Whole Tree Harvesting in Sitka Spruce. Possibilities and Implications

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ABSTRACT

A study was carried out in a 50 year old crop of Sitka spruce, Yield Class 20, in order to determine:

(i) The extent to which total production could be increased through implementing complete tree harvesting, and

(ii) The effect this would have on site fertility.

The result showed that the stemwood and bark represented 62%, the slash 20% and the roots 18% of the total dry matter production. Although inclusion of the slash in the final harvest would result in a very large increase in the amounts of nutrients removed, it is concluded that this would have serious consequences for site fertility only on impoverished mineral soils with low reserves of organic matter. Data are included on the actual value of the nutrients (N, P and K only) in the slash and on its energy content.

INTRODUCTION

Traditional methods of harvesting forest crops involve the removal of tree stems only and the leaving behind on the site of the other components such as branches, needles, cones and roots. Because the stemwood and bark are known to account for only about 50 per cent of the total dry matter production in coniferous crops (Keays and Hatton, 1976; Young, 1974) considerable interest has centred in recent years on the possibility of increasing

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production from forestry through the practice of more complete — tree harvesting systems. Although a more intensive harvesting system than that currently practiced may appear a remote possibility at this point in time, particularly with the recent problems in certain wood processing industries, the interest in whole tree harvesting nevertheless continues to increase on a world-wide scale. It has been added to considerably by the concern regarding future energy supplies and the possibilities for supplying part of these from forest residues (McCarthy, 1979). Advances in technology, both in timber processing and in the mechanics of forest harvesting, now seem certain to make the concept of whole tree harvesting increasingly attractive. Mobile total tree chippers have been developed in a number of countries and are already in practice on a limited scale in parts of Scandinavia and North America (Anonymous, 1977).

The main disadvantage of total tree harvesting is that it involves a considerable increase in the amounts of nutrients and organic matter removed from the site which may have serious long term repercussions for site fertility. This concern was expressed in a number of papers presented at a recent symposium in North America on "The impact of intensive harvesting on forest nutrient cycling" (Leaf, 1979) and was manifested in the results of a recently reported Irish study (Carey and O'Brien, 1979). This showed that the inclusion of the slash and roots at harvesting would increase overall production by nearly 75 per cent. However such a harvesting system would increase the removal of nitrogen, phosphorus and potassium by 68, 80 and 65 per cent respectively over and above that in a normal harvesting operation. This is mainly because of the higher concentration of nutrients in the needles and twigs relative to the stemwood components.

Because forest crops are known to recycle considerable quantities of nutrients and organic matter mainly through litter-fall, brashing and pruning operations as they develop and mature, the results from an unthinned 33 year old crop do not necessarily reflect the position in a crop at the end of a rotation. Consequently it was decided in 1976 to extend the initial studies to a clearfelling situation in which the crop had been managed normally and had reached the age of maximum mean annual increment. This article presents the findings from this study and attempts to draw conclusions on the potential and implications of practicing whole tree harvesting in Sitka spruce in Ireland. The study was confined to the three major nutrients, nitrogen, phosphorus and potassium. Other essential elements such as calcium and magnesium are also removed as a result of harvesting operations but may be of lesser importance.

METHODS

Field: The crop had been pit planted in 1927 at Glen Imaal State Forest, Co. Wicklow (National Grid ref. Glenmalure TO6 94) on a soil transitional between a shallow peat containing a large quantity of fine sand particles and a peaty podsol over a granite/shale base. The site was situated 250 metres above sea level and was reasonably sheltered. Crop statistics given in Table 1 show that the stand was 32% overstocked relative to the normal Forest Management Tables (Hamilton and Christie, 1971) but was probably representative of the situation in many other stands in this country at clearfelling age.

Table 1 Crop details

Age (yrs)	Top ht. (m)	Basal area (m^2 ha^{-1})	Density stems ha^{-1}	Yield class	Volume to 7cm (m^3 ha^{-1})
50	29.0	50.1	468	20	606

Selection of sample trees: A 0.25 ha plot was laid down in the centre of the stand and the diameter at breast height of all trees recorded to the nearest 0.1cm. Diameters ranged from 16.3 to 57.2cm and the total number of trees in the plot came to 117. This included 15 Norway spruce which were excluded from the sampling population but were included in the calculation of standing basal area and the final estimates.

The stand table for the Sitka spruce in the sample plot (102 trees) was divided into ten equal number classes and one sample tree selected randomly from each of these. Sample tree dimensions are given in Table 2.

Destructive sampling: A large sheet of P.V.C. was placed around the base of each sample tree. All branches were then removed (by climbing) using a short handled pruning saw. The branches were dropped onto the P.V.C. and separated into the following components for subsampling.

1. Dead branches: Branches to which no live foliage was attached.

2. Live coarse branches: Branches greater than 1cm diameter to which live foliage was attached.

3. Live fine branches: Branches less than 1cm diameter to which live foliage was attached.

If the diameter of any individual branch in categories 1 and 2 varied either side of the 1cm cutoff point that branch was then subdivided accordingly.

The total fresh weight of each category of branches was determined on the site to the nearest 0.5kg using a spring balance suspended between two standing trees. Subsamples were then taken from each category for moisture content determination and nutrient analysis. For the dead branches this was done by selecting about eight branches at random and chopping these up into 15cm lengths. A similar procedure was adopted for the live coarse branches but the final subsample was further divided into bark and timber, the moist bark being easily removed with a sharp knife. In the case of the live fine branches a large subsample weighing approximately 3kg was taken from about eight branches to enable a good estimate to be made of the needle/twig ratio. Although some live needles were also attached to the live coarse branches the previous study showed that the small amount of D.M. and nutrients involved did not justify their subdivision into a separate category (Carey and O'Brien, 1979).

Following removal and subsampling of the branches the main stem was felled, the cut being made at about 0.50m from the base. (The reason for leaving a high stump was to facilitate removal of the root system).

The main stem was then subdivided into 10 equal length sections. These were transported by lorry to a central point for weighing.

One disc 2cm in width was taken from the lower end of each section for the determination of moisture and nutrient contents and the wood:bark ratio.

The root systems were excavated with the aid of a rear mounted tractor excavator. Although the method appears crude the overall recovery of the root system appeared high (at least 95%) and while some fine roots were obviously not recovered their D.M. and nutrient contents would be small compared to the overall root system. That part of the main stem still attached to the stump was removed and included with the main stem category. The root systems were subdivided with a chain saw into easily transportable sizes and washed free of soil in a nearby stream. They were then allowed to air dry for some hours before recording of fresh weight and subsampling for moisture and nutrient contents. The subsampling of the root systems was very subjective and no attempt was made to separate fine from coarse roots. This was again based on the results from the earlier project which showed that fine roots (less than1cm) accounted for only a very small proportion of the total root D.M. and nutrient content (Carey and O'Brien op. cit.).

Table 2 Diameter Breast Height, Basal Area, Length and Volume of the Sample Trees.

Tree No.	1	2	3	4	5	6	7	8	9	10
Diameter B.H. cm	19.9	26.8	31.0	33.0	35.8	37.2	40.3	42.6	45.6	51.0
Basal area m^2	.03079	.05641	.07547	.08553	.10060	.10868	.12755	.14253	.16331	.20428
Total length (m)	20.8	25.8	25.9	25.7	30.6	27.4	30.9	30.0	26.6	28.5
Length to 7cm diam (m)	17.2	22.2	22.4	22.4	26.6	24.1	27.1	26.4	23.5	23.5
Volume to 7cm m^3	.32197	.75821	.89488	.86151	1.3402	1.3819	1.7428	1.7741	1.9388	2.2366

Soil and Forest Floor: Ten samples of the forest floor were taken at random within the stand using a 25 x 25cm metal frame. All organic matter encountered including twigs — which were sparse — was included. The boundary between the forest floor and forest soil was clear and abrupt and the two easily separated. One representative soil pit was opened and sampled for determination of bulk density, net soil volume (proportion of soil less than 2mm fraction expressed as a percentage of the total soil weight free of stones) and nutrient content. Because there were clear horizon boundaries at 30 and 55cm the nutrient contents were determined for 3 separate layers, 0-30, 0-55 and 0-100cm.

Laboratory: Moisture contents were determined by drying at 105°C to constant weight. Duplicate samples for chemical analysis were dried at 90°C. Nitrogen, phosphorus and potassium were ditermined on the tree and forest floor samples using conventional methods cited in the previous study (Carey and O'Brien op. cit.). Total N, P and K in the soil samples were determined following air drying using standard techniques. Soil bulk density was determined by the waxing technique.

Statistical: The nutrient contents for the various components were determined from their dry weights and nutrient concentrations. A series of linear regressions were then calculated relating both dry weights and nutrient contents of the components to the basal area of each of the sample trees. Because the relationship proved good in most instances, reliable estimates could be made of both nutrient and dry matter contents for the mean tree and from this the whole sample plot.

RESULTS AND DISCUSSION

The dry weights for the various components of each of the sample trees are given in Table 3. Moisture contents varied considerably between components and trees. The bole wood had an average moisture content of 50% (on a fresh weight basis). The dead branches had an average moisture content of 32% and the bark on both live branches and tree stems a mean moisture content of 65%. The total dry weights of the ten sample trees varied between 225 and 1290kg.

The results of the chemical analyses for the different components on each sample tree are presented in Table 4. As expected nutrient concentrations vary considerably between components. Highest concentrations occur in the needles, bark and cones, the lowest concentrations being associated with the wood samples. These findings are in agreement with results from the previous study

(Carey and O'Brien, 1979) but there are considerable differences between some of the nutrient concentrations for the two sites. There is also considerable variation between some of the nutrient levels for similar components on different sample trees. For instance there is a 300% variation in the concentration of phosphorus in the dead branches. The variation is equally high for phosphorus concentrations in the roots. These variations are most likely directly related to the difficulties involved in sampling these components (which include bark and wood material) representatively and are mainly responsible for the high error associated with some of the final estimates (Table 5).

The data presented in Table 5 have been grouped into the three major crop components, slash, (includes all branches, needles and cones), stemwood and bark, and roots. As can be seen a high degree of confidence can be attached to the estimates with the exception of the nutrient concentrations in the roots.

The estimates of dry matter and nutrient contents are reproduced in Table 6. Included are data on the percentage distribution for each component and on the D.M. and nutrient content of the forest floor. Data are also given for the *total* nutrient content of the soil to 1 metre at the site concerned. These latter figures only include the soil fraction less than 2mm in diameter and do not provide any real indication of the amounts that are or may become available to forest trees. However, they do give a broad indication of the total nutrient reserves in the site.

Table 6 shows that the wood and bark account for 62% of the total quantity of dry matter in the crop, the slash 20% (71 metric tonnes ha^{-1}) and the roots 18% or 64m tonnes ha^{-1}. Although the slash fraction only accounts for one fifth of the total dry matter it contains approximately half of the total quantities of N, P and K in the crop. Its removal from the site under a more intensive harvesting regime than that currently practiced would therefore at first sight appear to have serious implications for site fertility. For instance, if the amounts of nutrients in the slash are divided by the approximate quantities considered necessary to sustain growth (60, 3 and 15kg) it is apparent that it contains the equivalent of about 8 years supply of nitrogen, 15 years supply of phosphorus and 14 years supply of potassium. However, the amounts of nutrients involved are quite small relative to the considerably larger quantities being used nowadays to sustain high production under intensive agriculture.

The effects of the removal of the slash ultimately depend on the nutrient and organic matter reserves in the site which in this particular instance are quite large. Reference to Table 6 shows that the nutrient contents of the slash represent less than 3 per cent of the total amounts present in the top 30cm of the mineral soil. Although

Table 3 Dry weights of components of each sample tree (kg).

Sample Tree No.	1	2	3	4	5	6	7	8	9	10
Dead Branches	22.3	29.7	28.6	28.5	29.6	90.9	36.4	61.3	39.2	88.1
Live coarse branch wood	6.6	13.5	17.5	10.7	41.9	36.7	44.0	31.7	50.9	74.3
Live coarse branch bark	1.0	2.7	8.2	2.1	9.8	10.7	11.7	9.4	9.1	16.9
Live fine branch twigs	7.6	25.3	17.3	16.6	32.5	42.6	46.2	36.1	51.0	52.1
Live fine branch needles	8.9	27.4	18.0	18.2	30.4	46.7	37.6	42.9	77.8	54.0
Cones	0	0.8	0.9	0	3.1	3.7	0	2.7	5.0	1.6
Bole wood	136.0	232.6	299.2	280.6	495.0	529.7	557.5	582.0	549.3	799.2
Bole bark	10.1	15.5	18.5	17.9	30.5	29.3	30.0	40.0	27.5	52.1
Roots	33.0	94.5	95.0	96.3	155.0	119.7	228.5	208.1	210.0	152.5
D.M. above ground	192.5	347.7	408.3	374.7	673.7	790.3	763.4	806.1	809.8	1138.2
Total slash D.M.	46.4	99.6	90.6	76.6	147.3	231.3	175.9	184.1	233.0	286.9
Total D.M.	225.5	442.2	503.3	471.0	827.8	909.9	991.9	1014.2	1019.8	1290.7

Table 4 Chemical Analyses Used in Nutrient Content Estimates (% D.M.)

Tree Number	1	2	3	4	5	6	7	8	9	10
Dead branches										
N	.44	.54	.48	.44	.40	.30	.32	.39	.37	.50
P	.02	.03	.02	.01	.02	.01	.01	.02	.02	.02
K	.02	.02	.02	.01	.03	.02	.02	.02	.04	.02
Live coarse branch wood										
N	.10	.14	.10	.13	.14	.10	.10	.14	.09	.12
P	.0041	.0081	.0048	.0060	.0071	.0092	.0049	.0061	.0080	.0091
K	.05	.04	.04	.05	.03	.05	.05	.04	.06	.07
Live coarse branch bark										
N	1.00	.68	.64	.54	.65	.67	.80	.72	.75	.49
P	.099	.086	.082	.073	.079	.080	.122	.089	.095	.062
K	.38	.39	.40	.35	.39	.44	.48	.39	.49	.36
Live fine branches										
N	.81	.70	.77	.69	.74	.78	.63	.71	.80	.87
P	.09	.10	.09	.08	.09	.11	.08	.09	.12	.11
K	.32	.42	.37	.35	.38	.42	.33	.32	.49	.45
Live fine branch needles										
N	1.52	1.45	1.39	1.27	1.41	1.39	1.19	1.33	1.46	1.60
P	.17	.12	.11	.11	.11	.11	.09	.10	.13	.12
K	.79	.57	.50	.66	.58	.52	.51	.40	.66	.64

Table 4 Continued

Tree Number		1	2	3	4	5	6	7	8	9	10
Bole Wood											
	N	.07	.07	.08	.08	.06	.08	.07	.05	.05	.05
	P	.033	.002	.003	.003	.005	.002	.004	.003	.004	.003
	K	.03	.04	.03	.04	.06	.02	.03	.03	.02	.02
Bole Bark											
	N	.80	.51	.56	.46	.42	.50	.62	.62	.53	.40
	P	.078	.063	.068	.057	.048	.065	.076	.086	.066	.043
	K	.28	.33	.39	.30	.28	.33	.48	.45	.35	.27
Cones											
	N	—	.78	1.14	—	1.18	.91	—	.67	.94	1.66
	P	—	.09	.19	—	.19	.13	—	.10	.16	.29
	K	—	.38	.35	—	.25	.19	—	.21	.28	.44
Roots											
	N	.36	.30	.34	.24	.30	.27	.24	.30	.17	.17
	P	.03	.02	.02	.01	.02	.03	.02	.03	.02	.01
	K	.19	.15	.22	.11	.14	.19	.18	.13	.15	.12

Forest Floor

N	P	K
1.68	.07	.05

Table 5 Regression Equations, Coefficients of Determination, Crop Estimates and Confidence Intervals for D.M. and Nutrient Estimates.

		Intercept	Slope	R^2	Crop Estimate kg/ha	95% confidence limit (kg/ha) + −
Slash	DM	4.51379	1393.65625	.91	71,939	4,960.0
	N	.00019	9.62744	.88	493	41.1
	P	.02726	.64543	.75	46	4.7
	K	.02150	3.62854	.80	196	23.4
Stemwood and Bark	DM	41.81152	3939.53809	.95	216,954	10,062.0
	N	.16155	2.60900	.78	209	16.8
	P	.00670	.22554	.82	14	1.4
	K	.09035	1.27307	.64	107	12.1
Roots	DM	38.93408	916.09351	.75	64,120	6,495.5
	N	.22210	1.19837	.40	165	21.9
	P	.11065	−.36585	.39	33	70.2
	K	.13320	.84458	.44	105	14.0
Total crop	DM	85.26343	6249.06641	.90	353,006	15,523.5
	N	.38383	13.43482	.91	867	48.6
	P	.14457	.50534	.55	93	6.0
	K	.24505	5.74613	.84	408	29.9

the nutrient contents of the forest floor at this particular site are considerably less than those found in other (younger and more dense) stands of Sitka spruce (Carey and Farrell, 1978) they nevertheless represent a sizeable reserve and are very likely to be more available in the short term than those contained in the slash or mineral soil. It would seem reasonable to assume therefore that the overall release of nutrients from the forest floor and mineral soil would at least equal if not exceed those quantities present in the slash component. The forest floor also contains a sizeable reserve of organic matter (23 metric tonnes ha^{-1}).

On this particular site therefore the introduction of a whole tree harvesting policy would not appear to have serious consequences for either the nutrient or organic matter reserves. However, on an impoverished mineral soil such as those derived from Old Red Sandstone, with low reserves of organic matter and nitrogen, the situation would be very different and the practice undesirable.

Table 6 Dry Matter (t ha^{-1}) Nitrogen, Phosphorus and Potassium (kg ha^{-1}) Estimates for Major Crop Components, Forest Floor and Soil to 1 metre. Data in parentheses represent the percentage of the total for the crop in each instance.

		D.M.	N	P	K
Wood and Bark		216 (62)	209 (24)	14 (15)	107 (26)
Slash		71 (20)	493 (57)	46 (49)	196 (48)
Roots		64 (18)	165 (19)	33 (36)	105 (26)
Total		351	867	93	408
Forest Floor		23	386	16	11
Mineral Soil	0- 30cm	—	18154	1623	8265
(Glen Imaal)	0- 55cm	—	20647	2529	23678
	0-100cm	—	22389	4707	57067
Blanket peat soil (Nephin Beg State Forest)*	0-100cm	86.2	20540	405	195

* Based on unpublished work by Carey, M. L. and O Carroll, N. Forest and Wildlife Service, Dublin.

Data are included in Table 6 on the total nutrient content of a blanket peat soil to 100cm at Nephin Beg forest in the west of Ireland in order to make a broad comparison between two very different situations in relation to nutrient and organic matter reserves. Thus, it is seen that although the amounts of total nitrogen in the two systems are roughly the same, there are considerably less reserves of phosphorus and potassium in the peat soil. However, the amount of phosphorus in the peat soil is almost ten times greater than that present in the slash category for the Sitka spruce at Glen Imaal although the quantities of potassium are more or less equal. The data would appear to suggest therefore that the removal of the amounts of nutrients present in the slash component of Glen Imaal would not have serious consequences on blanket peat soils.

However most of the N and P in peat soils is present in organic form and availability for future tree rotations is a matter for conjecture at this point in time.

Slash consists essentially of branches and needles and a small quantity of cones (less than 1 metric ton ha^{-1}). Table 7 gives a breakdown of the actual distribution of organic matter and nutrients between the needles and branches for the Glen Imaal data. From this it is apparent that although the needles represent approximately one quarter of the total dry matter content of the slash they still account for nearly one half of the total amount of nutrients present.

Table 7 Distribution of Dry Matter and N, P and K within Slash ($kg\ ha^{-1}$). Based on data in Table 3.

	DM	N	P	K
Needles	16936 (23%)	235 (48%)	19 (41%)	96 (48%)
Branches	55000 (77%)	258 (52%)	27 (59%)	102 (52%)
Total	71939 (100)	493 (100)	46 (100)	198 (100)

From the point of view of conserving nutrients therefore, and at the same time increasing production, a harvesting system utilising the branchwood parts only of the slash and leaving behind the needles would appear to have advantages although it may present some technical difficulties.

Data are presented in Table 8 on the actual replacement value of the N, P and K (1979 prices) in the slash. Although these show that the total value comes to £187 ha^{-1} the data do not obviously imply that the removal of these materials will result in such an expenditure on fertiliser materials for obvious reasons.

Table 8 Value of Nutrients in Slash (£/ha).

	Branches	*Needles*	*Total*
N	75.0	68.0	143
P	9.4	6.6	16
K	14.3	13.7	28
Total	98.7	88.3	187

An estimate of the *fresh* weight of the slash at Glen Imaal (using the data given in Table 3) gave a figure of 139 tons ha^{-1}. Because forest produce is normally sold in the moist state, it can be calculated from Table 8 that if a price of £1.34 per ton net could be obtained for slash material it would compensate for the cost of the nutrients involved. Studies have been carried out in Sweden on the suitability of logging residues for particleboard manufacture (Anonymous, 1977). It was concluded that although chipped slash was less suitable for manufacturing purposes than tree stems, most of the technical problems encountered could be easily overcome.

Because of the growing interest in the energy value of forest crops and residues in recent years an estimate was also made of the energy content of the slash category. In order to do this use was made of calorific values given by Madgwick, Jackson and Knight (1977) for needles and branches of *Pinus radiata* as follows:

Branches	4.68k cal/g.o.d.
Needles	4.87k cal/g.o.d.

(The values for Sitka spruce would not differ appreciably). When these figures are applied to the data in Table 7 and converted to British thermal units and expressed as coal, oil and turf equivalents using conventional conversion factors it emerges that the slash in the Glen Imaal stand contained the equivalent energy content of:

52 tonnes of coal or
35 tonnes of oil or
113 tonnes of sod turf

A considerable amount of the total dry matter production (18%) is also accounted for by the roots, a large proportion of which is included in the stumps. Although it may appear to be a far reaching idea to consider harvesting the stump and root fraction, machines have been developed in a number of countries in recent years which are capable of extracting large tree stumps and roots on both peat and mineral soils (Anonymous, 1977). Such excavation is likely to cause considerable disturbance of the soil which could have either good or bad effects depending on the nature of the site. For instance, it could result in a loosening up of the profile on compacted mineral soils thus reducing the need for other forms of cultivation at the start of the second rotation. However, on sloped areas the practice could result in serious soil erosion. On deep peat soils the removal of stumps and roots, although a far easier mechanical exercise than on mineral soils, would appear undesirable in that it would fracture the soil surface and thereby reduce considerably the bearing pressure. It could also result in serious drainage problems depending on the extent to which the watertable rises after clearfelling. However the fact is that the stump and root system contain a sizeable amount of material which in Swedish studies has been shown to closely resemble the fibre characteristics of the stemwood (Anonymous, 1977).

CONCLUSIONS

Conventional systems of harvesting forest crops are wasteful in that only a relatively small amount of the standing crop can be utilised. In this study the figure was 62% at 50 years of age. Because of the concentration of nutrients in the needles, the removal of the slash component, representing a further 20% of total production, would increase the nutrient drain considerably. The extra drain would however appear to be relatively small when compared with the remaining nutrient stores on a number of sites and the cost of replacement, should it be necessary, would not appear prohibitive. However, on soils low in organic matter, such as those derived from Old Red sandstone, the practice would be most undesirable.

It should be borne in mind that the data presented here refer to one particular crop only and considerable reservation must be attached to their extrapolation to other crops of different ages growing on different site types. Furthermore, tree growth is affected by other elements besides N. P and K and it may well be that the practice of whole tree harvesting could result in the supply of one or more of these becoming exhausted. What is certain is that as the gap between supply and demand for forest products widens on a world scale man will increasingly turn to forest residues as a basic raw material. Whether the slash and/or stumps are used for energy production, or the production of particleboard, or to manufacture animal foods — as is being researched in the Soviet Union (Anonymous 1977) — is not directly the concern of the forest manager. However, he does need to know what the production capability of his forest is and what the consequences may be of implementing more intensive tree harvesting systems. The data presented provide at least a base for more enlightened discussion.

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