362	.690	.580	.565	.542	.045
Live coarse branch needles	N	1.86	1.59	1.66	1.66	1.66	1.66	1.52	1.59	1.65	.035
	P	.1300	.1100	.1400	.1900	.0700	.1500	.1200	.1300	.1300	.0121
	K	.845	.725	.690	.840	.327	.850	.670	.545	.687	.063
Live fine branchwood	N	1.24	1.04	1.24	1.73	1.24	1.52	1.11	1.45	1.32	.080
	P	.1100	.0800	.1100	.0900	.0800	.1600	.1200	.1200	.1087	.0087
	K	.250	.260	.330	.460	.190	.450	.380	.260	.323	.035
Live fine branch needles	N	1.73	1.99	1.99	1.73	1.86	1.92	2.12	1.86	1.80	.047
	P	.1100	.0800	.1100	.1900	.0800	.1600	.1200	.1200	.1212	.0132
	K	.900	.725	.580	.660	.635	.500	.710	.860	.696	.047
Bole timber	N	.19	.14	.19	.12	.11	.19	.18	.12	.16	.012
	P	.0030	.0025	.0035	.0040	.0050	.0030	.0030	.0040	.0035	.0003
	K	.050	.050	.067	.062	.045	.067	.062	.067	.059	.003
Bole bark	N	.92	.89	.91	.71	.81	.65	.74	.79	.80	.035
	P	.0700	.0620	.0700	.0820	.0670	.0650	.0870	.0900	.0741	.0037
	K	.250	.330	.240	.400	.205	.400	.410	.400	.329	.030
Coarse roots	N	.16	.20	.14	.16	.24	.23	.18	.20	.19	.012
	P	.0108	.0083	.0075	.0097	.0202	.0222	.0137	.0126	.0131	.0054
	K	.132	.095	.072	.112	.127	.185	.132	.107	.120	.0117
Fine roots	N	.78	1.59	1.11	1.04	.84	.90	.78	1.11	1.02	.094
	P	.0520	.0540	.0500	.0600	.0550	.0800	.0560	.0750	.0620	.0039
	K	.177	.225	.172	.440	.272	.590	.282	.385	.318	.051

main stem less than 7cm diameter was included with the coarse branch category. The branch components were chopped up into approximately 15cm lengths to facilitate subsampling. Ten discs were taken at equal distance along each bole in order to determine the ratio between bole timber and bark and their moisture contents and nutrient concentrations. Although many fine roots were observed at 100-110cm the overall excavation of the root systems proved easy due to the aid of a block and chain which was suspended from a specially constructed heavy frame. Recovery of roots appeared to be in the order of 95-98 *per cent.*

Laboratory

Dry weights were determined on duplicate samples by drying at 105°C for forty eight hours. Samples for chemical analyses were dried at 70°C for the same period. Subsamples of the live coarse branches were further separated into branch timber, branch bark and branch needles. For the live fine branches a separation was made between root timber and root bark. All samples were ground in a Glen Creston mill before chemical analyses were carried out (in duplicate). Total nitrogen was determined using a micro-Kjeldahl method after Jackson (1958). Phosphorus was determined colourimetrically using the molybdenum blue method, ascorbic acid acting as the reductant after Alexander and Robinson (1970). Potassium was measured by flame emission spectrometry. The results from the chemical analyses are presented in Table 2.

Statistical

The moisture contents and nutrient concentrations were used to determine the dry matter and nutrient contents of each sampling component on each of the sample trees; the total dry weights and contents of N, P and K present being obtained by addition. A series of simple linear regression equations relating the sample tree dry weights and their nutrient contents to independent variables such as basal area, mid-diameter, volume and total height was then calculated. These showed that basal area was more closely related to the dependent variables than any of the other variables, the r^2 values in each case being 0.94 or more (Table 3). Because it is also an easily measured stand characteristic it was used for prediction purposes. Further, as the r^2 values were sufficiently high it was not deemed necessary to use any alternative models.

Table 3 — Coefficient of determination for the equations relating DM, N, P and K of the sample trees to certain tree parameters.

Dependent variables	Basal Area	Volume	Independent variables DBH	Mid-Diam.	Total Height
Total DM	.97	.94	.88	.90	.27
Total N	.94	.90	.88	.86	.18
Total P	.95	.90	.90	.88	.24
Total K	.94	.92	.88	.85	.32

Separate regression equations were calculated in order to provide a breakdown of the distribution of DM and nutrients within the crop. Basal area was again used as the independent variable due to its reasonably close relationship with the dry weights and nutrient levels of the different crop components. (Table 4). The dry weights and nutrient contents of the component parts were converted to a unit area basis. Examination of the crop estimates (Table 4) shows that while the confidence intervals are quite variable in some cases, the prediction of the larger components together with the total are quite satisfactory (±12% for total DM). This would seem to indicate that improvements in the accuracy could be attained by estimating the dry weight and nutrient contents of the whole tree by chipping and sub-sampling rather than splitting into subjective components. Certain estimates are very unreliable e.g. live coarse branch needles, mainly because it's not an easily described component.

Results and Discussion

The basal area, volume, total height, dry matter distribution and total N, P and K contents for each of the sample trees are shown in Table 5. Table 6 shows the DM, N, P and K contents for the crop, and the forest floor based on earlier work (Carey and Farrell 1978).

The total DM and nutrient contents were determined by addition of the data for crop and forest floor and the figures on gross annual accumulation were obtained by dividing these by the age of the crop, 33 years. These figures do not take account of losses of organic matter from the site through decomposition, respiration or root death. However these are likely to be small in view of the dense nature of the crop and the fact that no silvicultural treatment other than brashing had taken place.

The relatively large quantities of organic matter and nutrients, particularly N and P, in the forest floor are a reflection of the very dense nature of the crop. This resulted in an unusually high fall of litter (Carey and Farrell 1978) and at the same time probably contributed to slow rates of decomposition. The small quantity of potassium present in the forest floor relative to that in the crop is a reflection of the high mobility of this nutrient compared with N and P and is in agreement with results found by other investigators (Cole *et al* 1967).

Table 6 indicates that the crop has produced in excess of thirteen metric tons of organic matter per hectare per annum and in doing so it has taken up an average of 81kg N, 4.4kg P and 15kg K each year. The figure for organic matter, although within the range given in the literature for coniferous trees, is nevertheless high bearing in mind that the timber production is less than the national average for Sitka spruce in Ireland (Purcell 1977). However it still only represents forty three *per cent* of the figure given by Curran (1968) for maximum production potential of organic matter in the country.

Table 4 — Regression equations and coefficients of determination, crop estimates and confidence intervals for dry matter and nutrient level by components and for the complete tree.

		Intercept		Slope		R^2	Crop Estimate (kg/ha)	95% Confidence Intervals (kg/ha)±	% of mean±
Dead branches	DM	3.66119	NS	419.89087	NS	.46	45,131.9	23,408.8	51%
	N	.00415	NS	5.01476	*	.65	390.2	186.3	48%
	P	.00227	NS	.20756	NS	.40	24.0	13.1	55%
	K	.00228	NS	.24287	NS	.30	26.7	19.0	71%
Live coarse Branch Bark	DM	-0.5264	NS	69.03462	***	.91	3,177.4	1,094.3	34%
	N	- .00845	NS	.89814	***	.88	35.3	16.7	47%
	P	- .00097	*	.10302	***	.92	4.0	1.5	36%
	K	- .00342	NS	.40567	***	.91	17.4	1.6	9%
Live coarse Branch Wood	DM	-1.40251	NS	309.89868	***	.90	17,876.0	5,192.0	29%
	N	- .00273	NS	.44714	***	.92	23.1	14.8	64%
	P	- .00710	*	.41585	*	.68	4.4	14.6	332%
	K	- .00196	NS	.30056	***	.86	15.1	5.1	34%
Live coarse Branch Needles	DM	-0.13781	NS	12.14865	**	.72	389.3	390.1	100%
	N	- .00203	NS	.18844	*	.69	6.4	6.4	100%
	P	- .00017	NS	.01565	**	.71	.5	.5	100%
	K	- .00050	NS	.06528	*	.68	3.0	2.2	73%
Live fine Branch Wood	DM	-3.08226	*	343.68433	***	.92	14,083.9	5,147.1	37%
	N	- .04862	*	4.89276	***	.94	182.7	63.0	34%
	P	- .00433	*	.43340	***	.90	16.1	7.5	47%
	K	- .00722	NS	.99259	**	.81	47.0	24.6	52%

Live Fine Branch Needles	DM	–5.48316	**	467.53687	***	.89	14,308.3	8,295.4	58%
	N	– .10219	*	8.87506	***	.89	278.7	162.0	58%
	P	– .00663	*	.57251	***	.91	17.8	9.3	52%
	K	– .05194	*	3.93288	**	.84	98.5	87.8	89%
Bole Timber	DM	–0.01790	NS	2,700.71729	***	.91	201,676.3	42,650.8	21%
	N	.01438	NS	3.51416	*	.59	316.6	150.0	47%
	P	– .00021	NS	.10488	***	.95	7.0	1.2	17%
	K	– .00426	NS	1.84652	***	.89	121.9	32.3	26%
Bole bark	DM	0.48120	NS	213.58185	***	.94	7,763.9	2,785.9	16%
	N	.00678	NS	1.54186	***	.89	140.7	27.0	19%
	P	– .00119	NS	.21906	***	.86	11.9	4.5	38%
	K	– .00333	NS	.96207	***	.87	59.3	21.0	35%
Coarse roots	DM	–0.59856	NS	749.08325	***	.96	53,705.9	8,157.3	15%
	N	– .00312	NS	1.55764	***	.86	104.6	32.3	31%
	P	– .00021	NS	.11112	**	.70	7.5	3.7	49%
	K	– .00034	NS	.90113	**	.83	66.0	21.0	32%
Fine roots	DM	0.58190	*	12.26289	NS	.30	3,104.0	959.7	31%
	N	.00330	NS	.18602	NS	.50	26.3	9.5	36%
	P	.00024	NS	.01214	*	.61	1.8	.5	28%
	K	.00104	NS	.02544	NS	.44	9.5	4.4	46%
TOTAL	DM	–6.52438	NS	5,297.8393	***	.97	371,216.9	43,634.7	12%
	N	– .13869	NS	27.12363	***	.94	1,504.6	352.8	23%
	P	– .01828	*	2.19340	***	.95	95.1	25.6	27%
	K	– .06969	*	9.72180	***	.94	464.2	121.5	26%

Table 5 — Basal area, volume, total length, dry matter distribution (kg) and total N, P and K contents (kg) of sample trees.

Tree characteristics	Sample tree number							
	1	2	3	4	5	6	7	8
Basal area (m^2)	.00849	.01227	.01690	.02010	.02406	.02835	.03365	.05147
Volume to 7cm diam (m^3)	.04863	.07286	.09657	.11889	.14668	.23905	.23816	.36272
Total length (m)	12.7	14.6	11.9	13.8	11.5	15.6	15.9	14.6
Tree component								
Dead branches	3.47	6.43	24.22	7.89	12.91	9.67	22.35	24.35
Live coarse branch wood	3.06	3.61	3.11	4.10	4.79	5.46	9.07	16.10
Live coarse branch bark	0.47	0.51	0.48	0.84	0.69	1.17	1.76	3.35
Live coarse branch needles	0.11	0.05	0.07	0.09	0.02	0.12	0.18	0.63
Live fine branch wood	1.40	2.34	2.15	1.89	3.67	5.88	9.93	15.20
Live fine branch needles	0.60	2.43	2.61	2.75	2.21	5.29	10.73	20.82
Bole timber	20.14	29.01	37.55	59.22	56.67	88.25	111.10	125.34
Bole bark	2.34	4.31	3.67	4.07	5.35	6.51	8.57	11.34
Coarse roots	5.22	11.11	10.33	12.55	21.31	18.97	23.28	38.73
Fine roots	0.74	0.36	0.68	0.94	1.38	0.81	1.08	1.06
Total dry weight	37.55	60.16	85.09	94.34	109.00	142.13	198.06	256.94
Total N (g $tree^{-1}$)	139	243	401	295	382	557	907	1271
Total P (g $tree^{-1}$)	8	12	25	20	23	37	56	83
Total K (g $tree^{-1}$)	40	72	84	111	100	197	293	441

Table 6 — Total DM, N, P and K contents of crop and forest floor (kg ha^{-1}) and gross annual accumulation patterns (kg ha^{-1} $year^{-1}$).

	DM	N	P	K
Crop	371,217	1,505	95	464
Forest floor	60,212	1,174	51	36
Total	431,429	2,679	145	500
Annual	13,073	81	4.4	15

The figures on gross annual uptake of N, P and K in Table 6 do not necessarily indicate the actual quantities necessary to sustain the growth rate achieved at this particular site nor do they represent the actual quantities taken up each year. Nutrient uptake by forest trees is known to vary considerably with age (Switzer and Nelson 1972) and uptake of nutrients in excess of actual requirements, termed "luxury consumption", is also a well established phenomenon (Tamm 1964). If the data by Rodin and Bazilevech (1965) are applicable, then the figure for nitrogen uptake found here would appear to be well in excess of actual requirements. They estimate that the annual growth of organic matter in these islands requires 10-20kg N, 1-3kg P and 6-10kg K ha^{-1} $annum^{-1}$. The fact that the nutrient levels in the newly formed foliage on the crop (N=2.05%, P=0.20%, K=0.80% are well in excess of what are considered threshold levels for conifers (Tamm 1964) also suggests that tree growth at this site is not limited by lack of available nutrients. This has recently been demonstrated for phosphorus in that the application of phosphate fertiliser to the crop in 1975, although it resulted in increased P levels in the trees in the following years, has had no effect on their diameter growth so far (Carey 1977, unpublished data).

Despite the shortcomings associated with the estimates on nutrient uptake the figures are nevertheless reasonably comparable with those published elsewhere for certain other coniferous species. For instance Ovington (1961) gives figures of 61, 3 and 18kg for N, P and K respectively for *Picea abies* while Miller and Miller (1976) in their studies on *Pinus nigra* estimated the uptakes per hectare associated with a steady growth rate of YC 16 were 69, 6 and 28 for the three nutrients. The result for nitrogen found here is particularly high when compared with corresponding figures for other conifers in some American and Scandinavian studies (Cole *et al* 1967, Melkonen 1974).

A breakdown of the distribution of organic matter and nutrients within the crop and forest floor is presented on a percentage basis in Table 7. The bole timber and bark represent just over half of the total production, the remainder being distribution between the

Table 7 — Percentage distribution of DM, N, P and K within the crop and forest floor.

Component	DM	N	P	K
Dead branches	10.5	14.6	16.4	5.4
Live coarse branch wood	4.1	0.8	2.7	3.0
Live coarse branch bark	.7	1.3	2.7	3.4
Live coarse branch needles	.1	0.2	0.7	0.6
Live fine branch wood	3.2	6.8	11.0	9.4
Live fine branch needles	3.3	10.4	12.3	19.6
Bole timber	46.7	11.8	4.8	24.4
Bole bark	4.1	5.3	8.2	11.8
Coarse roots	12.4	3.9	5.4	13.2
Fine roots	.7	1.0	1.4	2.0
Forest floor	14.0	43.8	34.9	7.2
Total	100.0	100.0	100.0	100.0

roots (13%), the branches and needles (22%) and the forest floor (14%). The striking feature with regard to the data in the context of existing forest harvesting systems is the fact that only about half of the total production is usable. This explains the growing interest in complete tree harvesting systems in forestry in recent years (Keays and Hatton 1976, Young 1974).

Although the stemwood and bark account for half of the total dry matter production these components only contain 17, 13 and 36% of the quantities of N, P and K present in the crop and forest floor. As expected the main proportions of the nutrients are present in the needles and branches which account for 34, 46 and 41% of the quantities present. The high concentration of nutrients in these components illustrates the increased drain on the nutrient budget that would arise should complete tree utilisation systems be adapted. However, this crop is by no means mature or indeed representative of the way in which Sitka spruce is normally managed and considerable redistribution of both nutrients and organic matter can be expected as it is thinned and gradually matures (Madgwick 1977, Webber 1977). Further studies need to be carried out in more mature crops on the distribution of nutrients and organic matter in order to determine the real inpact on nutrient budgets of more complete tree harvesting systems.

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