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 Demeyer-De Smet, 1970; Jorgensen *et al.*, 1975; Patric and Smith, 1975, 1977; 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
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

<table>
<thead>
<tr>
<th>Species</th>
<th>10</th>
<th>20</th>
<th>40</th>
<th>60</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Pinus taeda</em></td>
<td>26</td>
<td>72</td>
<td>191</td>
<td>210</td>
</tr>
<tr>
<td><em>P. taedai</em></td>
<td>20</td>
<td>43</td>
<td>118</td>
<td>150</td>
</tr>
<tr>
<td><em>Pinus sylvestris</em></td>
<td>26</td>
<td>65</td>
<td>163(35)</td>
<td>150(55)</td>
</tr>
<tr>
<td><em>P. sylvestris</em></td>
<td>52(11)</td>
<td>55(18)</td>
<td>112(48)</td>
<td>119(64)</td>
</tr>
<tr>
<td><em>Pseudotsuga menziesii</em></td>
<td>8(12)</td>
<td>16(28)</td>
<td>24(39)</td>
<td>264(75)</td>
</tr>
<tr>
<td><em>Pinus radiata</em></td>
<td>104</td>
<td>264(18)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Species</th>
<th>Total Above Ground</th>
<th>Merchantable Timber</th>
<th>Residual Material</th>
<th>Per cent Merchantable</th>
</tr>
</thead>
<tbody>
<tr>
<td>100-year-old <em>Fagus</em>¹</td>
<td>128</td>
<td>57</td>
<td>71</td>
<td>45</td>
</tr>
<tr>
<td><em>Populus tremuloides</em> and Hardwoods¹</td>
<td>179</td>
<td>74</td>
<td>105</td>
<td>41</td>
</tr>
<tr>
<td><em>P. tremuloides</em> and Hardwoods¹</td>
<td>60</td>
<td>30</td>
<td>30</td>
<td>50</td>
</tr>
<tr>
<td><em>P. tremuloides</em>¹</td>
<td>70</td>
<td>27</td>
<td>43</td>
<td>39</td>
</tr>
<tr>
<td><em>Pinus</em> sp.¹</td>
<td>12</td>
<td>8</td>
<td>4</td>
<td>67</td>
</tr>
<tr>
<td><em>P. taeda</em> — 16 years²</td>
<td>156</td>
<td>116</td>
<td>40</td>
<td>60</td>
</tr>
<tr>
<td>Mixed Wood³</td>
<td>312</td>
<td>164</td>
<td>148</td>
<td>53</td>
</tr>
<tr>
<td><em>P. radiata</em> — 26 years⁴</td>
<td>222</td>
<td>201</td>
<td>21</td>
<td>91</td>
</tr>
<tr>
<td><em>Picea rubens</em> — <em>Abies balsamifera</em>⁵</td>
<td>132</td>
<td>82</td>
<td>50</td>
<td>62</td>
</tr>
<tr>
<td>(all aged)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Picea mariana</em> — 65 years⁵</td>
<td>107</td>
<td>54</td>
<td>53</td>
<td>59</td>
</tr>
<tr>
<td>Mixed Hardwood⁶</td>
<td>167</td>
<td>120</td>
<td>47</td>
<td>72</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Species</th>
<th>Nutrient</th>
<th>N</th>
<th>P</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Pinus radiata</em>¹</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>1</td>
<td>1</td>
<td>185</td>
<td>26</td>
<td>229</td>
<td>151</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>58</td>
<td>63</td>
<td>71</td>
<td>81</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>21</td>
<td>23</td>
<td>5</td>
<td>5</td>
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</tr>
<tr>
<td>Softwoods¹b</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>80</td>
<td>10</td>
<td>52</td>
<td>143</td>
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<td>2</td>
<td>2</td>
<td>23</td>
<td>15</td>
<td>33</td>
<td>32</td>
<td></td>
</tr>
<tr>
<td><em>Pinus taeda</em>¹b</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>104</td>
<td>14</td>
<td>80</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>32</td>
<td>29</td>
<td>35</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>12</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Picea mariana</em>c</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>44</td>
<td>12</td>
<td>25</td>
<td>98</td>
<td>8</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>26</td>
<td>21</td>
<td>30</td>
<td>36</td>
<td>30</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>23</td>
<td>13</td>
<td>12</td>
<td>31</td>
<td>10</td>
</tr>
<tr>
<td><em>Picea rubens</em>—<em>Abies balsamifera</em>c</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>79</td>
<td>11</td>
<td>47</td>
<td>150</td>
<td>14</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>20</td>
<td>21</td>
<td>32</td>
<td>36</td>
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</tr>
<tr>
<td>3</td>
<td>3</td>
<td>20</td>
<td>19</td>
<td>21</td>
<td>28</td>
<td>22</td>
</tr>
</tbody>
</table>

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**

<table>
<thead>
<tr>
<th>Species</th>
<th>Conventional</th>
<th>Full-tree</th>
<th>% increase</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Populus tremuloides—Quercus rubra</em>¹</td>
<td>91</td>
<td>188</td>
<td>105</td>
</tr>
<tr>
<td><em>P. tremuloides</em>—mixed hardwoods¹</td>
<td>69</td>
<td>236</td>
<td>96</td>
</tr>
<tr>
<td><em>P. tremuloides</em>—mixed hardwoods²</td>
<td>52</td>
<td>109</td>
<td>110</td>
</tr>
<tr>
<td>Mixed hardwoods¹</td>
<td>51</td>
<td>107</td>
<td>110</td>
</tr>
<tr>
<td>Mixed hardwoods and pines¹</td>
<td>7</td>
<td>38</td>
<td>474</td>
</tr>
<tr>
<td><em>Pinus virginiana</em>²</td>
<td>23</td>
<td>98</td>
<td>330</td>
</tr>
<tr>
<td><em>Picea mariana</em>²</td>
<td>54</td>
<td>107</td>
<td>99</td>
</tr>
<tr>
<td><em>Picea rubens—Abies balsamifera</em>²</td>
<td>82</td>
<td>132</td>
<td>60</td>
</tr>
<tr>
<td><em>Pinus taeda</em>³</td>
<td>116</td>
<td>155</td>
<td>81</td>
</tr>
<tr>
<td><em>P. radiata</em>⁴</td>
<td>201</td>
<td>222</td>
<td>10</td>
</tr>
</tbody>
</table>

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 (Mäkelönen, 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 conventional to full-tree harvesting

<table>
<thead>
<tr>
<th>Species</th>
<th>Age</th>
<th>Reference</th>
<th>Nitrogen</th>
<th>Phosphorus</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Conventional</td>
<td>Full-tree</td>
</tr>
<tr>
<td>Pinus taeda</td>
<td>40</td>
<td>1</td>
<td>138</td>
<td>245</td>
</tr>
<tr>
<td>Mixed softwoods</td>
<td>40</td>
<td>2</td>
<td>80</td>
<td>346</td>
</tr>
<tr>
<td>Picea mariana</td>
<td>65</td>
<td>3</td>
<td>43</td>
<td>167</td>
</tr>
<tr>
<td>Picea abies</td>
<td>100</td>
<td>4</td>
<td>111</td>
<td>369</td>
</tr>
<tr>
<td>Pinus taeda</td>
<td>16</td>
<td>5</td>
<td>104</td>
<td>254</td>
</tr>
<tr>
<td>Pinus sp.</td>
<td>70</td>
<td>6</td>
<td>50</td>
<td>148</td>
</tr>
<tr>
<td>Pinus radiata</td>
<td>26</td>
<td>7</td>
<td>128</td>
<td>224</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Species</th>
<th>Age</th>
<th>Reference</th>
<th>Potassium</th>
<th>Calcium</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Conventional</td>
<td>Full-tree</td>
</tr>
<tr>
<td>P. taeda</td>
<td>40</td>
<td>1</td>
<td>96</td>
<td>149</td>
</tr>
<tr>
<td>Mixed softwoods</td>
<td>40</td>
<td>2</td>
<td>52</td>
<td>158</td>
</tr>
<tr>
<td>P. mariana</td>
<td>65</td>
<td>3</td>
<td>25</td>
<td>84</td>
</tr>
<tr>
<td>(8.1)</td>
<td></td>
<td></td>
<td>(27.0)</td>
<td>(233)</td>
</tr>
<tr>
<td>P. abies</td>
<td>100</td>
<td>4</td>
<td>56</td>
<td>160</td>
</tr>
<tr>
<td>P. radiata</td>
<td>26</td>
<td>7</td>
<td>157</td>
<td>224</td>
</tr>
<tr>
<td>P. taeda</td>
<td>16</td>
<td>5</td>
<td>80</td>
<td>165</td>
</tr>
<tr>
<td>P. sp.</td>
<td>17</td>
<td>6</td>
<td>38</td>
<td>80</td>
</tr>
</tbody>
</table>

2. Norton and Young, 1976    1975
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**

<table>
<thead>
<tr>
<th>Element</th>
<th>Partial utilisation</th>
<th>Full utilisation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20 years</td>
<td>40 years</td>
</tr>
<tr>
<td>N</td>
<td>1460</td>
<td>1160</td>
</tr>
<tr>
<td>P</td>
<td>84</td>
<td>69</td>
</tr>
<tr>
<td>K</td>
<td>840</td>
<td>730</td>
</tr>
<tr>
<td>Ca</td>
<td>890</td>
<td>760</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Element</th>
<th>Tree length</th>
<th></th>
<th></th>
<th>Full tree</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10 years</td>
<td>35(T) years</td>
<td>10 years</td>
<td>35(T) years</td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>1220</td>
<td>657</td>
<td>3360</td>
<td>1043</td>
<td></td>
</tr>
<tr>
<td>P</td>
<td>110</td>
<td>95</td>
<td>307</td>
<td>137</td>
<td></td>
</tr>
<tr>
<td>K</td>
<td>1340</td>
<td>811</td>
<td>2811</td>
<td>1082</td>
<td></td>
</tr>
<tr>
<td>Ca</td>
<td>1000</td>
<td>537</td>
<td>1697</td>
<td>640</td>
<td></td>
</tr>
</tbody>
</table>

(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)

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Natural Stand</th>
<th>Plantations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No Culture</td>
<td>Moderate culture</td>
</tr>
<tr>
<td>N</td>
<td>23</td>
<td>35</td>
</tr>
<tr>
<td>P</td>
<td>1.3</td>
<td>3.1</td>
</tr>
<tr>
<td>K</td>
<td>11</td>
<td>20</td>
</tr>
<tr>
<td>Ca</td>
<td>12</td>
<td>19</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Land Preparation</th>
<th>Rotation length (years)</th>
<th>10a</th>
<th>25b</th>
<th>25(T)a</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TL</td>
<td>FT</td>
<td>TL</td>
<td>FT</td>
</tr>
<tr>
<td>Logging only</td>
<td>12</td>
<td>34</td>
<td>12</td>
<td>22</td>
</tr>
<tr>
<td>Logging and burning</td>
<td>66</td>
<td>66</td>
<td>33</td>
<td>33</td>
</tr>
<tr>
<td>Logging and windrowing</td>
<td>236</td>
<td>236</td>
<td>101</td>
<td>101</td>
</tr>
</tbody>
</table>

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)

<table>
<thead>
<tr>
<th>Land Preparation</th>
<th>Rotation length (years)</th>
<th>10</th>
<th>25</th>
<th>25(T)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TL</td>
<td>FT</td>
<td>TL</td>
<td>FT</td>
</tr>
<tr>
<td>Logging only</td>
<td>80</td>
<td>300</td>
<td>200</td>
<td>450</td>
</tr>
<tr>
<td>Logging and burning</td>
<td>620</td>
<td>620</td>
<td>725</td>
<td>725</td>
</tr>
<tr>
<td>Logging and windrowing</td>
<td>2320</td>
<td>2320</td>
<td>2425</td>
<td>2425</td>
</tr>
</tbody>
</table>
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**


