BIOMASS AND NUTRIENT CONTENT OF A 29-YEAR-OLD PINUS RADIATA STAND

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ABSTRACT

A 29-year-old **Pinus radiata** D. Don stand contained 426 tonnes of above-ground standing biomass per hectare. This included 434 kg N/ha, 66 kg P/ha, 464 kg K/ha, 333 kg Ca/ha, 102 kg Mg/ha, 4.7 kg Zn/ha, 8.6 kg Fe/ha, 28.9 kg Mn/ha, 35 kg Al/ha, and 54 kg S/ha.

INTRODUCTION

The prediction of long-term changes in the nutrient status of forest soils necessitates an understanding of nutrient cycling within the ecosystem and a knowledge of the impact of harvesting practice on nutrient status. Previous studies provide limited information on nutrient uptake by *P. radiata* forests in New Zealand (Will 1968; Madgwick *et al.* 1977). The objective of this study was to assess the weight and nutrient content of *P. radiata* in a stand with a structure similar to that which can be expected from current sawlog regimes. The new data collected allowed tests of prediction equations for stand component weight and nutrient content published earlier (Madgwick *et al.* 1977; Madgwick 1982).

MATERIALS AND METHODS

Study Area

A 29-year-old stand in Kaingaroa State Forest (lat. 38°S, long. 177°E) was selected as its structure was believed to be representative of sawlog stands which will be harvested in the future. This first-rotation stand was established in 1947 at 1.8-m^2 spacing. In 1956–57 low and medium pruning were followed by a poison thinning to waste, leaving 590 stems/ha. The stand was high pruned in 1957–58 and extraction thinned in 1962 to 360 stems/ha. At the time of sampling the basal area was 56.5 m^2/ha and stand height was 39.9 m.

The soil is a Pekepeke sand, a coarse-textured, well-drained, volcanic ash. The present topsoil has developed in a 50-cm-thick layer of Kaharoa ash, approximately 800 years old. This overlies older soils developed in previous ash showers (Vucetich

et al. 1960). Studies of root systems in an adjoining stand showed that, at age 18 years, the greater part of the tree roots were in the top 30–45 cm but some roots penetrated to 3–4 m (Will 1966).

Field Sampling

In March 1976 a 50 × 50-m plot was established and all trees were measured for diameter at breast height. Fifteen trees encompassing the diameter range were randomly selected for biomass determination. Each tree was felled at approximately 10 cm above ground-level, and total height and diameter at breast height were recorded. Branches and foliage were removed from the stem and foliage-bearing twigs separated by age classes (1-year, 2-year, 3-year, and 4-year and older). All foliage was stripped from the needle-bearing twigs. Non-needle-bearing branches were classed as either live or dead. Stem and branch foliage was combined; cones were kept separate.

All components were weighed fresh in the field on the day of sampling and subsamples were randomly selected to determine dry matter and nutrient contents.

The main stem from stump to the commencement of stem foliage was divided into five equal sections. Each section was measured for total length and diameter (over bark) at both ends and the mid-point. Two discs, one for chemical analysis and the other for volume-weight determination, were cut from the midpoint of each section and weighed fresh. On the day of collection, all samples were brought to the laboratory and stored at 6°C until further processing.

Five soil pits were dug to a depth of 103 cm and samples were collected to characterise the eight pedogenic horizons present for nutrient status.

Laboratory Analysis

Stem discs for volume-weight determination were submerged and their volumes estimated by weighing the water displaced. Bark was removed and the volume of wood alone determined. Bark volume was obtained by the volume difference.

All dry weights were obtained after drying to constant weight at 70°C. Wood, branch, bark, and cone material were chipped before being ground in a stainless steel Wiley Mill (needles were ground directly) to pass a 20-mesh (1-mm) sieve.

Plant and soil nitrogen were determined by semi-microKjeldahl digestion using a selenium catalyst followed by auto-analyser estimation of ammonium nitrogen using the indophenol blue method. Potassium in stem wood was determined by atomic absorption after dry ashing and solution in dilute hydrochloric acid.

Except for potassium in stem wood all phosphorus, potassium, calcium, magnesium, zinc, copper, iron, manganese, chlorine, aluminium, and sulphur concentrations in plant material were analysed by the Soil Bureau of the Department of Scientific and Industrial Research in Lower Hutt, using X-ray Fluorescence (XRF).

Soil phosphorus was determined colorimetrically by the phosphomolybdic blue method after a 1-minute extraction with Bray-2 solution. Exchangeable soil cations were determined by atomic absorption after leaching of samples with 1N ammonium acetate. Strontium chloride was used to suppress interference. Cation exchange capacity was measured by saturating samples with ammonium ions followed by displacement with

1N sodium chloride. The ammonium nitrogen was determined colorimetrically using the indophenol reaction. The pH measurements were made using a glass electrode at 20°C with a soil : water ratio of 1.0 : 2.5. Organic carbon was determined by an adaptation of the Walkley-Black method using concentrated sulphuric acid and chromium trioxide.

Log volumes were calculated using the spline curve adaptation of Smalian's formula.

The nutrient contents of each sample tree were obtained by multiplying the oven-dry weight of each component by the relevant concentration. Regressions were calculated relating the logarithmic component dry weight, and nutrient content, to the logarithmic diameter at breast height. Total stand dry weight and nutrient contents were found by applying the regression equations to tree diameter, incorporating a correction for bias due to logarithmic transformation (Madgwick & Satoo 1975).

RESULTS

Nutrient concentrations in soil horizons generally decreased from the topsoil (0–14 cm) down to the bottom of the Kaharoa ash layer at 48 cm (Table 1). The buried soil lying beneath this depth contained higher nutrient levels, particularly nitrogen, magnesium, and potassium.

TABLE 1—Mineral soil analyses

Pedogenic horizon (cm)	pH	Total N (%)	Bray P (ppm)	Total C (%)	Exchangeable Ca (m.e./100 g)	Mg	K	Cation exchange capacity (m.e./100 g)
0– 14	5.5	0.08	32	2.9	2.04	0.89	0.47	18
14– 24	5.7	0.02	45	0.8	0.44	0.17	0.14	7
24– 32	5.7	0.01	23	0.5	0.29	0.11	0.49	6
32– 38	5.9	0.01	12	0.4	0.29	0.16	0.54	6
38– 43	5.8	0.01	9	0.2	0.37	0.08	0.50	9
43– 48	5.8	0.01	16	0.4	0.30	0.12	0.57	9
48– 65	5.7	0.05	13	1.2	0.50	0.34	1.26	20
65–103	5.8	0.03	13	0.7	0.46	0.23	2.76	20

Above-ground the stand contained 426 tonnes dry matter/ha (Table 2). This is higher than found in earlier studies of *P. radiata* in the same area which considered only stands up to age 26 years (Orman & Will 1960; Will 1968; Madgwick *et al.* 1977). However, the weight of stems was within 2% of that predicted from basal area and mean height using the equation by Madgwick (1982). Foliage weight was less than the average of 10 tonnes/ha expected on closed stands of *P. radiata* (Madgwick 1982) but the relatively low foliage and high branch amounts might have been suspected owing to the relatively low stocking (Madgwick *et al.* 1977).

Average nutrient concentrations may be calculated from data in Table 2. The concentrations of nitrogen, phosphorus, potassium, calcium, magnesium, manganese, and zinc in component tissues were all within the range of values expected for the study area (Madgwick *et al.* 1977).

TABLE 2—Biomass and nutrient weights of 29-year-old **P. radiata**

Component	Biomass (t/ha)	Nutrients (kg/ha)									
		N	P	K	Ca	Mg	Zn	Fe	Mn	Al	S
1-year-old foliage	3.2	46.4	6.9	33.6	8.0	4.5	0.18	0.21	1.11	1.12	5.0
2-year-old foliage	2.9	40.9	5.5	27.7	11.7	3.2	0.17	0.20	1.51	1.61	4.6
3-year-old foliage	1.5	21.7	2.9	14.8	8.6	1.9	0.10	0.10	1.03	1.04	2.5
4-year-old and older foliage	0.6	7.6	1.1	5.3	4.1	0.8	0.04	0.05	0.45	0.38	0.9
Needle-bearing branches	3.4	16.9	3.6	24.2	8.1	3.9	0.12	0.18	0.50	0.76	2.5
Live branches	22.2	40.9	7.3	58.5	44.3	12.1	0.51	0.73	2.77	2.91	5.3
Dead branches	13.0	20.9	2.2	8.9	26.9	6.1	0.26	0.60	1.45	2.45	2.5
Cones	9.3	22.2	5.5	6.0	1.1	3.4	0.09	0.31	0.24	0.80	1.4
Stem bark	32.3	67.9	7.4	90.6	48.8	14.5	2.98	1.35	1.66	12.96	8.3
Stem wood	337.3	149.0	24.0	194.8	171.7	51.8	2.20	4.92	18.17	10.98	21.1
Total tree	425.8	434.4	66.3	464.3	333.3	102.2	4.66	8.64	28.88	35.01	54.1

The total contents of the various nutrients within the above-ground parts of the trees are presented in Table 2. The prediction equations by Madgwick *et al.* (1977) gave expected values of phosphorus, potassium, calcium, and zinc within one standard deviation of measured values. The prediction equations seriously over-estimated the actual nitrogen amounts (by 40%) and under-estimated manganese (by 70%).

DISCUSSION

Attempts to estimate nutrient drain as a result of logging, using studies such as the one reported here, must be accepted with reservation. The fraction of wood harvested will vary from operation to operation depending on the nature of the site and stand and on the skill of the logging crew. It is clear that total nutrient drain will increase with the amount of wood removed and, as an approximation, the concentrations of nutrient elements in logs can be assumed to be similar to those reported here. The closeness of actual and predicted total stem material using the equation of Madgwick (1982) suggests that total stem weight in a stand might be obtained from stand basal area and mean height. Thus estimates of nutrient drain may be obtained by combining expected nutrient concentrations, predicted stem weights, and empirically determined percentage of stem wood harvested.

Predicting the increase in yields and nutrient removals as a result of more-intensive harvesting procedures is more difficult for two reasons. Firstly, estimates of the amounts of canopy material are much less accurate than for stems (Madgwick 1982). Secondly, there is less experience in more-intensive logging so losses through breakages are harder to predict. McIntosh & Wright (1977), working with *Pinus contorta* Loud. and *Picea glauca* (Moench) Voss, found that full-tree logging increased biomass harvested by less than half the theoretical amount because of breakage during felling and skidding. Such a loss would be expected to increase with tree size and so would be affected by stand age and silvicultural practice.

Estimating the impact of harvesting on each nutrient in the ecosystem is difficult. Except for nitrogen the standard soil analytical techniques used give estimates of the so-called available, not the total, pool of each nutrient present. If totals of other nutrients are determined these totals reflect the amounts available only on a geological time scale. Some authors prefer one form over the other (Freedman 1981). Estimates of nutrients in harvested material probably give the most reliable measure of harvesting impact and enable a dollar value to be placed on the nutrients removed (Bengtson 1981).

Freedman (1981), reviewing the literature on whole-tree harvesting, reported increases in biomass yield of conifer stands of 2–99% depending on species and stand conditions. The relative increase in nutrient removal was directly correlated with, and much greater than, the increase in biomass yield. Our *P. radiata* stand contained more dry matter than all but one stand tabulated by Freedman (1981) and, as a consequence, any estimated relative increases in nutrient removal would tend to be low compared with most previously published data. However, following the argument of Bengtson (1981) and using the 1982 prices of fertiliser nitrogen, phosphorus, and potassium of $1.05/kg, $1.2/kg and $0.42/kg, respectively, foresters would incur an indirect cost of approximately $6/tonne or $350/ha for replacement of nutrients in crown biomass

which would be removed by changing from a conventional to a whole-tree harvesting system. This compares with about $1/tonne for the replacement of nutrients in conventionally harvested stem material. Considerable quantities of nutrients will become available from natural processes such as nitrogen fixation, soil weathering, and cyclic salt deposition. While these may go a long way towards balancing conventional harvesting losses, it seems certain that whole-tree harvesting of short-rotation tree crops will deplete soil nutrient pools unless fertilisers are used to replace removals.

Carey *et al.* (1982) studied the litter layers of six first-rotation and seven second-rotation stands of *P. radiata* aged 18 to 20 years in Kaingaroa Forest. They found 287 kg N/ha, 18.1 kg P/ha, 25.7 kg K/ha, and 28.8 kg Mg/ha in the litter layers of first-rotation stands and 540 kg N/ha, 369 kg P/ha, 49.4 kg K/ha, and 31.9 kg Mg/ha in second-rotation stands (M. J. Carey, pers. comm.). Thus, after two rotations more nitrogen and phosphorus were stored in the litter layers than would be removed in a conventional harvesting operation. Even for potassium, which is much more mobile in the ecosystem, the litter layer contained 17% of the total amount found in the standing crop of stems.

The increase in yields which could be obtained from more intensive harvesting of typical sawlog stands on pumice soils of the central North Island of New Zealand appears small. The cost of obtaining these increased yields in terms of increased nutrient removal would appear disproportionately large.

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