REMOVAL OF LOGGING WASTE, THINNING DEBRIS, AND LITTER FROM A PINUS RADIATA PUMICE SOIL SITE

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ABSTRACT

After felling of the first crop of **Pinus radiata** D. Don on rhyolitic pumice soil, an area was cleared of all logging debris. During the ensuing 16 years of the second **P. radiata** crop all litter material, including that of a pre-commercial thinning, was raked off this area regularly. Just prior to a late second-thinning at age 16 (from **c.** 1000 to 250 stems/ha) the impact of this treatment on stand productivity, foliar nutrient, and soil properties was examined.

It was estimated, using stem analysis procedures, that the raked area contained 471 m^3 total stemwood/ha compared to 535 m^3/ha in a control area – a reduction in productivity of some 12%. This was considered a real difference as basal areas were identical in the two areas at age 6 years.

Analysis of the current year's foliage prior to thinning showed that the only nutrient significantly lower in the raked area was boron – 7.2 ppm compared to 10.6 ppm for the control area. In addition to boron, potassium and manganese were also significantly lower in older foliage, but neither approached levels considered critical for growth. A year after thinning, differences in boron concentrations increased and foliage nitrogen concentrations in the raked area became critical for growth and significantly lower than those in the control area.

The biggest difference in soil properties between the two areas occurred at a depth of 5-10 cm, rather than in the surface 5 cm. Consistent with the removal of organic matter, the raked area had lower concentrations of carbon, total nitrogen, total phosphorus, Bray 2 phosphorus, and moisture. The cation exchange capacity and levels of exchangeable calcium, magnesium, and potassium were also significantly lower in the raked area. The depletion effect was greatest on exchangeable magnesium levels which were not so well buffered as calcium and potassium in this rhyolitic pumice soil. The relatively high reserves of phosphorus and nitrogen in this soil were not seriously depleted by the treatment.

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INTRODUCTION

The litter layer, in addition to acting as a reservoir of nutrients and an integral part of the nutrient cycle (Bray & Gorham 1964), strongly influences the physical properties of forest soils through its physical presence and decomposition products (Pritchett 1979). Treatments which remove or disturb this layer can greatly modify the dominant physical, chemical, and biological processes in the soil and thereby influence soil development and nutrient availability.

In intensively managed exotic forests in New Zealand physical removal of litter from the whole or part of the site occurs only during certain site-preparation operations such as windrowing. However, whole-tree removal during harvesting would have the same depletive effect on the litter as removal of logging debris during site preparation. The old European practice of harvesting litter from the forest floor (Baule & Fricker 1970) is unknown in New Zealand's exotic forests. Nevertheless in 1959 an area was set aside in Kaingaroa State Forest from which all logging debris was to be removed prior to establishment of the second crop of *P. radiata,* and litter produced in future was to be removed by regular raking. This was not intended to simulate any existing or future forestry practice in New Zealand, but it was felt that such a severe disruption of the nutrient cycle and gross nutrient drain on the site would provide information in a short time on the long-term effects of harvesting successive crops from the site.

This paper presents the results of an investigation into the effect of this litter removal on the site until thinning in 1975, at tree age 16 years.

MATERIALS AND METHODS

Site Description

The trial area is on a flat site in Cpt 69 of Kaingaroa State Forest. A comprehensive description of the soil, geology, topography, and climate in Cpt 69 has been given by Knight & Will (1977). For details of the site and stand history *see* Ballard & Will (1981). After clearfelling of the first-rotation *P. radiata* crop in 1957–58, a 0.16-ha (40×40 m) area in the centre of the compartment was manually cleared of all logging debris. Although the area was raked to remove the fine debris, this raking removed little of the old litter layer as most of it had become incorporated into the soil during logging disturbance.

In 1963 a control plot was established adjacent to the raked plot; both plots were thinned to roughly 1000 stems/ha, and the remaining trees were low pruned. The thinning and pruning slash was removed from the raked plot. Inner measurement plots of 0.04 ha (20×20 m) were established within the raked and control plots during 1965 and the breast height diameters (d.b.h.) of all trees within these inner plots measured. In order to adjust the plots to equal basal area some trees in the control plot were felled. The raked plot was cleared of litterfall at this date and raking has been repeated annually ever since. The trial area was subjected to no further silvicultural treatment (but some natural mortality occurred) until March 1975 when it was thinned to a nominal 250 stems/ha. All thinnings and slash were removed from the raked plot, while only the merchantable timber was removed from the control plot.

Just prior to thinning a coarse assessment of annual litterfall in the raked plot gave a value of 8000–9000 kg/ha. Using this single estimate, an assumption that litter production had been constant since the stand was 7 years of age (Will 1959), and information provided by Webber (1978) on nutrient removal during harvesting of *P. radiata,* it was estimated that the amounts of nitrogen, phosphorus, potassium, and calcium removed by raking were equivalent to amounts removed during conventional stemwood harvesting in four, three, less than one, and two 25-year rotations respectively. These estimates are conservative as no allowance was made for nutrients in slash removed after harvesting of the first crop and precommercial thinning.

Growth Assessment

Breast-height-diameters of all trees in the measurement plots were recorded in 1965 and 1975. In order to gain an accurate assessment of standing volume in 1975 and of volume trends over the interval 1965 to 1975, nine trees per plot were subjected to intensive stem analysis using the procedures detailed by Whyte & Mead (1977). The trees were selected to represent the diameter range encountered in the plots and, as far as possible, trees of similar diameter without gross stem malformations were selected from each plot.

Foliage Samples

Two composite foliage samples of current season's needles were collected from the raked plot in May 1964. No samples were collected from the control plot, but samples were collected from three nil-treatment plots of another trial, all within 200 m of the raked plot.

In March 1975, the inner plots of both the raked and control plots were split into eight 5 × 10-m subplots. The dominant tree in each subplot was identified and sampled for foliage. Samples representing current and the immediate previous season's foliage were collected from secondary branches in the upper part of the crown not subject to light competition. In March 1976, 1 year after thinning, samples of the current season's foliage were collected from the three remaining foliage sampling trees in each main plot.

Foliage samples were air-dried, ground, and analysed for nutrient element content as outlined for the litter samples of Ballard & Will (1981).

Soil Samples

Composite soil samples were collected from the 0–5, 5–10, 10–20, and 20–40 cm depths in each of the eight subplots of both main plots. Each composite sample consisted of 20 cores collected randomly throughout the subplot using a 2-cm-diameter cylinder auger. All surface litter was removed from each collection point. The depth of the A1 horizon was recorded for each core collected.

All soil samples were sealed in plastic bags for transport back to the laboratory. On arrival wet weights were recorded and duplicate 10-g subsamples were taken from the 0–5 cm sample for extraction of ammonium-nitrogen with 2*N* potassium chloride. After air-drying sample weights were recorded again. After correcting for the subsample removed from the 0–5 cm sample, bulk densities (air-dry weight/volume of cores) and field moisture contents ((wet wt – air-dry wt)/air-dry wt) were calculated.

Total nitrogen, carbon, total phosphorus, organic phosphorus, exchangeable potassium, calcium, and magnesium, and cation exchange capacity (CEC) were determined on the air-dry soil samples, after sieving through a 2-mm sieve, using standard N.Z. Soil Bureau extraction techniques (Blakemore *et al.* 1972). Available soil phosphorus was extracted using the Bray 2 method which has been calibrated for forestry purposes in New Zealand (Ballard 1974). Phosphorus in extracts was determined colorimetrically with an auto-analyser using a manifold based on the molybdate-antimony-ascorbic acid method (Grigg 1975). Ammonium ions in the potassium chloride, Kjeldahl, and sodium chloride (CEC) extracts were also determined with an auto-analyser using a manifold based on the indophenol reaction (Searle 1975). Water content of the 0–5 cm samples at 15 atmospheres pressure (wilting point) was determined on a pressure-plate apparatus.

RESULTS AND DISCUSSION

Because of the lack of replication of the main plots, it was assumed that there were no inherent differences between the adjacent control and raked sites prior to treatment. This appears to be a reasonable assumption in view of the flat terrain, the aerial deposition of the soil parent material, and the uniform management of the area.

Foliar Nutrient Concentrations

At stand age 5 years nutrient concentrations in the foliage of the raked plot and the control plots of an adjacent fertiliser trial (Table 1) indicated that the removal of logging debris had little effect on nitrogen, phosphorus, and calcium levels, but tended to increase magnesium and lower potassium levels. Despite the controls not being a true control for the raked plot, later analysis of foliage from the true control and raked plot (Tables 2 and 3) still showed the same magnesium and potassium differences. All nutrient concentrations in Table 1 are in the range considered satisfactory for growth of *P. radiata,* except for magnesium in the controls which is in the range considered marginal for growth (Will 1978).

TABLE 1—Mean nutrient concentrations (%) at age 5 years in foliage from the raked plot and three control plots in an adjacent fertiliser trial (1964)

Plot	N	P	K	Ca	Mg
Controls	1.49	0.16	0.93	0.24	0.097
Raked	1.50	0.16	0.85	0.26	0.120

At age 16 years just prior to thinning, concentrations of phosphorus, potassium, calcium, boron, and manganese in the current season's foliage were lower in the raked than the control plot, although only the boron concentrations were significantly different (Table 2). Nitrogen, magnesium, copper, and zinc concentrations were all slightly but not significantly higher in the raked plot. In the previous season's foliage collected at the same time concentrations of all elements, except magnesium, were lower in the raked plot, although only the potassium, boron, and manganese concentrations were significantly lower (Table 2). Concentrations of phosphorus, potassium, calcium, manganese, and zinc in the current season's foliage of both plots prior to thinning were

TABLE 2—Mean nutrient concentrations at age 16 years in two age-classes of foliage collected from the control and raked plots prior to thinning

Element	Current season's foliage			Previous season's foliage		
	Control	Raked	Diff.	Control	Raked	Diff.
N (%)	1.375	1.380	+0.005	1.307	1.306	-0.001
P (%)	0.187	0.178	-0.009	0.200	0.185	-0.015
K (%)	1.030	1.018	-0.012	1.022	0.937	-0.085*
Ca (%)	0.171	0.152	-0.019	0.246	0.242	-0.004
Mg (%)	0.077	0.087	+0.010	0.062	0.066	+0.004
B (ppm)	10.6	7.2	-3.4**	8.3	6.2	-2.1**
Cu (ppm)	6.2	6.6	+0.4	6.0	4.7	-2.3
Mn (ppm)	304	203	-101	477	308	-169**
Zn (ppm)	42	45	+3	43	41	-2

* Significantly different at the 5% level
** Significantly different at the 1% level

TABLE 3—Mean nutrient concentrations at age 17 years in current season's foliage collected from control and raked plots 1 year after thinning

Element	Control	Raked	Difference
N (%)	1.256	1.167	-0.089 (10%)
P (%)	0.195	0.198	+0.003
K (%)	1.095	0.904	-0.191
Ca (%)	0.100	0.124	+0.024
Mg (%)	0.093	0.118	+0.025
B (ppm)	16.9	6.8	-10.1**
Cu (ppm)	5.4	5.5	+0.1
Mn (ppm)	181	169	-12
Zn (ppm)	41	39	-2

** Significantly different at the 1% level
(10%) Significantly different at the 10% level

in the satisfactory range; nitrogen in both plots, magnesium in the raked plot, and boron in the control plot were marginal; and magnesium in the control plot and boron in the raked plot were low for normal growth of *P. radiata.*

Samples of current season's foliage taken 1 year after thinning showed significantly lower boron levels in the raked plot (Table 3), although the increase in difference over that recorded before thinning was principally because of an increase in the concentration in the control plot. The nitrogen levels in both plots declined after thinning (dilution effect), but the decline was much more marked in the control plot, giving a difference significant at the 10% level. All other differences were non-significant. The significantly lower level of boron and nitrogen in foliage of the thinned, raked plot is consistent with the dependence of boron and nitrogen supply on organic matter turnover (Snowden 1971). The higher level of magnesium in the foliage of the raked plot is difficult to explain, particularly as exchangeable levels in the soil are lower in the raked plot (*see* Table 4). A possible explanation is that the absence of a litter layer in the raked plot has resulted in a greater concentration of roots in lower soil horizons relatively rich in magnesium. Will & Knight (1968), in an evaluation of the nutrient supply from layers of the soil profile in Cpt 69, showed that while the three layers immediately below the topsoil (encompassing the depth sampled in the current study) contained low levels of magnesium, an old buried topsoil at *c.* 2 m depth contained a good supply, although available levels of other nutrients were low. In this readily penetrable pumice soil, roots should be able to penetrate to layers at 2 m depth within 4 to 5 years.

Soil Properties

A feature of the soil properties is that there are fewer significant differences at the 0–5 cm depth (Table 4) than at the other depths examined, particularly the 5–10 cm depth (Table 5). In some instances this can be attributed to the greater variability in properties at the 0–5 cm depth, but in most cases the differences are actually greater at the lower depths. It would appear that the main differences between soil properties have resulted not from the direct influence of the litter layer, which should have the greatest effect on the surface soil, but the effect of the presence or absence of the litter layer on root distribution. The need for a buffer layer between the zone of major root activity and the inhospitable immediate surface of the forest floor has probably led to the 0–5 cm and 5–10 cm depths being the zones of major root activity in the mineral soil of the control and raked plots respectively.

Although some of the differences anticipated from organic matter removal, such as lower calcium, nitrogen, phosphorus, exchangeable magnesium, CEC, and field moisture levels, appear at the 0–5 cm depth, only differences in total phosphorus and exchangeable

TABLE 4—Mean values for topsoil (0-5 cm) properties of the control and raked plots

Soil property	Control	Raked	Difference
pH	5.09	5.23	+0.14
Bray 2 P (ppm)	79.3	67.2	-12.1
Total P (ppm)	511	478	-33*
Organic P (ppm)	264	247	-17
Total N (%)	0.238	0.231	-0.007
Carbon (%)	5.26	4.92	-0.34
NH_4-N (ppm)	47.9	90.3	+42.4
Exch. K (me/100 g)	0.53	0.60	+0.07
Exch. Ca (me/100 g)	2.25	2.54	+0.19
Exch. Mg (me/100 g)	0.73	0.51	-0.22*
CEC (me/100 g)	29.4	23.2	-6.2
15 Atm. H_2O (%)	10.2	11.3	+1.1
Field moisture (%)	51.4	46.6	-4.8
Bulk density (g/cc)	0.61	0.61	0
Depth A1 horizon (cm)	14.9	15.4	+0.5

* Significantly different at the 5% level

TABLE 5—Mean values for soil properties at three depths in the control and raked plots

Soil property	5–10 cm			10–20 cm			20–40 cm		
	Control	Raked	Diff.	Control	Raked	Diff.	Control	Raked	Diff.
pH	5.47	5.45	–0.02	5.76	5.59	–0.17**	5.84	5.75	–0.09
Bray 2 P (ppm)	37.3	23.9	–13.4**	18.3	15.1	–3.2	13.4	10.5	–2.9*
Total P (ppm)	415	379	–36*	363	338	–24	271	251	–20
Organic P (ppm)	234	213	–21	182	182	0	79	93	+14
Total N (%)	0.171	0.147	–0.025*	0.117	0.106	–0.011	0.054	0.051	–0.003
Carbon (%)	3.56	2.73	–0.83**	2.18	1.85	–0.33*	0.70	0.74	+0.04
Exch. K (me/100 g)	0.47	0.35	–0.12*	0.49	0.33	–0.16**	0.67	0.58	–0.09
Exch. Ca (me/100 g)	1.75	1.21	–0.54*	1.11	0.95	–0.16	0.57	0.71	+0.14
Exch. Mg (me/100 g)	0.46	0.16	–0.30**	0.31	0.10	–0.21**	0.14	0.05	–0.09**
CEC (me/100 g)	20.8	14.9	–5.9*	17.4	11.6	–5.8	11.1	5.9	–5.2**
Field moisture (%)	49.1	42.6	–6.5*	46.1	42.6	–3.5	41.1	40.2	–0.9
Bulk density (g/cc)	0.73	0.76	+0.03**	0.72	0.74	+0.02*	0.78	0.79	+0.01

* Significantly different at the 5% level

** Significantly different at the 1% level magnesium are significant (Table 4). An unexpected feature of the differences at the 0–5 cm depth is the higher, although not significantly, levels of extractable ammonium-nitrogen and exchangeable potassium and calcium in the raked plot. This tends to suggest a lower rooting activity in this zone in the raked plot, although such an explanation is inconsistent with the lower exchangeable magnesium levels in this zone. However, as Will (1967) found that at the 6-month stage of decomposition (the mean residence time of litter in the raked plot) litter had released considerable quantities of potassium, some calcium, and no magnesium, the above explanation still appears reasonable.

The mean depth of the A1 horizon in both plots is very nearly the same. As this is a soil property which changes very slowly with time, it gives support to the assumption that the two main plots possessed similar soil properties prior to imposing the treatments.

Carbon is significantly lower in the raked plot at the 5–10 cm depth (Table 5). Properties closely related to organic matter, such as total nitrogen, CEC, and bulk density, show expected and significant differences at this depth. The lower organic matter content and the speculated greater rooting activity are probably responsible for the lower levels of phosphorus and exchangeable cations in the raked plot. The lower organic matter content and lack of an effective mulching layer, resulting from the litter layer removal, could account for the lower field moisture level which was a consistent feature at all depths, although most pronounced at the 5–10 cm depth – the zone of speculated maximum root activity.

Similar but generally smaller differences occur in soil properties at the 10–20 cm depth. At the lowest depth examined (20–40 cm) the differences in properties are more variable and only Bray 2 phosphorus, exchangeable magnesium, and field moisture are significantly lower in the raked plot, but the magnitude of the differences for these properties is smaller than observed at the 5–10 and 10–20 cm depths (Table 5).

Growth Assessment

Basal area data for the plots in 1965 (Table 6) show the similarity in basal area per hectare at this date just after a light thinning of the control plot to bring about this parity. As the stocking rate was slightly higher in the control plot the basal area per tree was lower in this plot. By 1975 the basal area per tree was almost identical in the two plots but, because of its greater stocking, the basal area per hectare was greater in the control plot.

Regressions of stem volume under bark (u.b.) (Y, m^3) on d.b.h. u.b. (X, mm) were computed for each plot using the 1975 data from the nine trees per plot subjected to stem analysis. A comparison of regression coefficients for the two plots revealed no significant differences between either slopes or intercepts so a regression from the combined data,

$$Y = 0.005\ X - 0.6316\ (R^2 = 0.955)$$

was used to compute the volumes per hectare in 1975 prior to thinning. In 1975, at age 16 years, the control plot contained 535 m^3 of stemwood, which was 64 m^3 more than the raked plot. Since the plots had an almost identical basal area per hectare in

1965, it appears reasonable to assume that the observed volume difference is a real one associated with the treatment rather than the result of stocking or other effects.

The mean heights for the plots in 1975, calculated from the heights of the stem analysis trees, were 25.8 m and 24.6 m for the control and raked plots respectively. These correspond to a Site Index (height in metres at 20 years) of 32 and 31 respectively (Tennent & Burkhart 1977).

It is anticipated, on the basis of the divergence of nitrogen and boron foliar concentrations after thinning, that differences in growth rates between the two plots will increase in the future.

TABLE 6—Growth data for plots prior to thinning in 1975

	1965			1975			
	Stems/ha	Basal area (m^2/ha)	Basal area (m^2/tree)	Stems/ha	Basal area (m^2/ha)	Basal area (m^2/tree)	Volume (m^3/ha)
Control	1125	12.89	0.0115	950	56.64	0.0596	535
Raked	900	12.54	0.0139	825	49.33	0.0598	471
Diff.		−0.35	+0.0024		−7.31	+0.0002	−64

GENERAL DISCUSSION

Baule and Fricker (1970), in reviewing European work on the effects of litter removal on site productivity, reported increment losses ranging from 10% to 70%, depending on the inherent fertility of the site and frequency of litter removal. On the assumption that the volume loss reported in Table 6 is real, then litter and logging debris removal has resulted in a loss in productivity of 12% over 16 years at Cpt 69. Considering the large quantities of nutrient removed from the site, this relatively small loss is a reflection of the good inherent fertility and nutrient buffering capacity of the central North Island pumice soils. It is possible that the small loss in productivity was not associated with reduced nutrient status, but with other effects associated with the removal of the litter layer.

Up to thinning in 1975, foliar analysis data showed the only element to be both significantly reduced in concentration by litter removal and to decline to concentrations considered sub-optimal for *P. radiata* growth was boron. As boron levels in *P. radiata* foliage have been calibrated mainly against deficiency symptoms (meristematic dieback) and not growth, it is difficult to ascertain whether such reduced levels could have caused the observed productivity loss. At the 1975 measurement all stems were visually assessed for malformation; 55% of trees in the raked plot had some form of stem malformation compared to 47% in the control.

Some or all of the productivity loss in the raked plot could have been associated with greater periods of unfavourable moisture and temperature conditions within the root zone resulting from the loss of the "mulch" layer. If so, then the effect on productivity of growing a number of crops, which remove the same amount of nutrients as the raking treatment in this study, will be much less, unless the development of a normal litter layer is interfered with.

The removal of litter from forest sites normally affects productivity through a reduced nitrogen supply (Baule & Fricker 1970). Concentrations of nitrogen in foliage indicate that before thinning the litter removal had had little adverse effect on the nitrogen supply. However, after thinning when the trees' nitrogen requirements increase to meet the needs of expanding green crowns (Madgwick *et al.* 1977), foliar analysis indicated that the capacity of the raked area to meet this increased demand had been impaired. During the years prior to thinning the rate of mineralisation of the soil humus had obviously been sufficient to supply the nitrogen needs of the trees. But mineralisation in the absence of fresh organic matter inputs probably leads to impoverishment of the more easily decomposed organic compounds so important in nitrogen nutrition (Keeney 1980). Thus, despite the occurrence of conditions favourable to rapid mineralisation after thinning, the amount of readily decomposable soil humus present is apparently insufficient to fully meet the increased demands of the trees. It is anticipated that this restricted nitrogen supply in the raked plot will lead to a detectable reduction in growth within 3 to 5 years after thinning.

Using an exhaustive cropping experiment in the greenhouse, Will & Knight (1968) concluded that the soil profile in Cpt 69 contained sufficient phosphorus, magnesium, and nitrogen for only one or two more crops, but enough potassium and calcium for several more crops. Comparing amounts of nutrients removed in rotation equivalents with effects on foliar nutrient concentrations in the present study indicates that supplies of phosphorus and nitrogen should be adequate for more than one or two crops. Even after removing phosphorus equivalent to that in three harvests, foliar concentrations are still well above the marginal range (0.12% to 0.14%) and Bray 2 phosphorus levels, although they declined significantly, are also well above marginal levels (9 to 12 ppm). The high total phosphorus and Bray 2 levels indicate that phosphorus supplies are unlikely to be a problem on this soil type for several rotations. Nitrogen supplies, although marginal even without further depletion, are well buffered. Since nitrogen depletion under conventional management should not occur solely at the expense of the readily mineraliseable nitrogen fraction, as it did in this study, it would appear that nitrogen supplies in this soil should be sufficient to sustain nitrogen supply at close to current levels for several rotations. It also appears that the magnesium is unlikely to be a future problem, at least during periods when the root systems are "tapping" the old buried topsoils. However, as the exchangeable levels in the upper horizons will fall off more rapidly over successive rotations than other cations (because of the low reserves of magnesium) magnesium deficiencies may ultimately become a real problem in the early rotational stages.

The discrepancies between these predictions and those of Will & Knight (1968) can be attributed to (1) the more contracted time of their depletion treatment – 4 years *v.* 16 years in the current study, and (2) the use of seedlings in a greenhouse study to simulate the effect of trees in the field, i.e., seedlings tend to rely on different forms or fractions of some soil nutrients for their supply (*see* Ballard & Pritchett 1975).

The technique of using litter removal to obtain a relatively rapid assessment of the effects of organic matter and nutrient losses in harvesting several crops obviously has drawbacks, the principal one being that some of the effects observed are probably due to the lack of a litter layer which would be present under conditions the treatment is attempting to simulate. However, the results do show the general resilience (buffering capacity) of the nutrient supply of the Kaingaroa silty sand. They also indicate that on soils with low nutrient reserves, levels of available or exchangeable nutrients will drop quite dramatically with successive crops. For instance, in this well-buffered Kaingaroa soil, phosphorus removed by the equivalent of three crops reduced available phosphorus concentrations in the surface 10 cm by around 12 ppm. In many of the soils being used or available for forestry in New Zealand, Bray 2 phosphorus concentrations are less than 12 ppm, and total phosphorus concentrations are also very low (Ballard 1974). On soils with a fragile nutrient status, nutrients lost in harvest products must be replaced if productivity is to be maintained.

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