Nutrient removal in harvesting mature *Pinus radiata*

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ABSTRACT

A clear-felling harvest of a 29-year-old plantation in Kaingaroa Forest removed 85% of the stem material. The relatively lower nutrient concentrations in larger diameter logs meant that 77 and 84% of total nutrients in the stems were removed in harvesting. The effects of a range of harvesting intensities on nutrient removal from the site can be estimated from the relationship between utilization limit nutrient content and the total amount of nutrients in the stand.

INTRODUCTION

In recent years there has been increasing interest in the environmental impact of forestry practices including the amounts of nutrients removed at harvesting. Past studies of nutrient removal in radiata pine (*Pinus radiata* D. Don) harvests have assumed that all stem material is removed from the site (Crane and Raison 1980, Webber and Madgwick 1983, Dyck and Beets 1987). This paper uses data on the nutrients removed in harvesting a 29-year-old stand of radiata pine in Kaingaroa Forest (Webber and Madgwick 1983) to demonstrate how intensity of harvest affects the level of those removals. The data provided allow the estimation of nutrients likely to be removed under a range of harvesting options.

THE STUDY

The mature stand of radiata pine located on the Northern Boundary of Kaingaroa State Forest was growing on well-drained volcanic ash. Stocking was 360 stems ha^{-1}, basal area 56.5 m^2 ha^{-1} and mean stand height 39.9m. Details of the sampling procedures for 15 sample trees, and the methods of laboratory analysis for plant material and mineral soils have been described previously (Webber and Madgwick 1983).

Potentially harvestable stem material was considered to be that portion of the stem with a minimum diameter outside bark of 5.2cm. Sectional measurements were used to calculate the volumes over bark from the base of each tree to a 5.2cm top by 5cm-diameter steps for the 15 sample trees. Linear regressions of these volumes on basal area were used to estimate stand volumes to each diameter limit. Stand volumes were converted to weight using wood densities measured on discs taken at five equally spaced intervals in each stem. Nutrient concentrations in 75 stem wood discs and 75 associated bark samples were used to characterize the relationship between diameter and nutrient concentration and were combined with weights to determine the total nutrient contents of the stems.

We also estimated the quantity of nutrients in slash, litter and soil on the site.

The volume of logging residue was measured on four quadrats measuring 5 by 200m. All pieces of stem within the quadrats were measured for length and midpoint diameter. The calculated volumes were converted to weight using the weight: volume conversion factor determined from sample trees. For the purpose of this paper it has been assumed that the stem logging residue came from the top sections of the boles. Breakage of stems in felling is very variable (C. Mountford, pers. comm.) and may result in the inclusion of stem material other than stem tips in our samples. Our assumption will tend to underestimate nutrient removal.

The forest floor was sampled for weight and nutrient content using a 54mm diameter ring sampler. A total of 59 random samples were oven-dried at 70°C and weighed prior to compositing into 10 samples for chemical analysis. The bulked samples were ground to pass a 2mm sieve and analysed for nitrogen by semi-microKjeldahl digestion and for other elements by X-ray fluorescence (Webber and Madgwick 1983). Soil bulk density was determined using 16 random samples each of 77 cm^3 for each soil horizon to a depth of 103cm. These samples were also analysed for total nitrogen, Bray-2 available phosphorus and exchangeable cations.

RESULTS AND DISCUSSION

The weight and total nutrient contents of the major tree components and the litter layer as well as total soil nitrogen and exchangeable or extractable soil nutrients are summarized in Table 1. For each nutrient, stems contained the majority of the nutrient in the above-ground part of the trees. The trees contained more nutrient than the litter layer even though this was a second rotation stand with a relatively heavy litter layer (c.f. Carey *et al.* 1982). The total quantity of nitrogen in the mineral soil to a depth of 103cm was about seven times that in the above-ground parts of the trees. Comparisons for the other nutrients must be treated with care as only so-called available or extractable soil nutrients were estimated.

We did not measure root weights nor root nutrients. The estimating equation of Jackson and Chittenden (1981) predicted 79.5 t ha^{-1} of roots over 5mm in diameter. Will (1966) found that roots contained more phosphorus but less nitrogen than branches. Potassium levels were similar in large branches and roots. Ovington (1959) found that nitrogen, phosphorus, potassium, calcium and magnesium concentrations in roots and branches of *Pinus sylvestris* L. were of similar magnitude. Assuming that roots and branches have similar nutrient concentrations implies that roots contained about as much nutrient as the stem wood. The total tree, including roots, would contain 30 to 50 percent more nutrient than given in Table 1.

The relationships between utilization limits and the fraction of stem weight and nutrient removed are illustrated in Fig. 1 for both stem bark and stem wood.

Measured logging residue amounted to about 15 per cent of the stem. This compares with an expected removal of 80 to 90 per cent of the harvestable material from normal clear felling operations (C. Mountford, pers. comm.). Removing 85 per cent of the stem would be equivalent to harvesting to an average top diameter of 14cm and would have removed about 85 per cent of the stem wood but only 81 per cent of the stem bark.

Nutrient concentrations in both wood and bark tended to be lower in larger diameter material, as reported earlier by Orman and Will (1960). Consequently, harvesting operations will tend to remove a higher proportion of stem dry matter than of stem nutrients (Fig. 1). We estimated that the stem material in logging residue contained between 16% (for calcium) and 23% (for potassium) of the total nutrient contents in

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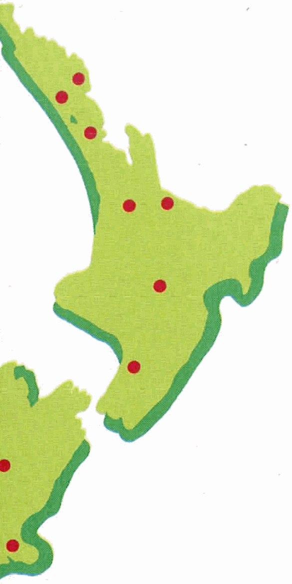

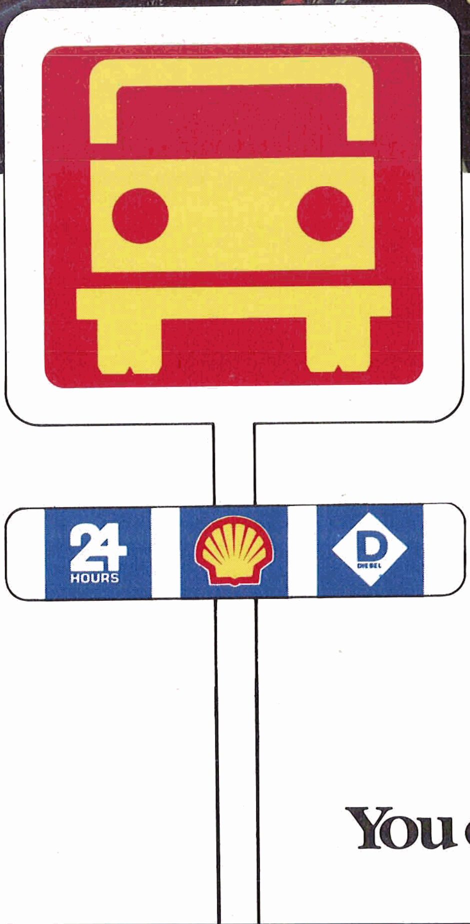

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stems to a 5.2cm top diameter. The total quantity of nutrient in this residue was equivalent to between 11 and 14% of that in the total above-ground parts of the trees, depending on the nutrient involved (Table 1).

For this 29-year-old stand the effects of a range of harvesting intensities can be estimated, given the information in Fig 1 and Table 1. For instance, if hauling logs to the landing had resulted in a 25 per cent sloughing of bark estimated nutrient removals would have been reduced by 6 to 8 per cent, depending on the nutrient involved. Alternatively, a 20cm utilization limit would have resulted in harvesting 63 per cent of the stem wood but would have removed only 53 per cent (phosphorus and potassium) to 61 per cent (calcium) of the nutrients in the stems.

Estimating the potential removal of nutrients using harvesting regimes which remove crown material is more difficult, since both total stand weights and fraction of logging residue must be estimated. Nutrient concentrations in branches and particularly in foliage are higher than in stems so that estimates of removals in these components are sensitive to assumptions made. Closed stands of radiata pine will carry 10-15 t/ha of foliage (Madgwick 1986). Published total branch weights are very variable but tend to increase with stand age and probably increase with decreased stocking (Madgwick 1986). The fraction of crown components potentially removable under any harvesting regime is unknown for radiata pine and will require detailed studies of breakage and loss through harvesting operations. However, in this stand total removal of the crowns and stem residue would have increased dry matter production by 29 per cent but nutrient removal from 80 (calcium) to 172 (phosphorus) per cent.

The quantity of nutrient removed in harvested trees is sensitive to utilization limits. The relationship between tree size and nutrient concentration (Madgwick *et al.* 1977) implies that nutrient removals will also be related to silvicultural regimes. The impact of nutrient removal in harvesting will increase on sites of marginal fertility since, on poor sites, a relatively large fraction of the nutrient capital is in the trees (P.N. Beets pers. comm.). If fertilizers are to be used to replace nutrients removed in harvesting it will be necessary to extend the information provided in this paper to cover a wide range of sites and silvicultural systems.

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Table 1: The weight and nutrient contents of a 29-year-old stand of *Pinus radiata* and in stem logging residue. Soil nutrients are total nitrogen, Bray-2 extractable phosphorus and exchangeable cations.
n.d. not determined

Component	Weight	Nutrients (kg/ha^{-1})						
	(t/ha^{-1})	N	P	K	Ca	Mg	Zn	S
Foliage	8.2	116.6	16.4	81.4	32.4	10.4	0.49	13.0
Branches	38.6	78.7	13.1	91.6	79.3	22.1	0.89	10.3
Cones	9.3	22.2	5.5	6.0	1.1	3.4	0.09	1.4
Stem bark	32.3	67.9	7.4	90.6	48.8	14.5	0.98	8.3
Stem wood	337.8	149.0	24.0	194.8	171.7	51.8	2.20	21.1
Total	425.8	434.4	66.3	464.3	333.3	102.2	4.66	54.1
Litter	32.6	301.8	32.9	149.9	177.3	38.4	1.53	43.0
Soil	n.d.	3049.	203.	3811.	1128.	296.	n.d.	n.d.
Residue	40.7	46.2	7.0	64.8	35.3	11.8	0.66	6.5

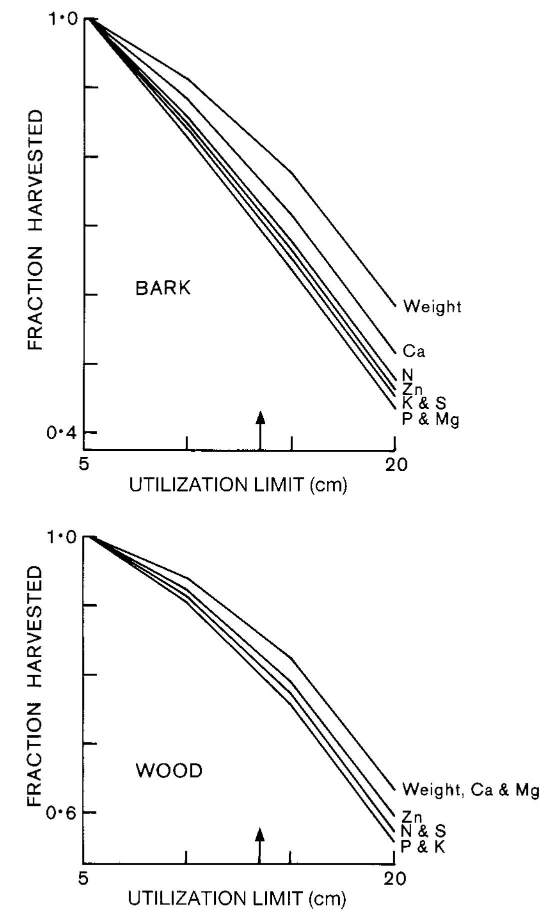

Fig 1. The relationship between utilization limit and the fraction of stem bark and stem wood weight and nutrients removed in a clear-felling harvest. The arrow indicates the estimated utilization limit in the clear-felling harvest studied.

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