POTENTIAL INCREASE IN NUTRIENT REQUIREMENTS OF *PINUS RADIATA* UNDER INTENSIFIED MANAGEMENT

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ABSTRACT

Only limited information is available in New Zealand on the effect of intensified forest management practices on nutrient status and potential fertiliser requirements of **Pinus radiata** forests. Projections must therefore use the substantial overseas literature.

Projections are made of nutrient depletion under a variety of management practices, such as waste and commercial thinnings, in addition to the final harvest. Owing to the limitations imposed by the information available, only provisional conclusions could be drawn. However, intensification in management through shorter rotations, closer utilisation, slash burning and windrowing must greatly increase nutrient removal particularly when two or more of these practices are used in conjunction. Other features of intensive management, such as thinning, clearfelling **per se**, and bedding in site preparation, have much smaller effects. Referring to nitrogen specifically, sufficient reserves and inputs are generally available for the next crop at present but, with intensified management, productivity will only be maintained through substantial fertilisation.

INTRODUCTION

The importance of forest nutrition and nutrient cycling is well acknowledged (Cole *et al.,* 1967; Duvigneaud and Denaeyer-De Smet, 1970; Jorgensen *et al.,* 1975; Patric and Smith, 1975; Rennie, 1955, 1957; Will, 1973) since nutrition can be manipulated to enhance growth. On "poor sites", however, certain intensified forestry practices, such as full tree logging, might lead to nutrient depletion with a reduction in site productivity (Switzer and Nelson, 1973; Weetman and Webber, 1972; White, 1974). The effects of forestry practices, and their degree, are debatable. However, tree harvesting has been found to have some environmental consequences (Maki, 1972; Patric and Smith, 1975; Stone, 1973; 1975).

Forest management practices have changed drastically to encompass short rotations, and intensive cultural and utilisation practices. With the short rotation concept forests are thought of as biological productivity units producing more than just the classic building and pulp material (Barton, 1976; Keays, 1976; Switzer and Nelson, 1973).

IMPACT OF INTRODUCED SPECIES ON NUTRIENT REGIMES

Effect of Species Change

The effect of introducing a new species is hard to determine since the introduction is often accompanied by new management practices. For New Zealand this difficulty represents an important problem since reduced productivity in second rotation

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P. radiata has been reported (Florence and Lamb, 1974; Whyte, 1973). Is reduced productivity a result of general soil deterioration, nutrient depletion caused by the tree species, or an effect of management practice? In Britain, Rennie (1955, 1957) posed the same questions with the introduction of trees onto moors. Calculations showed that soil depletion, and not enrichment, occurred due to nutrient accumulation in harvestable biomass.

Part of the difficulty in interpreting the effect of species substitution can be attributed to time scale, as we usually think in terms of one or two generations. Nature is not so myopic and requires hundreds to thousands of years for permanent change to occur. Stone (1975) stated "The early rates of change and the initial impact upon the soil surface are clearly species dependent but superficial. Beyond this period the consequences of choice of species are far less certain, less well documented, and in many ways much less profound than often believed". To Stone (1975) it was apparent that the ". . . often abrupt, profound and sometimes brutal . . ." forest management practices were more influential in affecting soil properties than merely species composition, a conclusion supported in New Zealand (Will and Ballard, 1976). The need to understand the potential of some treatments to enhance or degrade soil fertility, and to modify such treatments where necessary, requires a more realistic description and evaluation of the soil system than presented in current nutrient cycle diagrams (Stone, 1975).

Biomass and Nutrient Acquisition in Standing Crops

To evaluate biomass and nutrients removed in harvesting operations, accurate estimations of accrued biomass and nutrient content must be available. For both total and net primary production, an increasing quantity of data has been collated for terrestrial ecosystems (Rennie, 1955, 1957; Rodin and Bazilevich, 1967; Satoo, 1970). As nutrient relationships are site-specific, this information is required for specific locations. Both biomass and nutrients accumulate to maximum levels, the totals varying with such factors as species, age, site quality, management practices, and nutrient and tree, or tree component, under consideration.

Pinus radiata in New Zealand achieves high biomass at an early age, 15 to 20 years, and thus it can out-produce on a per-year basis, the other conifers mentioned in Table 1.

TABLE 1—Some estimates of standing dry weight (t/ha) for selected species at various times during stand development

Species	Stand Age (years)			
	10	20	40	60
Pinus taeda[1]	26	72	191	210
P. taeda[1]	20	43	118	150
Pinus sylvestris[2]	26	65	163(35)	150(55)
P. sylvestris[2]	52(11)	55(18)	112(48)	119(64)
Pseudotsuga menziesii[2]	8(12)	16(28)	24(39)	264(75)
Pinus radiata[3]	104	264(18)		

[1] Switzer, Nelson and Smith, 1966

[2] Ovington, 1957

[3] Will, 1968

Figures in brackets indicate ages different from column heading.

High production in *P. radiata* can be linked to climate, growing season and, more recently, physiological factors (most of the photosynthate produced goes to form new tissue; Rook, 1975). Total biomass is important because of possible utilisation by pyrolysis or secondary chemical industries (Barton, 1976; Keays, 1976). Equal importance has to be assigned to the distribution of biomass among tree components over time, since harvesting and other practices manipulate biomass components and thus a knowledge of component weights is required for any assessment of management practices. In *P. taeda,* it has been found that foliage weight reaches a constant value at about 25 years whereas stemwood and branch weight peaked at about 45 years (Switzer *et al.,* 1966).

The nutrient content of a standing crop depends on both nutrient concentration and component weight. Although nutrient and biomass accretion curves can differ the same broad patterns of net uptake for N, P, K, Ca, Mn, Zn, and Na have been found in *P. radiata,* since the variation in stand dry weight has been found to be greater than the variation in concentration of any one nutrient (Madgwick *et al.,* 1977; Table 4, Fig. 7). Over the first 30 years nutrient accumulation occurs in the ranking of N, K, Ca, Mg, P, and S. After 30 years Ca increases in relative dominance owing to greater accumulation of woody tissue and relatively constant foliage weight (Switzer *et al.,* 1966). Nutrient uptake from the soil is maximal early in the rotation and after 35 years nutrition is mainly dependent upon recycling. For *P. radiata,* full site occupancy, near maximal accumulations of total nutrients and maximal foliar biomass are attained very early (Will, 1964, 1968), thus the importance of nutrient cycling develops rapidly (Knight, 1973; Madgwick *et al.,* 1977; Will, 1968).

The significance of acquisition rates, distribution patterns, and nutrient cycling will be of even greater importance when consideration is given to shorter rotations and more intensive cultural practices (Switzer and Nelson, 1973).

BIOMASS AND NUTRIENT REMOVAL UNDER TRADITIONAL HARVESTING PRACTICES

Traditional harvesting, i.e., stemwood to a specified top diameter, gives a yield which is a function of species, diameter breast height, top diameter, tree height, stand density, site quality and tree age (Keays, 1975). Although biomass inventory is being stressed as an important adjunct to conventional inventory, the majority of forest inventories express yield as volume (total or net) per unit area. In applying biomass inventories to large forest regions, incompatibilities in the relationship between merchantable and total above-ground biomass arise because of the differing methods of inventory (Keays, 1975). Thus, as a proportion of total biomass production, merchantable biomass removal varies considerably (Table 2). Utilisation varies considerably; in *P. radiata,* for example, it often occurs at final felling only and therefore excludes thinning biomass. The effect of harvesting on site fertility depends upon a particular system's capacity to respond to a perturbation and any response is a function of the nutrient elements contained and cycled in the ecosystem.

Evaluations for selected species illustrate the possible magnitude of nutrient losses (Table 3), the magnitude being a function of the species present, development stage and the current harvesting practice. Amount of nutrients removed varies widely.

TABLE 2—Biomass of merchantable timber and total above ground portion (t/ha) of selected forest stands

Species	Total Above Ground	Merchantable Timber	Residual Material	Per cent Merchantable
100-year-old **Fagus**[1]	128	57	71	45
Populus tremuloides and Hardwoods[1]	179	74	105	41
P. remuloides and Hardwoods[1]	60	30	30	50
P. tremuloides[1]	70	27	43	39
Pinus sp.[1]	12	8	4	67
P. taeda — 16 years[2]	156	116	40	60
Mixed Wood[3]	312	164	148	53
P. radiata — 26 years[4]	222	201	21	91
Picea rubens — Abies balsamifera[5] (all aged)	132	82	50	62
Picea mariana — 65 years[5]	107	54	53	50
Mixed Hardwood[6]	167	120	47	72

[1] Keays, 1975
[2] Wells, Jorgensen and Burnett, 1975
[3] Norton and Young, 1976
[4] Orman and Will, 1960
[5] Weetman and Webber, 1972
[6] Boyle, Phillips and Ek, 1973

TABLE 3—Total nutrients removed from the forest in sawlog harvesting

Species		Nutrient				
		N	P	K	Ca	Mg
Pinus radiata[a]	1	185	26	229	151	
	2	58	63	71	81	
	3	21	23	5	5	
Softwoods[b]	1	80	10	52	143	
	2	23	15	33	32	
Pinus taeda[b]	1	104	14	80		
	2	32	29	35		
	3	4	3	12		
Picea mariana[c]	1	44	12	25	98	8
	2	26	21	30	36	30
	3	23	13	12	31	10
Picea rubens—Abies balsamifera[c]	1	79	11	47	150	14
	2	20	21	32	36	39
	3	20	19	21	28	22

[1] Total removed as kg/ha
[2] Total removed as % of total biomass
[3] Total removed as % of total in the ecosystem

(a) Knight, 1973
(b) Norton, 1975
(c) Weetman & Webber, 1972 (mixed stand)

However, in proportion to the "total" in the ecosystem (i.e., biomass total plus the soil "available" fraction), removal is quite low thus supporting Stone's (1973) statement that "There are no hard data indicating that stands following clear cutting are any less productive in a biological sense than those developed on partially cut or uncut forest". This conclusion, however, cannot be extended to marginal, or nutrient-deficient sites.

Clearfelling has a potential impact on soil properties, especially through accelerated nutrient movement. Much concern has been expressed over the effects of clearfelling on forest soils (Stone, 1973; Tamm *et al.,* 1974). The most outstanding investigation, in terms of both data and potential misunderstanding, has been the work at Hubbard Brook in the U.S. (Likens *et al.,* 1970). It is unfortunate that "clearfelling" has been associated with this study as the procedures used bore only slight resemblance to an operational practice.

Clear cutting triggers many significant effects with direct bearing on the soil solution and rates of nutrient leaching. These include:

(1) A removal of an ion uptake agency (trees) from the soil
(2) Increased soil temperature and moisture affecting decomposition, mineralisation and carbon dioxide production
(3) An increased quantity of water passing through the soil.

The possible end result is increased nutrient concentrations in soil water and accelerated leaching. However in most cases the effect of clear cutting on these processes has only been minor (Cole *et al.,* 1974) lending more support to the hypothesis that clear cutting has minimal effect on nutrient movements through the soil profile.

EFFECT OF INTENSIFICATION OF MANAGEMENT PRACTICES ON NUTRIENT REQUIREMENTS

Effect of Thinning on Nutrient Requirements

With stand development from the seedling to the closed canopy state, ground vegetation proliferates, diminishes, dies, decomposes and releases nutrients available for trees. Additional stimulatory effects are also possible through thinning operations. Thinning can raise soil temperature and hence increase microbial activity and mobilisation of humus-bound elements. Thinning is a common practice in New Zealand (Kirkland, 1976).

Thinning to waste has a dramatic effect on nutrient distribution in *P. radiata,* with up to 60-70% of the standing nitrogen content being returned to the forest floor (Madgwick, 1977) and a comparable return of other elements (Will, 1968). The importance of these returns to the soil is in their function as nutrient sources for residual trees. This results in a reduced net demand on the soil (Knight, 1973; Will, 1964; 1968).

Extraction thinning has a dual impact in terms of nutrient removal in harvested material and nutrient replenishment in logging slash. In 16-year-old loblolly pine in the U.S. (Jorgensen *et al.,* 1975; Wells and Jorgensen, 1974; Wells *et al.,* 1975) pulpwood thinning removed 60.6 t/ha of biomass along with 5 kg/ha of N, 7.7 of P, 42 of K, 58 of Ca, and 13.8 of Mg. This was equivalent to 39, 21, 25, 25, 31, and 33%

of the above ground biomass and nutrient content. In *P. radiata*, thinning has been estimated to remove 71 t/ha of biomass, 45 kg/ha of N, 7 of P, 55 of K, and 37 of Ca or, for the nutrients, 25, 32, 27, and 51% of the above ground nutrient content (Will, 1964).

Effect of More Complete Tree Utilisation on Nutrient Regimes

Increased yield by full-tree harvesting depends *inter alia* on species, site and age, but as Keays (1975) stresses, the potential increase generally exceeds that obtainable from such techniques as forest fertilisation. Thus, yield increases between 10 and 470% are possible (Table 4); 100% for northern hardwood forests and 60% for northern softwood forests are likely (Keays, 1975). Increased yields of this nature would not normally occur in New Zealand due to an apparently high level of utilisation.

TABLE 4—Comparison of biomass yield from conventional and full-tree harvesting

Species	Yield of Material Conventional	 Full-tree	 % increase
	— — — — t/ha — — —		
Populus tremuloides—Quercus rubra[1]	91	188	105
P. tremuloides—mixed hardwoods[1]	69	236	96
P. tremuloides—mixed hardwoods[1]	52	109	110
Mixed hardwoods[1]	51	107	110
Mixed hardwoods and pines[1]	7	38	474
Pinus virginiana[1]	23	98	330
Picea mariana[2]	54	107	99
Picea rubens—Abies balsamifera[2]	82	132	60
Pinus taeda[3]	116	156	81
P. radiata[4]	201	222	10

[1] Keays, 1975
[2] Weetman and Webber, 1972
[3] Jorgensen, Wells and Metz, 1975
[4] Orman and Will, 1960

Any increase in off-site biomass removal will have a direct bearing on nutrient removal and hence on the need for fertilisation. Although conventional harvesting practices generally have minor effects on nutrient regimes and depletion, it would be wrong to assume the same for more intensive practices. The possible increase in nutrient removal by changing from conventional to full-tree logging for various species is illustrated in Table 5.

Full tree utilisation (including stumps and roots in some cases), increases nitrogen removal, an expected result because of the higher nitrogen levels in foliage and smaller branches than in stemwood (Nykvist, 1974). Even with increased removal fertile sites generally have sufficient supplies to maintain growth (Mälkönen, 1973, 1976; Weetman and Webber, 1972); however, continuous removal of potential soil organic matter through full-tree harvesting on marginal sites can lead to nitrogen depletion (Weetman and Webber, 1972; White, 1974). The low increase in nitrogen removal for New Zealand, i.e., 75% (Table 5) can be explained through the growth dynamics of

P. radiata (Madgwick, 1977) which has a lower canopy/stemwood biomass ratio than the other species.

Phosphorus, a potential problem element, is highly concentrated in foliar biomass and thus full-tree harvesting can result in substantially greater removal (Table 5). On phosphorus-deficient soils in particular site impoverishment is possible. Again because of the crown/stemwood ratios, increasing utilisation would have the lowest effect on *P. radiata* (Table 5).

Potassium, calcium and magnesium differ in total quantities present, and in distribution among tree components but they are considered together because in most instances deficiencies are certainly imminent (Knight, 1974; Nykvist, 1974; Will, 1964, 1968). With conventional logging in New Zealand removal of K and Ca is already high and although the percent increase under full-tree utilisation is not large, the extra absolute quantities are (Table 5).

TABLE 5—The increase in off-site nutrient removal as a result of changing from convential to full-tree harvesting

			Nitrogen			Phosphorus		
Species	Age	Reference	Conventional	Full-tree	% increase	Conventional	Full-tree	% increase
			— —	kg/ha	— —	— — —	kg/ha	— — —
Pinus taeda	40	1	138	245	77	11.4	24.3	113
Mixed softwoods	40	2	80	346	333	10	65	550
Picea mariana	65	3	43	167	290	11.7	41.8	257
Picea abies	100	4	111	369	232	10	35	250
Pinus taeda	16	5	104	254	144	14	30	114
Pinus sp.	70	6	50	148	155	5.3	15.0	183
Pinus radiata	26	7	128	224	75	18	28	56
				Potassium			Calcium	
P. taeda	40	1	96	149	55	121	165	36
Mixed softwoods	40	2	52	158	204	143	448	214
P. mariana	65	3	25	84	236	98.3 (8.1)	277 (27.0)	178 (233)
P. abies	100	4	56	160	185	208	454	118
P. radiata	26	7	157	224	43	205	129	23
P. taeda	16	5	80	165	106			
P. sp.	17	6	38	80	58			

1. Switzer and Nelson, 1973
2. Norton and Young, 1976
3. Weetman and Webber, 1972
4. Nykvist 1974
5. Jorgensen, Wells & Metz, 1975
6. Malkonen, 1976.
7. Will, 1968
8. Values for magnesium in brackets

Effect of Shorter Rotations on Nutrient Requirements

Reduced, or short, rotation is a practice finding increasing favour (Switzer and Nelson, 1973; White, 1974). Short rotations have several implications for nutritional relationships:

(1) By shortening rotation length, a longer proportion of each rotation is devoted to the regeneration period, a time of high hazard because of increased degradation of forest floor material and possible increased nutrient leaching.

(2) With short rotations, the frequency of occurrence of regeneration periods is increased.

(3) Short rotations can put harvest time in the period when the crop is rapidly acquiring both biomass and nutrients.

(4) Even though harvesting is likely after the time of full site occupation nutrient drain per unit of harvested material, depending upon harvesting method, could be high.

Potential depletion values per 100 years for two rotation lengths and standards of utilisation in *P. taeda* stands (Table 6) show that the greatest increase is attributed to full-tree utilisation and short rotation lengths. The effect of two short versus one long rotation is to increase removal of N, P, K, and Ca by 26, 22, 15, and 17% respectively under partial utilisation. With full-tree utilisation removal of these elements increases to 35, 34, 23, and 17%. Increased utilisation at age 20 increases nutrient removal by 32, 60, 26, and 15% for N, P, K, and Ca; however at age 40 the increase is only 22, 46, 18, and 15%. Differences found, e.g., larger increases for N and P (32 and 60%) than Ca (15 and 17%) reflect the accumulation and distribution of each element within the stand at harvest time (Switzer and Nelson, 1973). Thus as the majority of calcium is found in the wood, only small increases can be expected under full-tree utilisation; however, the increase in N and P removal can be expected to be large.

TABLE 6—Potential nutrient removal over 100 years for **Pinus taeda** plantations for two intensities of utilisation and two rotation lengths

Element	Partial utilisation		Full utilisation	
	20 years	40 years	20 years	40 years
	— — — — — — — — — kg/ha/100 yrs		— — — — — — — — — — —	
N	1460	1160	1920	1420
P	84	69	135	101
K	840	730	1060	860
Ca	890	760	1020	870

Utilisation does not include stumps and roots. From Switzer and Nelson (1973).

Estimated removal for a 35- (thinned) and a 10-year rotation in *P. radiata* (figures from Will, 1964, 1968) shows that by shortening the rotation from 35 to 10 years and using tree-length standards, removal should increase by 86, 16, 65, and 86% for N, P, K, and Ca (Table 7). Under a 10-year rotation, there is proportionately more biomass in non-stemwood material, such as branches, than in a 35-year-old stand. Under full-

TABLE 7—Estimated nutrient removal over 100 years for full tree and tree length harvesting of **Pinus radiata** on central North Island pumice soils. Stumps and roots not included

Element	Tree length		Full tree	
	10 years	35(T) years	10 years	35(T) years
	— — — — — — — — kg/ha/100 yrs	— — — — — — — —	— — — — — — — —	— — — — — — — —
N	1220	657	3360	1043
P	110	95	307	137
K	1340	811	2811	1082
Ca	1000	537	1697	640

(T) Thinned

tree utilisation and short rotation, the increase in nutrient removal is very high with a 175, 179, 110, and 70% increase for N, P, K, and Ca. There are strong rotation-length: utilisation interactions present with substantially greater increases in removal through reducing rotation length and using full tree as opposed to tree-length utilisation. The differences between *P. taeda* and *P. radiata* can be attributed to two main factors — one being different growth patterns, and the other being the timing of the first cut. With *P. radiata,* the first cut at 10 years occurs just after full site occupancy when the total nutrient load in the foliage is probably at its peak.

Effect of Site Preparation on Nutrient Demands

The principal site preparation methods used in New Zealand and overseas include slash burning, bedding, windrowing, line blading and ripping, all of which affect the amount, distribution and movement of soil and slash nutrients. Although little information is available pertaining directly to New Zealand, it is almost certain that intensified cultural practices, such as site preparation and improved genetic stock, will be used in conjunction with other intensified practices. Thus an estimate of nutrient depletion, and potential fertiliser requirements, can only be made by considering these practices in conjunction.

Site preparation methods influence both physical and chemical soil properties, in terms of at least compaction and soil moisture dynamics (Kauppila and Lahde, 1975; McClurkin and Duffy, 1975; McKee and Shoulders, 1974; Mann and McGilvray, 1974), with additional implications for subsequent stand management. That intensified management results in increased yield and nutrient demand is well supported (Haines and Pritchett, 1965; Switzer and Nelson, 1973). Intensification of management practices on 10-year rotation of *P. taeda* raised productivity from 35 to 100 and 166 metric tons for moderate and intensive cultural practices as compared with natural stands, and was accompanied by an increased nutrient demand (Table 8). However, except for phosphorus, the percent increase in nutrient demand was less than the increase in biomass production, thus indicating a potential for relatively more efficient nutrient utilisation at the higher rates of production. Because of the marked increase in total nutrients needed for maintenance of productivity, it was concluded that increased

TABLE 8—The mean annual nutrient demand of **P. taeda** in natural stands receiving no culture and in plantations receiving moderate and intensive culture managed in 10-year rotations with complete utilisation (Switzer and Nelson, 1973)

Nutrient	Natural Stand No Culture	Plantations Moderate culture	Plantations Intensive culture
	— — kg/ha/yr — —		
N	23	35	57
P	1.3	3.1	5.2
K	11	20	29
Ca	12	19	29

demands associated with intensification of plantation culture are considerable and it would be doubtful if natural inputs and site reserves could meet these demands. Thus fertilisation will apparently be required.

Of the three methods, slash burning, windrowing and bedding, only the first two entail any form of nutrient removal. Bedding involves mixing debris and soil, which often results in enhanced organic matter breakdown and increased nutrient availability (Haines and Pritchett, 1965).

Slash burning rapidly oxidises organic matter (logging debris and surface organic matter). This results in a proliferation of nutrient elements in an alkaline, water soluble state accompanied by a substantial gaseous loss of sulphur and nitrogen. The amount of nitrogen lost, and extent of nutrient leaching, depends on fire intensity (Cole *et al.,* 1974; Debell and Ralston, 1970). The main impact on soil fertility results from volatilisation of nitrogen and not nutrient leaching. Between 70 and 90% of the cations entering the A and B mineral horizons are adsorbed by the soil (Debell and Ralston, 1970; Cole *et al.,* 1974).

Windrowing does not entail actual offsite biomass and nutrient removal as does slash burning (particularly for nitrogen), but it still needs reappraisal. The slash layer, and a variable quantity of litter and mineral soil, is moved to a confined space causing significant redistribution of on-site nutrient reserves. How much tree growth is stimulated in piled areas is doubtful, as it is questionable how much of the concentrated elements developing vegetation can retain (Glass, 1976; Smith and Pritchett, 1975).

The elements cycled through the biological pathway are those most strongly affected by these two practices. As data on impact of fire and windrowing in New Zealand are not available, only theoretical assumptions and calculations are possible. For windrowing all logging debris, litter and the 0-7.5 cm of mineral soil is assumed to be scraped into the windrows and the nutrients concentrated there are not used. In addition it is assumed there would be no inter-windrow gains through nitrogen fixation but that uptake by trees would continue. For slash burning, a complete burn of logging debris and litter and hence volatilisation of nitrogen is assumed. Such assumptions cannot be completely true, however it seems clear that intensification in cultural practices dramatically alters mean annual nitrogen removal (Table 9).

To estimate potential nitrogen fertilisation requirements, precipitation additions of

TABLE 9—Estimated effect of intensification of cultural practices on mean nitrogen removal (kg/ha/yr) for **P. radiata** growing on central North Island pumice soils

Land Preparation	Rotation length (years)					
	10[a]		25[b]		25(T)[a]	
	TL	FT	TL	FT	TL	FT
Logging only	12	34	12	22	7	11
Logging and burning	66	66	33	33	22	22
Logging and windrowing	236	236	101	101	90	90

T — Thinned (waste thinning at age 8 and extraction thinning at age 20); TL — tree length; FT — full tree

[a] Values from Will 1964, 1968.

[b] Values calculated using the method developed by Lewis (1954) and the raw data from Compartment 1099 Provisional Findings Report for 1973 and tree component breakdown and nutrient concentrations from Orman and Will, 1964.

4 kg/ha/yr (Fish, 1977a; 1977b; N.Z. Met. Services, 1975) must be accounted for (Table 10). Other additions, via nitrogen fixation, are also possible but data are unavailable. The calculations in Table 10 account for 280 kg/ha of nitrogen in the surface litter and 1700 kg/ha in the 0-7.5 cm of mineral soil (Ballard, 1976) but not the 1200 kg/ha in the 7.5-20 cm depth. Under conditions of excessive disturbance in windrowing, the latter will play a significant role in nitrogen nutrition of any subsequent crop.

As the values presented in Tables 9 and 10 are from stands located in different areas and subjected to different habitat conditions (such as *Sirex* kill for the 25 (T) stand) and, for the 25-year-old stand, are theoretically derived, only general observations are possible. As indicated, without any land preparation, the greatest effect can be attributed to changing utilisation standards. Although the net nitrogen removal per rotation is lowest for the 10-year rotation, equating both rotations on a sustained 100-year basis shows that shorter rotations lead to a substantially greater removal and hence need for fertilisation.

By intensifying cultural practice, the effect of utilisation standards is reduced, yet under the assumptions given, cultural practices override any influence of utilisation standards. With a reduction in burn, more efficient windrowing and less soil removal, more nitrogen will be left on site and the differences between preparation methods

TABLE 10—Estimated net nitrogen removal for **P. radiata** on central North Island pumice soils (see Table 9)

Land Preparation	Rotation length (years)					
	10		25		25(T)	
	TL	FT	TL	FT	TL	FT
Logging only	80	300	200	450	75	175
Logging and burning	620	620	725	725	450	450
Logging and windrowing	2320	2320	2425	2425	2150	2150

reduced. Simultaneously differences between utilisation standards should also reappear. These statements are hypothetical however as no data for any of these situations are available.

CONCLUSIONS

Conclusions for *P. radiata* in New Zealand can only be based on a limited amount of information relating to particular locations and stands. Thus the following statements are no more than cautionary guidelines.

(1) By shortening rotations, a greater proportion of rotation time is devoted to the regeneration period and reaching site occupancy, during which accelerated nutrient loss through degradation of the forest floor is possible. High hazard periods must recur more frequently under short than under long rotations.

(2) With short rotations total nutrient drain will be greater than with long rotations.

(3) Intensified utilisation, whereby foliage and other components are removed off-site, will accelerate nutrient depletion.

(4) Intensified site preparation practices, such as slash burning and windrowing, can result in additional nitrogen losses and advance the onset of nitrogen and possibly other deficiencies in future crops.

REFERENCES

BALLARD, R. 1976: Mechanisation — Possible impacts on soil fertility. **For. Ind. Rev. 7(6):** 42-4.

BARTON, G. M. 1976: Foliage. Part II. Foliage chemicals, their properties and uses. **Applied polymer symposium No. 28:** 465-84.

COLE, D. W., CRANE, W. J. and GRIER, C. C. 1974: The effect of forest management practices on water chemistry in a second growth Douglas fir ecosystem: **In** "Forest Soils and Land Management." ed. B. Bernier and C. H. Winget. Les Presses de L'Universite Laval. pp. 195-208.

DEBELL, D. S. and RALSTON, C. W. 1970: Release of N by burning light forest fuels. **Proc. Soil Sci. Soc. Amer. 34:** 936-8.

DUVIGNEAUD, P. and DENAEYER-DE SMET, S. 1970: Biological cycling of minerals in temperate deciduous forests. **In** "Analysis of Temperate Forest Ecosystems." ed. D. E. Reichle. Springer-Verlag, N.Y. pp. 199-225.

FISH, G. R. 1976: Nitrogen and phosphorus analysis of rainfall at Rotorua, N.Z. **N.Z. J. Hydrology 15(1):** 17-26.

——— 1976: The fallout of nitrogen and phosphorus compounds from the atmosphere at Ngapuna, near Rotorua, N.Z. **N.Z.' J. Hydrology 15(1):** 27-34.

FLORENCE, R. G. and LAMB D. 1974: Ecosystem processes and the management of radiata pine forests on sand dunes in South Australia. **Proc. Ecol. Soc. Aust. 9:** 34-48.

GLASS, G. G. JR. 1976: The effect from rootraking on an upland piedmont loblolly pine (**Pinus taeda** L.) site. **N.C. State Univ., School of Forest Resources, Tech. Rept. No. 56.**

HAINES, L. W. and PRITCHETT, W. L. 1965: The effects of site preparation on the availability of soil nutrients for slash pine growth. **Soil and Crop Soc. Fla. Proc. 25:** 356-64.

JORGENSEN, J. R., WELLS, C. G. and METZ, L. J. 1975: The nutrient cycle: key to continuous forest production. **J. For. 73:** 400-3.

KAUPPILA, A. and LAHDE, E. 1975: On the effects of site treatment on forest soil properties in North Finland. **Folia Forestalia 230:** 1-29.

KEAYS, J. L. 1975: Biomass of forest residuals. **AICHE. Symposium Series. 71(146):** 10-21.

——— 1976: Foliage. Part I. Practical utilisation of foliage. **Applied Polymer Symposium No. 28:** 445-64.

KIRKLAND, A. 1976: Review of New Zealand Thinning Practices. **N.Z. J. For. Sci. 6(2):** 141-51.

KNIGHT, P. J. 1973: Some facets of the mineral cycle in pine populations. DSIR Symposium on Mineral Cycling, Palmerston North. pp. 54-61.

KNIGHT, P. J. 1974: Natural leaching losses from a pumice soil planted with **Pinus radiata**: Results of 10 years of lysimetric observations in central Kaingaroa Forest (1962-64; 1967-73). **N.Z. For. Serv., For. Res. Inst., Soils and Site Productivity Rep. 38** (unpubl.).

LEWIS, E. R. 1954: Yield of unthinned **Pinus radiata** in New Zealand. **N.Z. For. Serv., For. Res. Inst., For. Res. Notes 1(10):** 28p.

LIKENS, G. E., BORMANN, F. H., JOHNSON, N. M., FISHER, D. W. and PIERCE, R. S. 1970: Effects of forest cutting and herbicide treatment on nutrient budgets in the Hubbard Brook watershed ecosystem. **Ecol. Monogr. 40:** 23-47.

McCLURKIN, D. C. and DUFFY, P. D. 1975: Evaluating impact of forest site preparation on soil and water quality in the U.S. coastal plain. **In** "Forest Soils and Land Management". Ed. B. Bernier and C. H. Winget Les Presses de L'Universite Laval. pp. 315-21.

McKEE, W. H. and SHOULDER, E. 1974: Slash pine biomass response to site preparation and soil properties. **Soil Sci. Soc. Amer. Proc. 38(1):** 144-8.

MADGWICK, H. A. I. 1977: Nutrient uptake by an age series of radiata pine plantations. **In** "Use of Fertilisers in N.Z. Forestry." **N.Z. For. Serv., For. Res. Inst. Symposium 19.**

MADGWICK, H. A. I., JACKSON, D. S. and KNIGHT, P. J. 1977: Above-ground dry matter, energy and nutrient contents of trees in an age series of **Pinus radiata** plantations. **N.Z. J. For. Sci. 7(3):** 445-68.

MAKI, T. E. 1972: Clearcutting and Soil Depletion. **Forest Farmer 32(1):** 12-4.

MÄLKÖNEN, E. 1973: Effect of complete tree utilisation on the nutrient reserves of forest soils. IUFRO Biomass Studies, Nancy, France, 1973. pp. 375-86.

——— 1976: Effect of whole-tree harvesting on soil fertility. **Silva Fennica 10(3):** 157-64.

MANN, W. R., JR. and McGILVRAY, J. M. 1974: Response of slash pine to bedding and phosphorus applications in southeastern flatwoods. **U.S.D.A., For. Serv., Res. Paper SO-99.**

NEW ZEALAND METEOROLOGICAL SERVICES 1977: Rainfall observations for 1975. **Mis. pub. 110 (1975).**

NYKVIST, E. 1974: The loss of plant nutrients at whole-tree utilisation. **Research Note NR 76E. Department of Operational Efficiency, Royal College of Forestry, Sweden.** Pp. 76-96.

ORMAN, H. R. and WILL, G. M. 1960: The mineral content of **Pinus radiata** trees. **N.Z. J. Sci. 3:** 510-22.

OVINGTON, J. D. 1957: Dry matter production by **Pinus sylvestris** L. **Ann. Bot. N.S. 21(82):** 287-314.

PATRIC, J. H. and SMITH, D. W. 1975: Forest management and nutrient cycling in eastern hardwoods. **U.S.D.A., For. Serv., Res. Pap. NE-324.**

RENNIE, P. J. 1955: The uptake of nutrients by mature forest growth. **Plant & Soil 7:** 49-96.

——— 1957: The uptake of nutrients by timber forest and its importance to timber production in Britain. **Quat. J. For. 51:** 101-15.

RODIN, L. E. and BAZILEVICH, N. I. 1967: "Production and Mineral Cycling in Terrestrial Vegetation." Oliver and Boyd, London. 288pp.

ROOKE, D. A. 1975: Why does radiata pine grow so vigorously in New Zealand? **N.Z. For. Serv., Reprint 909.** 2p.

SATOO, T. 1970: A synthesis of studies by the harvest method: Primary production relations in temperate deciduous forests of Japan. **In** "Analysis of Temperate Forest Ecosystems". ed. D. E. Reichle. Springer-Verlag, N.Y. pp. 55-72.

SMITH, W. H. and PRITCHETT, W. L. 1975: Nutrient cycling in the slash pine ecosystem—Silvicultural implications. Soc. Amer. For. Ann. Meeting (GRIFF Pub. No. 76-2/1976).

STONE, E. L. 1973: The impact of timber harvest on soils and water. **In** "Report of the

President's Advisory Panel on Timber and the Environment." U.S. Govt. Printing Office. 641pp.

STONE, E. L. 1975: Effects of species on nutrient cycles and soil change. **Phil. Trans. Roy. Soc. London. B. 271:** 149-62.

SWITZER, G. L. and NELSON, L. E. 1973: Maintenance of productivity under short rotations. **Mississippi Ag. and For. Ext. Stn., Contribution No. 2655.**

SWITZER, G. L., NELSON, L. E. and SMITH, W. H. 1966: The characterisation of dry matter and nitrogen accumulation by loblolly pine. **Soil Sci. Soc. Amer. Proc. 30:** 114-9.

TAMM, C. O., HOLMEN, H., POPOVIC, B. and WIRKLANDER, C. 1974: Leaching of plant nutrients from soils as a consequence of forestry operations. **Ambio. 3(6):** 211-21.

WEETMAN, G. F. and WEBBER, B. D. 1972: The influence of wood harvesting on the nutrient status of two forest stands. **Can. J. For. Res. 2:** 351-69.

WELLS, C. G. and JORGENSEN, J. R. 1974: Nutrient cycling in loblolly pine plantations. **In** "Forest Soils and Forest Land Management." ed. B. Bernier and C. H. Winget. Les Presses de L'Universite Laval. Pp. 137-58.

WELLS, C. G., JORGENSEN, J. R. and BURNETT, C. E. 1975: Biomass and Mineral Elements in a Thinned loblolly pine plantation at age 16. **U.S.D.A., For. Serv., Res. Pap. SE-126.**

WHITE, E. H. 1974: Whole tree harvesting depletes soil nutrients. **Can. J. For. Res. 4:** 530-5.

WHYTE, A. G. D. 1973: Productivity of first and second crops of **Pinus radiata** on the Moutere gravel soils of Nelson. **N.Z. J. For. 21(2):** 248-52.

WILL, G. M. 1964: Dry matter production and nutrient uptake by **Pinus radiata**. **Comm. For. Rev. 40:** 57-70.

WILL, G. M. 1968: The uptake, cycling and removal of mineral elements by crops of **Pinus radiata**. **Proc. N.Z. Ecol. Soc. 15:** 20-4.

——— 1973: Nutrient cycling in a forest ecosystem. DSIR Symposium on Mineral Cycling, Palmerston North. Pp. 51-3.

WILL, G. M. and BALLARD, R. 1976: Radiata pine — soil degrader or improver? **N.Z. J. For. 21(2):** 248-52.