# EFFECT OF SLASH AND SOIL REMOVAL ON THE PRODUCTIVITY OF SECOND ROTATION RADIATA PINE ON A PUMICE SOIL

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## ABSTRACT

The effects of windrowing and skid site formation on site quality were examined in a 7-year-old, second rotation **Pinus radiata** stand growing on a yellow-brown pumice soil.

Four site types were recognised — normal cutover, windrow, inter-windrow and skids. Standing volumes, after first thinning to 573 stems/ha, were 34.3, 40.7, 20.5 and 5.2 $m^3$/ha respectively. Relative to the normal cutover the overall windrowed area contained 7 $m^3$/ha less volume or the equivalent of a reduction in Site Index (mean top height in metres at age 20 yrs) of 2 m.

Analysis of current season's foliage showed that N and B concentrations were lower on both skid and inter-windrow sites than on the windrow and normal cutover sites. Magnesium concentrations on the inter-windrow site were significantly lower than those on all other sites.

Levels of total N and exchangeable Mg were lower in the skid site and inter-windrow soil profiles than in the normal cutover profile. Using regressions of soil depth on total soil N it was calculated that **c.** 2.5 and 26 cm of soil had been scalped off the inter-windrow and skid sites respectively.

## INTRODUCTION

Windrowing of logging debris is a fairly common site preparation technique in many New Zealand exotic forests. Where conventional bolewood harvesting has been used windrowing is a prerequisite to site cultivation and mechanised planting. Theoretically, windrowing can adversely affect the nutrient status of the inter-windrow area in two principal ways. First, nutrients contained in the logging debris are removed from part of the site (inter-windrows): this is akin to whole-tree removal which for *Pinus radiata* D.Don has a calculated nutrient depletion effect over and above conventional bole-wood removal of (per hectare); 202 kg N, 18 kg P, 26 kg Mg and 61 kg Ca (Ballard, 1976). Secondly, topsoil is often removed during raking, the adverse effects of which are well documented for "skid" sites (Mead, 1968). Although the topsoil should be left intact in properly performed windrowing operations, all too often considerable amounts of topsoil are pushed into the windrow along with the logging debris (Ballard, 1976).

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In an examination of the effect of rootraking on a loblolly pine (*Pinus taeda* L.) site in North Carolina, Glass (1976) found that removal of logging slash and 4.7 cm of topsoil from the rootraked area reduced the Site Index, compared to an adjacent burn-only area, from 24 to 20 m. At age 20 years the control area supported 98 m$^3$/ha more wood than the rootraked area.

Compartment 809 was one of the first areas windrowed in Kaingaroa State Forest. Portions of the compartment were windrowed in 1969 prior to planting the second crop of *P. radiata.* During thinning and pruning of this compartment in 1976 it was obvious that a productivity gradient existed across the site with tree growth better in and close to the windrows.

In December 1976 a study was undertaken in Cpt 809 to (1) quantify the effect of windrowing on site productivity, and (2) determine its effect on soil properties. Unwindrowed (normal) cutover sites and "scalped" skid sites were used for comparison purposes.

## MATERIALS AND METHODS

### *Site*

Compartment 809 is situated in the Wairapukao subdivision of Kaingaroa State Forest. The area is essentially flat with a broad, shallow drainage course crossing the unwindrowed section of the compartment. The soil type is Kaingaroa silty sand, a yellow-brown pumice soil formed from rhyolitic Taupo pumice deposited during the Taupo eruption of *c.* 150 A.D. (Vucetich, 1960). The area was first planted in radiata pine in 1930 and that crop was clearfelled in 1968. Approximately one-third of the compartment was windrowed on *c.* 30 m centres prior to replanting with radiata pine in 1969. The windrows were stocked during planting. Skid sites were ripped to a nominal 0.6 m depth prior to planting. The whole compartment was low pruned and thinned to 573 stems/ha in a non-commercial operation during March 1976.

### *Plots*

Ten 10 × 10 m (0.01 ha) plots were established in each of four areas in Cpt 809, (1) the inter-windrow area, (2) the windrow, (3) the normal cutover, and (4) skid sites (*see* Ballard, 1977a). Plots in (1) and (2) were located by selecting 10 random points along the road running through the centre of the windrowed area, taking left or right at each as determined by the toss of a coin and moving a random distance into the windrowed area on the selected side. The centre of the inter-windrow plot was located at the midpoint between the adjacent windrows, and that of the windrow plot in the centre of one of the adjacent windrows (determined by the toss of a coin). Plots in the normal cutover were located by randomly selecting 10 points along the roads on two sides of the windrowed area which separated it from the normal cutover and moving perpendicular to the road a random distance (not more than 100 m) into the stand. The skid site plots were located in the 10 skid sites on the roads running through the centre and around the periphery of the windrowed area. The plot alignment was arranged such that six trees were included in each. There was little difficulty in achieving this as the area had been very uniformly thinned.

Heights (H, m) and breast height diameters (d.b.h., cm) of individual trees in all plots were recorded. Individual tree volumes (V, m$^3$) were computed using the Rotorua

Conservancy volume equation from the Forest Research Institute's Permanent Sample Plot System:

$$\ln V = 1.711 \ln \text{d.b.h.} + 1.196 \left[ \frac{H^2}{H - 1.4} \right] - 10.18942$$

### *Transects*

A transect study was carried out in order to evaluate the effect of distance from the windrow on tree productivity, and to ascertain whether the degree of competition from neighbours to which individual trees were subject might explain the productivity gradients observed. Five transect lines, perpendicular to the windrows and each crossing three windrows, were located at random throughout the windrowed area using the same procedure as used for locating plots. All trees within a 6-m wide corridor about the transect lines were identified. Height, d.b.h. and volume were recorded or calculated from each tree as was its distance from the centre of the nearest windrow. As indices of the competition status of each tree the following were recorded, (1) the distance between the tree and its closest competitive neighbour (a standing or thinned tree with a stump height diameter of greater than 10 cm), and (2) the sum of this distance and that to the next closest competitive neighbour on the opposite side of the sample tree (i.e., at an angle greater than 90° to the other competitive neighbour). Stump diameters greater than 10 cm were used to eliminate small, essentially non-competitive trees, and because it was not possible to use any other parameter, such as distance between crowns, to assess competition in this recently thinned stand.

### *Soil and Foliage Samples*

In December a composite foliage sample was collected from four trees per plot using current year's needles from primary laterals on the northern side in the upper one-third of the crown.

Soil samples were collected from each of the plots in the normal cutover, inter-windrow and skid areas at depth of 0-5, 5-10, 20-20 and 20-30 cm. Those from the first two depths were made up of a composite of 20 2-cm diameter cores collected randomly from throughout the plot, while those from the two lower depths were made up of a composite of 4 sub-samples collected from a soil pit in each quarter of the plot. It was not possible to collect equivalent samples from plots in the windrows (because of irregular mixing of soil and slash).

Foliage samples were analysed for N, P, K, Ca, Mg and B using techniques outlined by Mead and Will (1976). Soil samples were analysed for total N, total C, Bray 2-extractable P and exchangeable Ca, Mg and K by standard N.Z. Soil Bureau techniques (Blakemore, Searle and Daly, 1972).

## RESULTS

### *Site Productivity*

Trees growing on the normal cutover had significantly lower volumes than those growing on the windrows, but significantly greater volumes than those on either the inter-windrow or skid sites (Table 1). In turn those on the inter-windrow sites had significantly greater volumes than those on the skid sites. In relation to volume production on the normal cutover, these differences represent a 19% increase on the windrows and reductions of 40% and 85% on the inter-windrow and skid sites respectively.

Height and d.b.h. measurements showed the same trends as volume although the differences between the normal and windrow sites were not significantly different. If it is assumed that treatments have permanently altered the Site Index (SI) of the sites (*see* Glass, 1976), then using the SI equation for volcanic plateau soils in the Rotorua region developed by Tennent and Burkhart (1977), it was calculated that the SI (mean top height in metres at age 20 years) of the normal site has been reduced from 27 to 25 in the inter-windrow areas and to 16 for the skid sites (Table 1). The SI of the area covered by the windrows has increased to 28. Extrapolating these data to the number of years required to reach a height of 35 m, the target height for a Fenton (1972) sawlog regime, it can be seen (Table 1) that the length of a rotation on the inter-windrow area will be increased by 3 years relative to the normal site. On the windrow sites the rotation length will be reduced by 1 year while on the skid sites it will be increased by 14 years.

TABLE 1—Mean growth[1] parameters for trees from four sites

| Site | Height (m) | d.b.h. (mm) | Volume/tree ($m^3$/tree) | Volume/ha ($m^3$/ha) | Site Index[2] (m. 20 yr) | Age at[2] ht 35 m (years) |
|---|---|---|---|---|---|---|
| Normal | 7.9 a | 145 a | 0.057 a | 34.3 a | 27 | 26 |
| Windrow | 8.3 a | 157 a | 0.068 b | 40.7 b | 28 | 25 |
| Inter-windrow | 6.7 b | 111 b | 0.034 c | 20.5 c | 25 | 29 |
| Skid | 3.9 c | 57 c | 0.009 d | 5.2 d | 16 | 40 |

[1] Individual plot data available in Ballard (1977a).
[2] Calculated.
Values within columns not followed by a common letter differ significantly at the 5% level using the LSD test.

A plot of average tree volume (averaged over each 2-m interval) against distance from the windrow centre (Fig. 1) confirmed the field observations of a sharp productivity gradient at the edge of the windrow and an average windrow width of *c.* 10 m. Within the windrow and inter-windrow areas there were small productivity gradients, increasing towards the centre of the windrow and decreasing towards the centre of the inter-windrow area, but these were negligible in comparison to that at the interface of the two areas. The sharp edge effect indicates little cross feeding between areas by the 7-year-old trees; only trees actually planted on the windrow have benefited from the accumulated material.

There is a good correspondence between mean tree volumes, for both the windrow and inter-windrow areas, obtained in the plot and transect studies.

### *Competition Effect*

A stepwise regression analysis of tree volume on distance from the windrow centre and the two indices of competition status was performed. Successive variables were added to the equation in order of decreasing significance until the added variable failed to make a significant contribution to the regression at the 10% level. The only

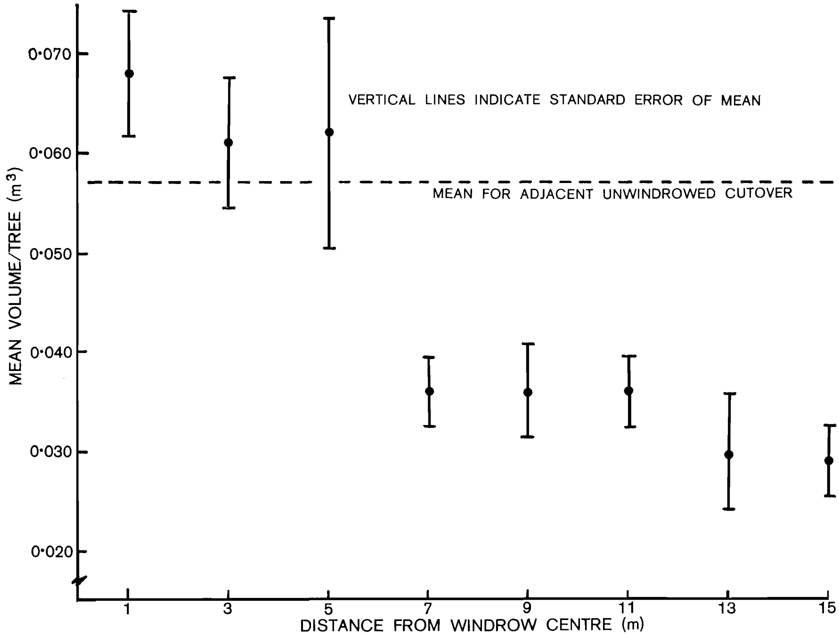

FIG. 1—Relationship between productivity of 7-year-old radiata pine and distance from windrow centre.

deviation from this input order was the cubic expression of distance from the windrow as all three expressions of this variable were forced into the regression, although only in the case of the cubic term did this instruction alter the normal input order.

The partial F values for entry of the variables into the regression equation before and following the addition of each variable in turn are shown in Table 2. The F values before any variable input (first row) indicate that all three expressions of distance are significantly correlated (1% level) with tree volume while of the competition variables only the squared term of the distance to the closest competitive neighbour ($Neib^2$) is significant (5% level). This strongly suggests that distance from the windrow was the dominant factor influencing tree volume. As the $Neib^2$ term is only very weakly correlated with distance from the windrow centre ($r = 0.092$) and continues to have a significant (10%) F value for entry after the windrow distance terms have been entered into the regression, it is apparent that the principal effect of competition on tree volume is independent of distance from the windrow. Thus the effect illustrated in Fig. 1 cannot be attributed to a reduced competition or border effect associated with lower stocking in the windrows.

An interesting feature of the results in Table 2 is that even the best fit model accounts for only 38% of the variation in tree volume. Part of this may be attributed to the mathematical expression for the variables not being the best possible and the measures of competition not completely reflecting the biological situation. The most likely explanation for the unaccounted variation is, however, the variation in quality

TABLE 2—Partial F values for entry of distance variables into a stepwise regression of tree volume on these variables

| Variable† entered | Partial F value for entry of variable |  |  |  |  |  |  | R$^2$ for regression |
|---|---|---|---|---|---|---|---|---|
|  | Dist (1) | Dist$^2$ (2) | Dist$^3$ (3) | Neib (4) | Neib$^2$ (5) | Tween (6) | Tween$^2$ (7) |  |
| — | 38.6** | 21.37** | 11.58** | 2.60 | 4.76 | 1.16 | 1.38 | — |
| (1) | — | 11.29** | 10.20** | 2.33 | 3.75(10%) | 2.07 | 2.05 | 0.255** |
| (1) + (2) | — | — | 0.35 | 2.20 | 3.46(10%) | 1.13 | 1.05 | 0.323** |
| (1) + (2) + (3) | — | — | — | 2.46 | 3.76(10%) | 1.21 | 1.12 | 0.325** |
| (1) + (2) + (3) + (5) | — | — | — | 5.90* | — | 0.00 | 0.00 | 0.347** |
| (1) + (2) + (3) + (5) + (4) | — | — | — | — | — | 0.00 | 0.00 | 0.381** |

(10%) Significant at the 10% level
* Significant at the 5% level
** Significant at the 1% level

† Dist = distance to centre of nearest windrow
Neib = distance to closest competitive neighbour
Tween = distance between opposite competitive neighbours.

TABLE 3—Mean[1] nutrient concentrations in current season's foliage collected from four sites

| Site | N | P | K | Ca | Mg | B |
|---|---|---|---|---|---|---|
|  | (%) |  |  |  |  | (ppm) |
| Normal | 1.39 a | 0.171 a | 0.80 a | 0.34 a | 0.074 a | 12.4 a |
| Windrow | 1.43 a | 0.131 b | 0.69 b | 0.30 a | 0.075 a | 14.4 b |
| Inter-windrow | 1.32 a | 0.132 b | 0.79 a | 0.30 a | 0.058 b | 11.5 a |
| Skid | 1.08 b | 0.128 b | 0.80 a | 0.31 a | 0.073 a | 8.9 c |

[1] Individual plot data are available in Ballard (1977a)
Values within columns not followed by a common letter differ significantly at the 5% level using the LSD test.

of planting sites at any particular distance from the centre of the windrow: the operation of windrowing appears to increase site variability in and between the windrows. Both along and across any windrow there is considerable variation in quantity and quality of slash as well as amount of included soil. In the inter-windrow area the degree of soil disturbance and "scalping" is highly variable, much of this variability being associated with the first crop stump distribution.

### *Foliar Nutrient Levels*

In the current season's foliage, the only nutrient concentrations to show the same trend over sites as productivity were N and B, although for N the differences between sites, except for the skid site, were small and non-significant (Table 3). Foliar P levels for the normal site were significantly higher than those for all other sites, while K levels for the windrow site and Mg levels for the inter-windrow site were significantly lower than those for the other sites.

Interpretation of nutrient concentrations in terms of "critical" levels is made difficult by the sampling of foliage in December rather than the customary time of February/March. However, data on nutrient concentration trends with time in young foliage of radiata pine grown on a pumice soil have shown that, except for P, there is negligible difference between the nutrient concentrations in foliage collected in either December or March (Mead and Will, 1976). Thus concentrations used for interpretative purposes (Ballard, 1977b) can be used to provide a coarse indication of whether nutrient concentrations in the current foliage are low, marginal or adequate: levels of K and Ca in foliage from all four sites are adequate; N levels are low for the skid site and marginal for the other three sites; Mg levels are low for the inter-windrow site and marginal for the other sites; B levels are marginal for the skid and inter-windrow sites and adequate for the normal and windrow sites; while P levels, which tend to be higher in December than March, appear to be adequate for the normal site but just marginal for the other three sites.

### *Soil Properties*

Soil properties which decrease consistently in value with depth in the normal site profile — total C, total N, Bray-2 P, exchangeable Mg — are lower in value at all depths in the skid site profile than in the normal site profile (Table 4). The reverse is true for soil pH which increases with depth in the normal profile. This is a reflection of the removal of considerable quantities of topsoil from skid sites.

Similar but less pronounced and consistent differences exist between the inter-windrow profile and the normal profile. However discrepancies exist in that the pH tends to be lower rather than higher, Bray-2 levels are much lower, as are exchangeable K values and exchangeable Ca at lower depths. The lower pH, Bray-2 P and exchangeable Ca and Mg values in the inter-windrow site profile compared to the skid site profile appear to have no simple explanation.

Total soil N, being both a good indicator of the depth of profile development and largely independent of variations in soil mineralogical properties, was measured to provide an indication of the depth of soil removed from the inter-windrow and skid sites. Regressions of depth (mean depth of sample, e.g., 0-5 cm = 2.5 cm) on total soil N were computed for each of three sites from which soil samples were collected (Table 5).

TABLE 4—Mean[1] chemical properties at four depths of soils collected from three sites

| Site | Total C | Total N | pH | Bray 2 P | Exchangeable Ca | Exchangeable Mg | Exchangeable K |
|---|---|---|---|---|---|---|---|
| | — — (%) — — | | | (ppm) | — — (me/100 g) — — | | |
| A. 0-5 cm | | | | | | | |
| Normal | 6.28 a | 0.34 a | 4.84 a | 24.4 a | 1.12 a | 0.32 a | 0.65 a |
| Inter | 5.56 a | 0.28 a | 4.83 a | 12.2 b | 0.46 b | 0.12 b | 0.42 b |
| Skid | 1.65 b | 0.04 b | 5.40 b | 18.7 c | 0.41 b | 0.05 c | 0.75 a |
| B. 5-10 cm | | | | | | | |
| Normal | 4.22 a | 0.25 a | 4.98 a | 21.0 a | 0.63 a | 0.19 a | 0.51 a |
| Inter | 4.02 a | 0.20 b | 4.89 a | 8.1 b | 0.29 b | 0.08 b | 0.26 b |
| Skid | 1.30 b | 0.03 c | 5.43 b | 16.3 c | 0.39 b | 0.05 b | 0.64 a |
| C. 10-20 cm | | | | | | | |
| Normal | 2.21 a | 0.15 a | 5.05 a | 17.2 a | 0.39 ab | 0.12 a | 0.48 a |
| Inter | 2.49 a | 0.14 a | 4.97 a | 7.5 b | 0.21 a | 0.05 b | 0.20 b |
| Skid | 0.95 b | 0.02 b | 5.55 b | 15.2 a | 0.42 b | 0.04 b | 0.64 a |
| D. 20-30 cm | | | | | | | |
| Normal | 0.88 ab | 0.07 a | 5.22 a | 18.8 a | 0.33 ab | 0.11 a | 0.59 a |
| Inter | 1.21 a | 0.07 a | 5.09 a | 8.3 b | 0.20 a | 0.03 b | 0.29 b |
| Skid | 0.69 b | 0.02 b | 5.78 b | 14.9 a | 0.39 b | 0.03 b | 0.57 a |

[1] Individual plot data are available in Ballard (1977a).

For any soil depth, values within columns not followed by a common letter differ significantly at the 5% level using the LSD tst.

TABLE 5—Regressions of soil depth (Y, cm) on total N (X, %) for three sites

| Site | Regresion equation | $R^2$ | Standard error of estimate |
|---|---|---|---|
| Normal | $Y = 35.14 - 160.22X + 189.91X^2$ | 0.999 | ± 0.55 |
| Inter-windrow | $Y = 37.41 - 202.33X + 278.52X^2$ | 0.999 | ± 0.48 |
| Skid | $Y = 51.69 - 217.89X + 24258.23X^2$ | 0.898 | ± 5.42 |

The mean total N values for the 0-5 cm depth of the inter-windrow and skid sites (Table 4) were substituted into both their own profile equations and the equation for the normal site. The differences in predicted depths between the normal site and the other two sites are assumed to indicate the depth of soil removed from each. Using this technique it was calculated that 2.54 cm of soil was removed on average from the inter-windrow sites and 25.66 cm from the skid sites.

## DISCUSSION

In the windrowed area of Cpt 809, the windrows occupy approximately one-third of the area. Thus, based on the volume/ha figures in Table 1, it can be shown that at age 7 years and after one thinning the windrowed area contains 7 $m^3$/ha less than the normal cutover (34.3 — 1/3 × 40.7 — 2/3 × 20.5). While this may not appear to be a particularly significant volume at this stage the loss over a rotation of 26 years would amount to 2 years in the rotation if it is assumed the current SI differences are maintained (Table 1). This is roughly equivalent to a loss of 50 $m^3$/ha for a site with m.a.i. of 25 $m^3$/ha/yr.

Although the windrows in Cpt 809 were planted, the tendency now is not to plant within the slash piles themselves. If these windrows had not been planted, the treated area would have contained even less volume. In an extreme case, where care was not taken to plant trees as close to windrows as possible (usual management prescription), the windrowed area would have contained 20.6 $m^3$/ha less volume than the normal cutover at age 7 (34.3 — 2/3 × 20.5). Over a rotation the loss would amount to 3 years in the rotation on the stocked area plus a total loss on the unstocked area. Because during thinning of an area with unstocked windrows a greater stocking would be left at the edge of the inter-windrow area to compensate for the unstocked windrow area, it is unlikely that the loss from the unstocked area would ever approach the proportion of that area not initially stocked. These projected losses are probably somewhat pessimistic also, as it is highly likely that as the trees' root systems expanded with age the "windrow effect" would extend further into the inter-windrow area than the immediate physical edge of the windrow.

The disastrous effect on site productivity of removing the topsoil during skid site preparation is well illustrated by the data in Table 1; the removal of *c.* 26 cm of topsoil has halved the standing volume at age 7 years and may increase the rotation length by 14 years. Tree growth on the skid sites, which were ripped but not fertilised at planting, is so far out of step with the remainder of the compartment that it is unlikely any significant merchantable yield will be obtained from them as it is unviable to manage such a small portion of the stand on a different schedule. Current management practice is to not only rip skid sites but to also fertilise them with NP fertilisers soon after planting; and evidence suggests that further fertilisation during the rotation will be required to maintain growth rates equivalent to those on the cutover (Ballard, 1978).

A gross N deficiency appears to be the principal cause of the severely reduced growth on the skid sites. Foliar N levels were well below those required for healthy growth of radiata pine and trees on these sites showed all the symptoms of N deficiency; short, yellowish-green needles and retention of only one to two age classes of needles in a narrow, finely branched crown. Total soil N in the top 0-5 cm of the skid sites was well below the topsoil value of 0.2% found by Jackson and Gifford (1974) to be necessary for reasonable growth of radiata pine in New Zealand. Foliar B and Mg levels were marginal on the skid sites, but the trees showed no overt symptoms of B deficiency and the Mg levels were no lower than those in foliage from the normal and windrow sites. It is interesting that foliar Mg levels were considerably lower for the inter-windrow sites than the skid sites despite exchangeable Mg levels being much lower in the surface 30 cm of the skid sites. Either the slow growth associated with the N deficiency resulted in a "concentration effect" or, because of the severe scalping of the skid sites, the trees growing on them have reached the Mg-rich buried topsoils which occur in the Kaingaroa soil profile (Will and Knight, 1968) before the trees on the deeper soil profiles. Undoubtedly the poor physical condition of the skid site soils — low organic matter and compacted (Mead, 1968) — has aggravated the productivity problem.

The direct cause of the reduced productivity of the inter-windrow sites is more difficult to ascertain. Foliar analysis data indicate that levels of N and B are marginal and Mg is deficient (Table 3). However, neither N or B levels are appreciably lower than those in foliage from the normal cutover, although using concentrations may mask the true situation somewhat as trees on both the normal cutover and windrow sites supported considerably greater foliage biomass than trees on the inter-windrow site. These latter trees did not show the overall greenish-yellow foliar colour of the skid site trees but their needle length and retention time was reduced and foliage lower in the crown showed marked tip chlorosis. Soil analysis data also show a slight reduction in total N and a marked reduction in exchangeable Mg in the inter-windrow profile.

If Mg is the principal limiting element on the inter-windrow site and if the tree roots in this area reach the Mg-rich layers in the near future then it is possible that the productivity differences at harvesting will be much less than predicted above.

It was observed in the field that trees in the inter-windrow area appeared to be more severely infected by *Dothistroma pini* than trees in the adjacent windrow. Whether this difference was associated with the nutritional condition of the trees or micro-environment effects of the contour of the windrowed area is uncertain. However association between foliar B levels and *D. pini* infection has been observed in Australia (Snowden, pers. comm.).

It would require fertiliser trials to determine the relative importance of the reduced supplies of N, Mg and B in controlling the productivity of the inter-windrow area. Nevertheless it is clear that the windrowing operation, by removing slash and topsoil, has restricted the supply of these nutrient elements to the tree. It is also likely that poorer soil physical conditions and a higher *D. pini* infection have contributed, together with the direct nutritional effect, to the observed loss in productivity. There is a possibility that artificial frost pockets may have been created between windrows which also would have contributed to the poorer growth of trees grown in the inter-windrow area.

The question of the relative contributions of logging debris removal and topsoil removal to site deterioration could be of importance to the future use and development of windrowing operations. If topsoil removal rather than slash removal is mainly responsible for reduction of site productivity then most of the adverse effects of windrowing can be avoided by preventing topsoil removal through use of properly designed equipment and close supervision. However, if slash removal *per se* has a significant effect on site productivity it may be wise to abandon the operation or in some way limit the effect of slash removal such as selectively windrowing only coarse material or reducing inter-windrow distances to a minimum. There is no direct evidence from Cpt 809 to provide an answer to the above question. However in a trial on the same soil type, removal of logging debris and annual removal of litter fall had only a little effect on the productivity of second rotation radiata pine up to assessment at 16 years of age (Ballard, 1977c). This suggests that for this particular site it was the topsoil removal which caused the decline in productivity. The removal of only 2.5 cm of topsoil from this site would remove *c.* 700 kg/ha/N. It should be appreciated that whereas this conclusion may be true for this particular site, which by forestry standards in New Zealand has reasonable nutrient reserves (Jackson and Gifford, 1974), it may not be so for nutritionally more fragile sites where the nutrients removed in logging debris alone could seriously deplete low site reserves.

In the past most management activities have been assessed on their ability to achieve immediate objectives. However the detrimental effects of certain harvesting and site preparation activities on nutrient reserves and availability may eventually offset their immediate advantages. Careful consideration needs to be given to these side effects at the planning stage and where possible adjustments made to limit adverse effects. Also management should not make the assumption that simple addition of fertiliser and/or site cultivation will restore the productivity of degraded sites. In many cases nutrients are removed from the site in existing or potential surface organic matter and/or topsoil, but these contribute to site productivity in a number of ways other than just as rich nutrient sources. Often it will probably be more efficient and environmentally safer to put an emphasis on prevention of problems rather than relying on amelioration practices to overcome them.

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