INFLUENCE OF CLEARFELLING ON DECOMPOSITION OF *PINUS RADIATA* LITTER

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ABSTRACT

Two experiments investigating the effect of clearfelling on decomposition of **Pinus radiata** D.Don litter are described. The first was a field trial in which **P. radiata** trees were felled without disturbance to the litter layer. Small plots were laid out in the clearfelled area and in an adjacent closed-canopy stand. Screens of shade cloth were erected over the plots. Of the litter originally present Degree of shading had no effect on litter decomposition. In the second experiment, cuttings of **P. radiata** were planted in troughs designed to expose weighed experimental litter to the influence of plant roots but not to the influence of plant tops. Shades were placed over the trough surfaces and the plants grown until mycelial wefts were visible in the litter. Twenty-four troughs were then selected and plants in 12 of them were severed at litter level. Six troughs containing a growing plant and six with a "felled" plant were placed in a growth room simulating the climate of an open, clearfelled area. A similar set was placed in another room simulating the climate under a closed-canopy pine stand. Shades were removed from the troughs in the "open" climate room. All troughs were watered to field capacity daily. After 6 months, significantly more litter remained in the troughs with intact plants than in those where the plants had been "felled", irrespective of whether they were in the "open" or in the "forest" climate room. The first experiment suggested and the second experiment confirmed that the biological changes resulting from clearfelling, including the removal of mycorrhizal root influence, were more important in increasing litter decomposition than the physical effect of the change in climate.

INTRODUCTION

It has been shown that the decomposition of *Pinus radiata* D.Don litter is suppressed if mycorrhizal roots have access to the litter layer (Gadgil and Gadgil, 1971; 1975). In the experiments which led to this conclusion, the influence of mycorrhizal roots was controlled either by repeated severance along the boundaries of small plots (field experiments) or by the use of non-mycorrhizal seedlings (laboratory experiment). It seemed reasonable to expect that any silvicultural operation (e.g. clearfelling) which reduces the amount of living ectomycorrhizal tree roots in the ecosystem would also accelerate the decomposition of litter.

Clearfelling undoubtedly frees large areas of the forest floor from the influence of mycorrhizal roots, but it also changes the physical environment. Tamm (1950) has drawn attention to the possible increased influence of solar energy and rain on litter

decomposition and to the fact that clearfelling adds large quantities of fresh litter and dead roots to the system. Kühnelt (1961) placed emphasis on (a) the increased magnitude of fluctuations in temperature and moisture and (b) the physical disturbance of the forest floor. Süchting and Christmann (1935), in their study on spruce litter decomposition after clearfelling, concluded that changes in temperature and water relations in the litter and soil, vigorous growth of weeds and mixing of the litter with soil all lead to more rapid decomposition. Wittich (1930) considered that the changes in microclimate and the type of vegetation that follows clearfelling are important in determining the rate of litter decomposition.

Observations on clearfelled areas are hampered by problems of sampling litter which has been disturbed by felling and extraction operations. Thus, although it is assumed that litter decomposition is accelerated by clearfelling (e.g. Stone, 1973), few data are available to demonstrate an increased decomposition rate. Süchting and Christmann (1935) give values of 11.3 and 9.5 kg/m^2 for the dry weight of spruce litter in a mature stand and in a 3- to 4-year-old clearfelled area, respectively. Grunda (1964) found that microbial activity in a mature spruce/fir stand was low and that fungi formed a large proportion of the microflora. After clearfelling, increased numbers of bacteria and increased rates of nitrification and CO_2 evolution provided evidence of greater microbial activity.

In this paper we describe the results of two experiments designed to examine the effect of clearfelling on litter decomposition. The first was a field trial in which care was taken to avoid litter disturbance while the trees were felled. The second was done in controlled climate growth rooms so that the effects of (i) biological changes and (ii) climatic changes brought about by tree felling could be studied separately.

FIELD EXPERIMENT

Methods

The trial was carried out in the Fenton's Mill block of Tasman Forest near Kawerau (50 km east of Rotorua). In this block, certain areas in a *P. radiata* spacing trial are clearfelled at intervals by research staff and the trees are measured *in situ*. No extraction is carried out and disturbance of soil and litter is therefore minimal.

Two hexagonal areas, each of 0.06 ha with a 0.12-ha surround were selected for this study. Both carried 11-year-old *P. radiata* planted at 2.1 × 2.1 m spacing and about 20 m in height. Canopy had closed at about age 5. In the area selected for clearfelling in 1974, heavy wooden covers were placed on the forest floor to protect the litter study sites. Trees were then felled away from these covers and the covers were removed when the tree measurements were complete.

In November 1974, within a week of clearfelling, two groups of 3 plots, each 1 × 1 m, were marked with pegs and string on the protected part of the cleared area. Six plots were similarly marked between the trees in the stand area. Litter from each plot was carefully removed (L and F layers together) and with minimum disturbance placed on a 1.5 × 1.5 m hardboard sheet for weighing. It was then replaced. In both areas, the litter layer was distinct from the mineral soil. Comparable litter samples were taken outside the plots for moisture content determination. The dry weight of litter on each plot was estimated from these determinations. All the litter examined was permeated with fungal mycelium.

Each plot was then covered with a screen of shade cloth set in a 2 × 2 m wooden frame and supported 0.5 m above the litter surface. Three grades of shade cloth giving heavy, medium or light shade were used. Light shade was provided by a finely woven white cloth and medium and heavy shade by coarse and fine woven black cloth respectively. The percentage of light (400-700 nm, measured by IL 150 photometer, International Light Inc., Newburyport, USA) admitted by the shade cloths was: Light 33.5%, Medium 19.5%, Heavy 12.4%. Only 2% of the light reached the forest floor under the natural tree shade. The shades were used (i) to give some idea of the influence of insolation on litter decomposition and (ii) to prevent fresh litter from falling on the plots. Heavy, medium and light shades were randomly assigned to plots in each group of three. The shades were cleared of debris every 4 weeks.

By March 1975, many herbaceous plants were growing in the clearfelled area. An estimate of weed cover was made for each plot and because it was necessary to minimise differences between plots, the weeds were then carefully removed. The resulting litter disturbance was minimal because most of the plants had a rosette habit and each individual covered a relatively large area. The tap root was easily removed if the litter beneath the leaves was held firmly in place.

Estimation of weed cover and plant removal was repeated during the April visit, when it was noted that large numbers of fruiting bodies of an agaric had developed in the stand area. The fungus was isolated and an attempt was made to synthesise mycorrhizas in *P. radiata* seedlings using a pure culture of the fungus. A count of fruiting bodies in each plot was made. From May onwards growth of weeds and fruiting bodies in the plots was negligible.

After one year (November 1975) the litter in each plot was carefully removed and the oven dry weight determined. Some difficulty was experienced in separating litter from the mineral soil in the cleared area plots because the litter texture had changed. Dried material from each plot was therefore subsampled by a quartering technique and the amount of organic matter present was estimated by determining the weight loss on ignition at 450°C.

RESULTS

Observations on the flora of the two areas

The weed cover which developed in the clearfelled area consisted mainly of seedlings of grasses and rosette-forming dicotyledons. It was less dense or absent within 2 m of the growing trees surrounding the area. No weed growth was observed in the stand area.

The fungal fruiting body distribution in the stand area was similar to other parts of the forest and in this respect the experimental plots were not distinguishable from the rest of the forest floor. No fruiting bodies were found in the clearfelled area except in the peripheral zone (about 2 m from the base of the growing trees). The fungus was identified as a species of *Inocybe* and mycorrhizas were successfully synthesised in *P. radiata* seedlings from pure fungus cultures using the method of Trappe (1967).

There was no consistent relationship between weed cover or number of fruiting bodies and the degree of artificial shading in either area.

Litter decomposition

After 12 months the litter in the cleared area plots was found to be loose and friable and there was no clear separation into L and F layers. By contrast, the litter in the stand area plots was thick and permeated with visible fungal mycelium. Large, unfragmented sections of needles were present and L and F layers were easily distinguishable. These differences are shown in Fig. 1.

During the course of the experiment it was noticed that some needles fell through the coarse-textured cloth which provided the medium shade. Litter weight results from the medium shade plots were therefore unreliable and only those from the heavy and light shade plots were used (Table 1a). Analysis of variance indicated that clearfelling had a significant effect on the rate of litter decomposition, whereas artificial shading did not (Table 1b). Of the litter originally present in the plots, 42% remained in the stand area and 31% in the clearfelled area.

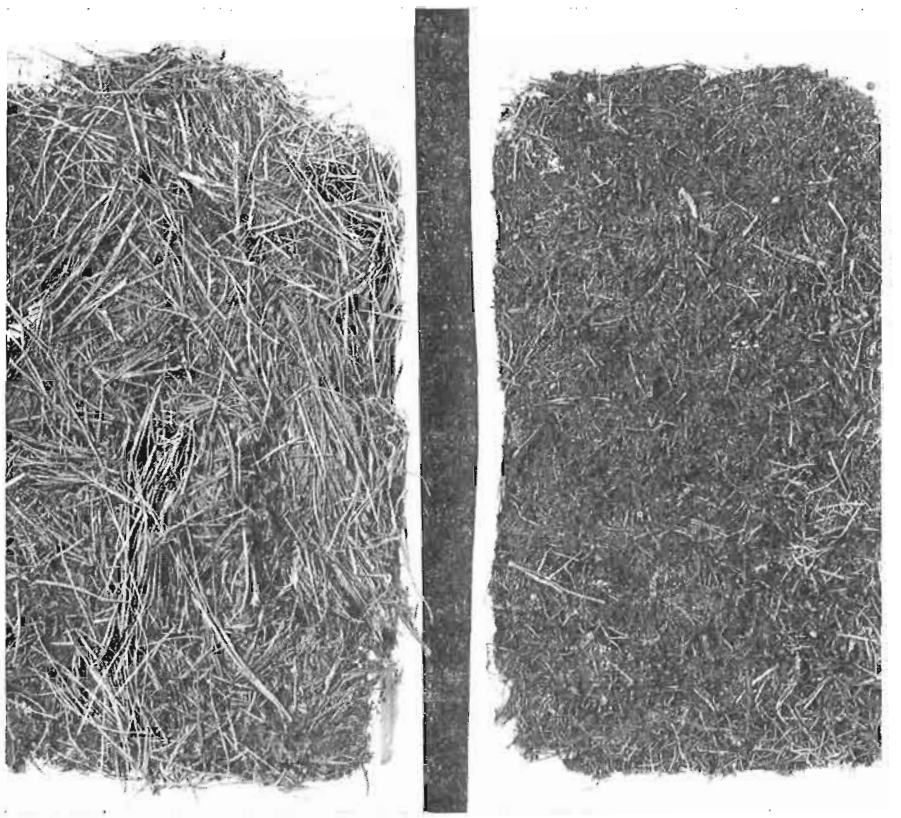

FIG. 1—Physical appearance of the litter at the end of the field experiment.

Left: Litter from the closed-canopy stand. Whole needles are still present.

Right: Litter from the clearfelled area. Note the absence of large needle fragments and the even texture.

TABLE 1a—Field experiment. Dry weight of litter in 1 × 1 m plots (organic matter only)

Shade type	Plot no.	Weight at beginning of experiment (kg)	Weight at end of experiment (kg)	Percent litter remaining
CLEARFELLED AREA				
Heavy	1	1.30	0.42	32.30
	6	2.24	0.85	37.95
Light	3	2.85	0.90	31.58
	5	2.28	0.54	23.68
STAND AREA				
Heavy	1	3.09	1.28	41.52
	6	2.52	1.14	45.24
Light	3	2.62	1.15	43.89
	4	2.38	0.93	39.08

TABLE 1b—Summary of analysis of variance showing degrees of freedom (df) and mean square ratios (MSR)

Source of variation	df	MSR
Clearing (C)	1	14.74*
Shade (S)	1	2.64 NS
C × S	1	0.96 NS
Residual	4	—

* $P < 0.05$ NS $P > 0.05$

CONTROLLED CLIMATE EXPERIMENT

METHODS

Rooted cuttings of *P. radiata* were grown in specially constructed PVC troughs, each fitted with a drainage outlet and a perforated PVC barrier designed to separate the litter in the "plant" compartment from that in the "experimental" compartment. The "experimental" compartment litter would be subject to influence by the roots but not the tops of the plants (Fig. 2).

Litter (L and F layers separately) and mineral soil (0-30 cm) were collected from a *P. radiata* stand in Fenton's Mill block. Each litter sample and the soil sample was thoroughly mixed and root fragments were removed. Sub-samples of litter were taken for the determination of moisture content and loss on ignition.

Two-year-old rooted cuttings of two clones of *P. radiata* (16 plants per clone) were selected for uniformity and compact growth. Root tips in both clones were dichotomously branched and bore evidence of hyphal sheathing. The plants of clone A had better developed root systems than those of clone B but there were no other

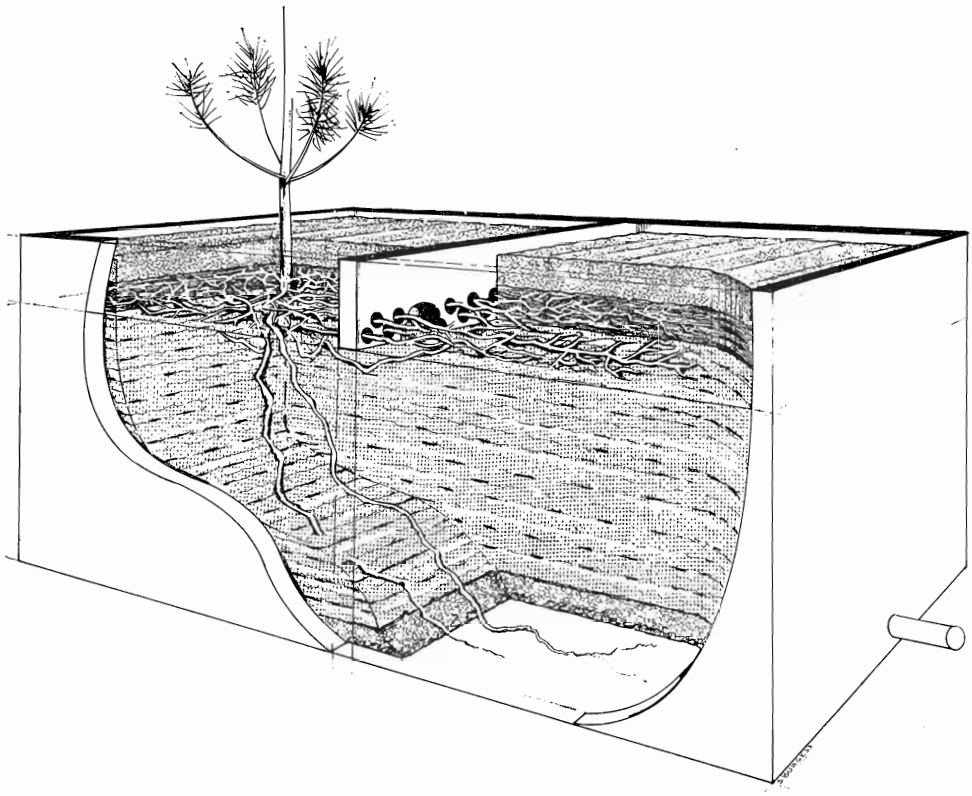

FIG. 2—Diagram of trough used in the controlled climate experiment. Dimensions 35 cm long × 15 cm wide × 15 cm deep.

obvious differences. A 2-cm layer of washed pumice chips was placed in the bottom of each trough and a plant was placed in the compartment furthest from the drainage hole. The trough was packed with soil to the base of the barrier and the soil was brought to field capacity with deionised water. F-layer litter (115.0 g wet weight) followed by L-layer litter (75.0 g wet weight) was spread evenly on the soil surface in each half of each trough and pressed down firmly.

Pretreatment Phase

Troughs were covered with fine-woven black shade cloth and placed in a glasshouse, Both halves of the troughs were watered to field capacity with deionised water every second day. To avoid influence of nutrients on experimental litter, any leachate was returned at the next watering to the "plant" compartment only. Nutrient deficiency symptoms observed shortly after planting were corrected by watering the "plant" compartment of each trough with a nutrient solution (12 ml) containing 16.0 g NH_4NO_3, 10.4 g $NaH_2PO_4,2H_20$ and 18.4 g $MgSO_4,7H_2O$ per litre. Any leachate was returned as before.

The object of this phase of the experiment was to establish a litter layer in the "experimental" compartment of each trough which would be moist, shaded and permeated with fungal hyphae. In these respects it would resemble forest floor litter in a closed-canopy tree stand. After 3 months in the glasshouse (December 1975), examination showed that the required conditions were not being achieved. In order to improve the moisture content of the litter, the L-layer material was removed and the needles cut into segments about 2.5 cm long. A further 115.0 g of F-layer litter was added to each half of each trough and the L-layer litter was replaced. Trough surfaces were then covered with a double layer of black shade cloth and transferred to a growth room to stimulate root development by more suitable growth conditions (see Table 2). Nitrogen deficiency symptoms which appeared on the change of environment were corrected by addition of NH_4NO_3 (16.0 g/litre, 4 ml/trough) to the "plant" compartment of each trough. After a further 3 months (April 1976), fungal mycelium bearing clamp-connections had permeated the litter in most of the troughs.

Experimental Phase

Twelve troughs of each clone were selected on the basis of good fungal development in the litter. Six plants of each clone were severed at the litter level and the tops discarded. Using a randomised block layout, 3 troughs containing an intact plant of each clone and 3 troughs containing a "felled" plant of each clone were placed in a growth room set to simulate the climate of an open, clearfelled area (Table 2). A similar set of 12 troughs was placed in another growth room set to simulate the climate of a closed-canopy stand at forest floor level (Table 2). These climates were based on data reported in Geiger (1965) and on summer climate records collected from a recently planted stand and a closed-canopy stand in Kaingaroa State Forest (Weston and Jackson, unpublished data). The shades were removed from troughs in the "open" climate room to expose the litter to the influence of light. In the "forest" climate room the shades were raised from the tops of the troughs so that shade conditions were maintained but air circulation over the litter surface was not impeded.

TABLE 2—Controlled climate data

	"Forest" climate simulation (including pretreatment phase)		"Open" climate simulation	
	Day	Night	Day	Night
Temperature (°C)	21	12	23	9
Vapour pressure deficit (mb)	7	1	14	1
Relative humidity (%)	72	92	50	91
Light intensity (W/m^2 400-700 nm)				
At plant top height	180	—	180	—
Under raised shades	70	—	No shades	—
Photoperiod (h)	16	—	16	—

Troughs were now watered to field capacity daily to minimise moisture differences caused by climate regime or plant top removal. Both litter compartments were watered as in the pretreatment phase.

After 6 months (October 1976) the litter in the "experimental" compartment of each trough was removed, oven dried at 70°C and weighed. Loss on ignition at 450°C was also determined. Data were subjected to analysis of variance.

RESULTS

Dry weight data corrected for mineral soil inclusion (Table 3a) show that troughs with intact plants contained more litter than those in which the plants had been "felled". Climate and clonal effects were not significant (Table 3b).

Growth of weeds (which were removed regularly) was confined to three "felled" troughs in the "forest" climate room and to five "felled" and one "plant present" trough in the "open" climate room. Fungal fruiting body development was observed in three troughs containing intact plants of clone A in the "forest" climate room. In the "forest" climate room, mycelial development in the litter was very much greater in

TABLE 3a—Litter dry weights (g) at the end of the controlled climate experiment (organic matter only)

	"Forest" climate		"Open" climate	
	Growing plant present	Plant top removed	Growing plant present	Plant top removed
Clone A	50.00†	40.83	49.11	44.06
Clone B	49.78	43.38	50.57	42.76
Mean	49.89	42.11	49.84	43.41

† Mean of litter dry weights from the "experimental" compartment of 3 troughs

TABLE 3b—Summary of analysis of variance, showing degrees of freedom (df) and mean square ratios (MSR)

Source of variation	df	MSR
Clones (C)	1	0.33 NS
Environment (E)	1	0.33 NS
Plant (P)	1	43.10 **
C × E	1	0.25 NS
P × E	1	0.38 NS
P × C	1	0.00 NS
C × P × E	1	1.60 NS
Residual	16	—

** $P < 0.01$ NS $P > 0.05$

troughs which contained plants than in the "felled" troughs. The difference was not so marked in the room with the "open" climate where mycelial development was generally lower although the troughs with plants had more mycelium than the "felled" troughs (Table 4).

TABLE 4—Weeds, liverworts and percent mycelial cover (area of litter obviously colonised by fungal hyphae, estimated visually) in the "experimental" compartments of troughs at the end of the controlled climate experiment (figures are means of 6 troughs)

	'Forest' climate			'Open' climate		
	Weeds	Liverworts	Mycelium (%)	Weeds	Liverworts	Mycelium (%)
Growing plant present	0	0	92	0.5	0	43
Plant top removed	0.3	1.0	12	0.7	1.7	19

DISCUSSION

The field experiment showed that at the end of the experimental period significantly less litter remained on plots in the clearfelled area than that on plots sited under trees. Since the basidiomycetous mycelial mat which was conspicuous in the litter under the trees was absent from the litter in the clearfelled area, the difference in the litter weights between the two areas could be at least partly due to the mycelial biomass. Data for mycelial biomass in forest litter are extremely limited. Stark (1972) estimated that under a *Pinus jeffreyi* Grev. et Balf. stand, fungi accounted for 0.14-0.53% of the litter weight. The basis on which the estimate was made is not clear.

Harmsen *et al.* (1974) estimated that 1 g of birch forest topsoil contained 3 000 m of hyphae. Working on the quite arbitrary assumption that 1 g *P. radiata* litter might also contain 3 000 m of hyphae, only 12% of the mean weight difference between the clearfelled and stand areas would be accounted for*. The lower weight of litter in the clearfelled area can almost certainly be ascribed to increased litter decomposition. Litter disturbance was no greater in the clearfelled area than in the stand area and mixing of litter with soil was not a factor affecting litter decomposition in the field experiment. The increased rate of decomposition can only be attributed to the removal of the influence of living trees. Removal of trees undoubtedly changed the microclimate at the litter surface and this might be expected to have an influence on litter decomposition. In the field experiment, shading had no effect on litter decomposition. Similarly, in the controlled climate experiment, climate modification did not affect litter decomposition rate. These results suggest strongly that, in our experiments, the biological changes resulting from clearfelling were more important than the physical effect of climate modification.

* Based on further estimates from Harmsen **et al.** (1974): Diameter of hyphae: 5 μm, dry matter content: 17%, density: 1.3 g/cm^3. Final litter weight in the clearfelled area was 11% less than that in the stand area in our experiment.

TABLE 5—Comparison of litter weight data from clearfelling and root exclusion studies in **Pinus radiata** forests. Dimensions of all plots were 1 × 1 m, and duration of experiment was 12 months

Experimental area		Treatment	Climate over exptl period			Soil type	Mean dry weight of litter (kg)			Reference
Location and altitude	Tree Age (yr)		Rain fall (mm)	Rain days (>0.2 mm)	Mean Temp (°C)		Treated plots	Control plots	Treated / Control × 100	
Tasman Forest 60 m a.s.l.	11	Plots sited in clearfelled area	1946	152	13.7	Tarawera gravel	0.68	1.13	60	This paper
Latitude 38°08'S										
Kaingaroa State Forest 550 m a.s.l.	10	Tree roots excluded from plots within stands	1759	151	11.7	Taupo silty sand, upland phase	0.66	1.68	39	Gadgil and Gadgil, 1971
Latitude 38°24'S										
Kaingaroa State Forest	22	Tree roots excluded from plots within stands	1339	150	10.8	Taupo silty sand, upland phase	2.10	4.69	45	Gadgil and Gadgil, 1975

One of the main biological effects of clearfelling would be expected to be the death of mycorrhizal roots and mycorrhizas. The absence of the fruiting bodies of the mycorrhiza-forming *Inocybe* sp. from the clearfelled area and the disappearance of the basidiomycetous mycelium from the litter layer suggest that mycorrhizal roots and mycorrhizas were not active in the clearfelled area. It has been previously shown that reduction in the activity of mycorrhizal roots was associated with increased litter decomposition (Gadgil and Gadgil, 1971; 1975). This finding and the results of the present experiments indicate that release from the mycorrhizal influence after clearfelling was the major biological change which led to increased litter decomposition. In the controlled climate experiment particular care was taken to see that the treatments were not associated with long-term differences in moisture level and it is unlikely that differential availability of moisture was an important part of the biological influence on litter decomposition rate. Weeds which appeared in the clearfelled area were regularly removed from the experimental plots and their growth is unlikely to have influenced litter decomposition.

Our observation that visible mycelial development was reduced in the litter of the clearfelled area agrees with that of Tvorogova (1971). From studies with Rossi-Cholodny slides in a spruce forest she reported that fungi were more prolific in the soil under a forest stand while bacteria and actinomycetes were more numerous on clearfelled sites. Although not conclusive, these observations are compatible with the hypothesis that a saprophytic microflora develops in the litter of a clearfelled area from propagules of organisms which were present in the tree stand but suppressed by the mycorrhizal mycelia.

The increased rate of litter decomposition after clearfelling has been attributed to changes in local climate by a number of workers (e.g. Stone, 1973; Hornbeck *et al.*, 1975). We suggest that the release of the saprophytic micro-flora from mycorrhizal suppression provides an alternative and more convincing explanation. In temperate regions, climatic changes occurring after clearfelling involve increased temperature and moisture fluctuations (Geiger, 1965) which do not necessarily favour microbial activity. In this context it is interesting to note that in our experiments, the increase in litter decomposition after clearfelling was much less than the increase in litter decomposition obtained when mycorrhizal roots were excluded from areas within stands over a similar period (Table 5). It would appear that where mycorrhizal influence is reduced, the even climate under a closed-canopy stand is more favourable to the activity of litter decomposing organisms than the fluctuating climatic conditions of a clearfelled area.

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