

Effects of Fire on Nitrogen in Forest Floor Horizons¹

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ABSTRACT

The effects of burning on nitrogen (N) losses and transformations in red pine (*Pinus resinosa* Ait.), eastern hemlock [*Tsuga canadensis* (L.) Carr.], and Douglas-fir (*Pseudotsuga menziesii*) / western larch (*Larix occidentalis* Nutt.) forest floor were investigated. Organic horizon samples were burned at 400°C for 30 min in a top-heating oven to simulate field conditions. Measurements taken immediately after burning showed total and available N losses from the O₁ horizons but gains in total and available N in underlying layers. After burning, the litter was incubated for 5 weeks and analyzed for ammonium and nitrate concentrations and changes in acidity. Each forest floor type displayed varying patterns of ammonification, nitrification and immobilization of N. The N changes appeared related to the differing initial N contents of the organic material.

Additional Index Words: nitrification, ammonification, volatilization, red pine, hemlock, Douglas-fir.

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FIRE HAS BEEN USED as a forest management tool for many years. Recently, questions have been raised as to the environmental impact that fire may have on the forest ecosystem. One small but important aspect of this concern deals with the effects of fire on soil nitrogen (N). Fire affects soil N levels either directly by volatilization and oxidation of N present in soil organic matter, particularly the forest floor horizons, or indirectly, by altering soil chemical and physical properties which affect N transformations (Wells, 1971).

Conflicting reports have been made on the effects of fire on total soil N. Isaac and Hopkins (1937) reported that burning slash after logging caused the loss of an equivalent of 450 kg/ha of N from the site. Presumably this N was lost as N₂ gas to the atmosphere (Debell and Ralston, 1970). Studies have shown that ammonium is readily decomposed to elemental N

and water at temperatures near 700°C (Bailar et al., 1965). Such temperatures have been produced by fire just below the soil surface (Ralston and Hatchell, 1971). The amount of N lost by volatilization depends upon the intensity of the burn with hotter fires causing greater losses (Alway and Rost, 1928; Knight, 1966). In contrast, reports of N increases after burning have been made (Garren, 1943; Lunt, 1951), and may be due to greater nonsymbiotic N-fixing activity in burned soils (Jorgensen and Hodges, 1970) or by the possible occurrence of legumes on these sites after burning (Vogl, 1974).

The lack of agreement as to whether fire increases or decreases total N may be attributed to the methods used in each study. Knight (1966) reported that burning of the forest floor increased the N concentration of the residual material, but the total amount of N decreased. Another point of confusion is the time of sampling after a fire. Studies have indicated that total N increased slightly immediately after fire and declined over a 1-year period (Neal et al., 1965; Sopper, 1975). Limited sampling at one point in time rather than systematically over a longer period may account for the discrepancy between reported increases and decreases in total N.

Fire also affects available N levels by influencing N transformations in the soil. Burning has caused ammonium (NH₄) concentration increases in underlying humus and mineral soil layers (Viro, 1974). The mechanism causing ammonium release would presumably be the direct heat oxidation of organic materials or increased microbial activity following the fire (Wells et al., 1979). Nitrate (NO₃) is not believed to be increased directly by burning but a rise in NO₃ levels sometimes occurs after the burn due to greater nitrification rates (Christensen, 1973). Again, however, the element of time in these studies has not been given proper attention. In many studies, it is not clear how much time had elapsed between cessation of burning and soil sampling.

This paper reports on a study designed to investigate the immediate effects of burning and subsequent changes due to microbial activity on levels of available and total N in forest litter. The organic horizons from three forest stands having a range of N content were used: Red pine (*Pinus resinosa* Ait.) — low N, eastern hemlock [*Tsuga canadensis* (L.) Carr.] — medium N, Douglas-fir/western larch (*Pseudotsuga menziesii*/Larix occidentalis Nutt.) — high N.

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Table 1—Temperatures attained at different soil depths in burned pots.

Forest floor type	Horizon	Depth, cm	Temperature range, °C
Red pine	O1	0-3	400°-204°
	O21	3-7	204°- 66°
	O22	7-9	66°- 52°
Hemlock	O1	0-5	400°-316°
	O2	5-9	316°-149°
Douglas-fir/western larch	O1	0-6	400°-316°
	O2	6-9	316°-149°

METHODS AND MATERIALS

Sample Preparation

Forest floor samples were obtained from randomly selected points in a red pine plantation near Houghton, Michigan, an eastern hemlock stand near South Range, Michigan, and a Douglas-fir/western larch stand on the Coram Experimental Forest in western Montana. Samples were taken to the lab where both O1 and O2 horizon samples from each area were leached with 1 liter of distilled water/kg of material in a size 7 Bauchner-style table top funnel connected to an aspirator. The organic layers were air-dried and mixed in a blender at low speed to break up large pieces and reduce variability with samples. A reduction in heterogeneity of samples was desired to lessen sample numbers facilitating processing after burning.

Seventy-two 7.5-cm clay pots were filled with the blended organic material to approximate original horizon depth and position. Fresh and oven dry weights (105°C) were recorded to determine moisture content.

Litter Burning

Thirty-six pots were subjected to burning in a manner simulating a forest fire (DeBano et al., 1970). The heating elements were preheated to 400°C and samples burned for 30 min. Two

disposable microslides painted with strips of Tempilaq temperature indicator ranging from 38 to 400°C were included in each pot to estimate maximum temperatures attained at different depths in the litter. The remaining 36 unburned pots served as controls.

Immediately after burning, three composite samples of two pots each were taken from burned and unburned forest floor for measurement of pH and levels of NO_3^- and NH_4^+ . Two horizons (O1, O2) were designated in the hemlock and Douglas-fir/western larch samples and three horizons (O1, O1, O22) in the red pine samples. The O1 horizon in all cases was the actual O1 (litter layer) that was found in the field. The O21 and O22 horizons, although made up of the same O2 materials, were established on the basis of temperatures attained during the burn. A temperature range of 52-66°C was used to define the O22 horizon because it was the lowest temperature range indicated by the Tempilaq in the pots. The remaining O2 material was designated as O21. Table 1 shows the relationship of horizon, temperature, and sampling depth. Unburned control pots were sampled at depths which approximated the sampling zones in the burned pots. Each horizon from both burned and control pots was analyzed for total nitrogen content.

The weight loss of forest floor materials due to burning was determined for each horizon so that NH_4^+ , NO_3^- , and total-N levels could be expressed on an original sample weight basis. These were calculated using the following formula:

$$\text{original value} - \% \text{ weight loss} = \text{corrected value.}$$

This was done in order that both burned and control values would be expressed on an equal weight basis to more clearly detect the effects of fire on soil nitrogen levels.

Incubation Studies

After the burn, the remaining 48 pots of each forest floor type received 0.5 cm of distilled water to simulate rain and were incubated at 20°C for from 3 days to 5 weeks. At 3 days, 1, 2, and 5 weeks after burning, six burned and six unburned pots were again sampled for pH, NO_3^- , and NH_4^+ content.

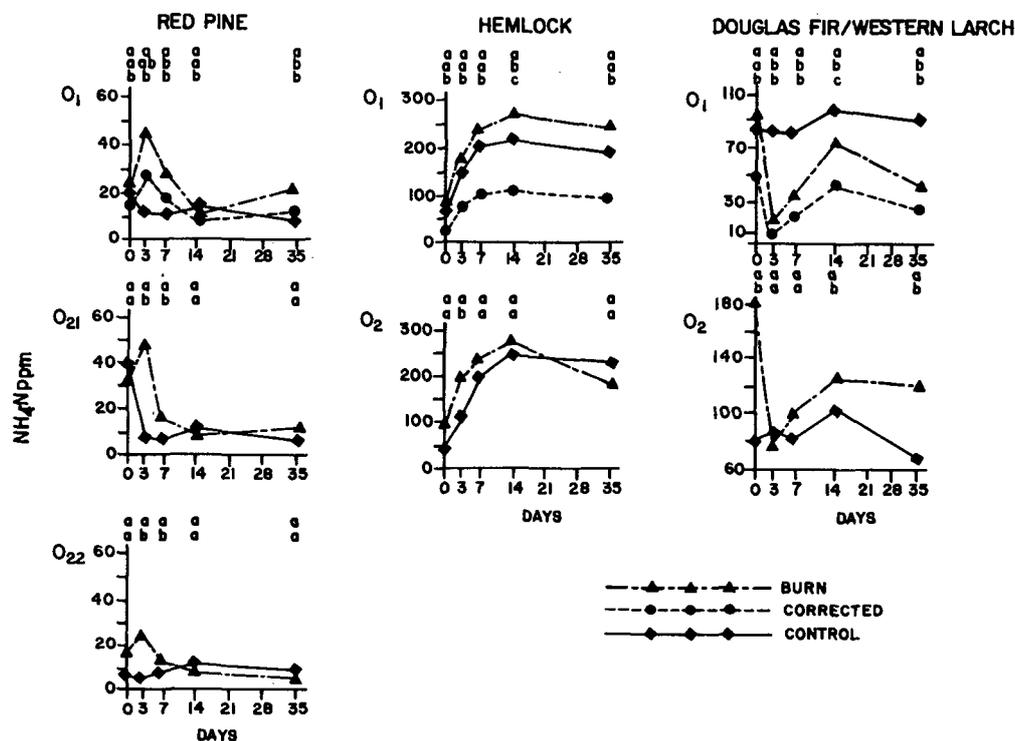


Fig. 1—Effects of burning on $\text{NH}_4\text{-N}$ concentrations in forest floor horizons [significant differences ($p=0.05$) between values obtained at a specified number of days are indicated by *a*, *b*, or *c*. Similar letters indicate nonsignificance while dissimilar letters indicate significance].

Chemical Analyses

Orion specific ion electrodes were used in conjunction with an Orion 701 meter to determine NH₄ (Banwart et al., 1972) and NO₃ (Bremner et al., 1968) levels in each sample horizon. The pH of the organic layers was determined electrometrically on a 1:4 sample/water mixture.

The organic samples were dried at 35°C for 48 hours and ground using a Wiley Mill to pass through a 40-mesh sieve. Total N content was determined by macro-Kjeldahl techniques using the NH₄ electrode modification (Bremner and Tabatabai, 1972).

Statistical Analyses

The statistical tests used to analyze data were the classical 1, 2, 3, and 4 way analysis of variance using the *F-test* for significance (Sokal and Rohlf, 1969). The Duncan Multiple Range Test at the 0.05 probability level was used for grouping data (Duncan, 1955).

RESULTS

A three-way analysis of variance tested the effects of burning on NH₄, NO₃ and pH (dependent variables) as related to litter type, horizon, and incubation time (independent variables). The Multiple Range test was used to indicate differences between burn and control for NH₄, NO₃, and pH levels of each litter type (Fig. 1-3). The letters at the top of each graph correspond to the points for that time. Points corresponding to the same letter are not significantly different (*p* = 0.05).

Red Pine

Ammonium—Ammonium concentrations of the burned O1 horizon were not significantly lower than

in the control immediately after burning (Fig. 1). Subsequent activity of ammonifying organisms is shown by the rapid increase in NH₄ levels 3 days after the burn. The NH₄ concentrations gradually decreased until after 14 days they had returned to control levels. Control values for this same time period decreased sharply in all horizons, probably due to rapid assimilation of NH₄ by microorganisms after the addition of water. However, NH₄ concentration in the burned horizons was not a good indicator of N lost during the fire. Correcting the NH₄ values for sample weight loss showed that burning did cause significant lowering of NH₄ concentrations in the O1 horizon. Ammonium concentrations in the burned O21 and O22 horizons were not different than control at time 0 but were significantly higher after 3 and seven days of incubation.

Nitrate—In contrast to the NH₄ results, NO₃ concentrations showed a significant increase immediately after burning in the O1 and O21 horizons (Fig. 2). However, when NO₃ levels in the O1 were corrected for weight loss, burn and control treatments were the same. Nitrate levels in the O1 and O21 horizon remained significantly different than control values during the initial part of the incubation period possibly because of nitrification. Nitrate concentrations were similar to controls in O22 horizons.

pH—The pH in the O1 horizon increases significantly due to burning (Fig. 3). There was also a subsequent increase in pH at 3 days after which it stabilized for the duration of the study. This pH rise may be related to the increased ammonification during this period. Although the data are not pre-

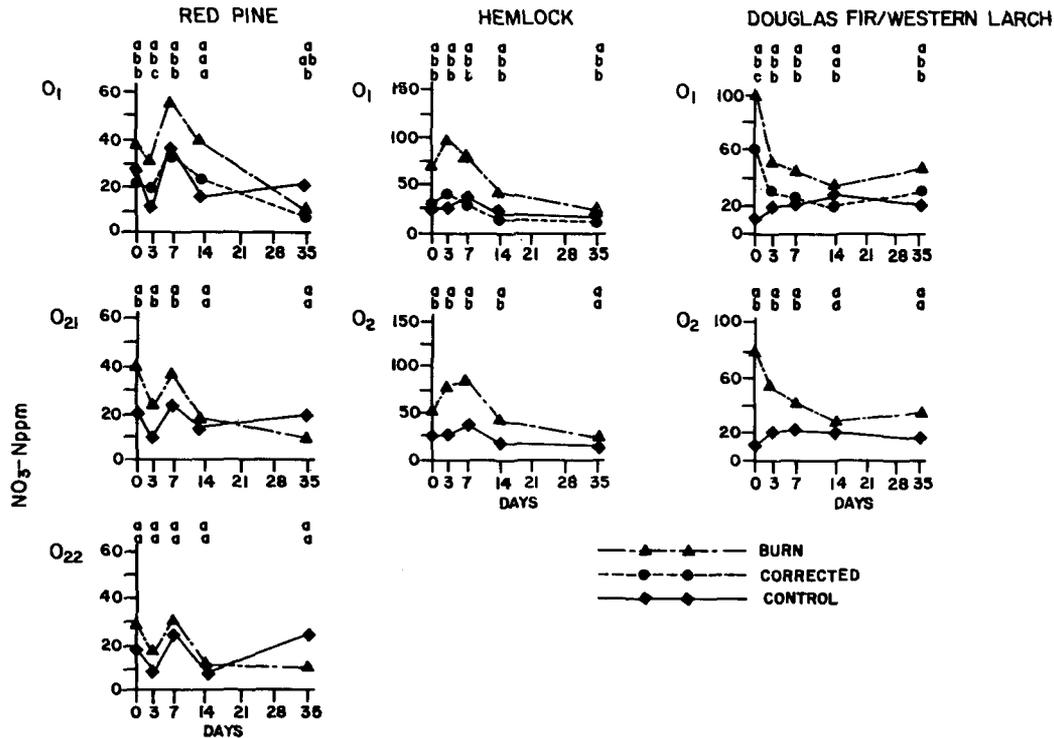


Fig. 2—Effects of burning on NO₃-N concentrations in forest floor horizons [significant differences (*p*=0.05) between values obtained at a specified number of days are indicated by a, b, or c. Similar letters indicate nonsignificance while dissimilar letters indicate significance.].

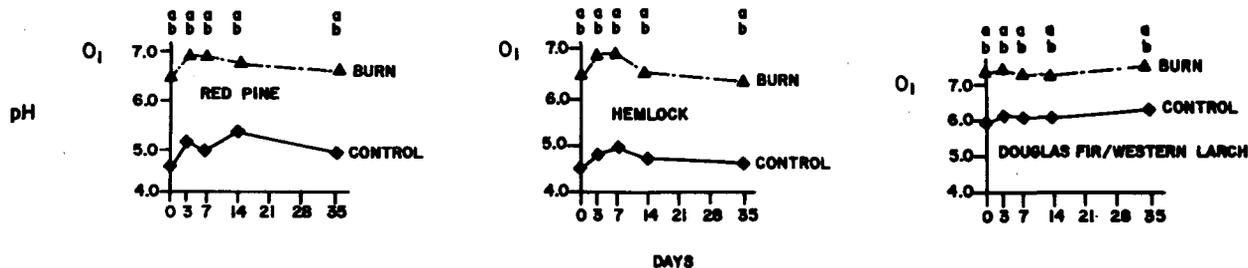


Fig. 3—Effects of burning on pH values in forest floor horizons. [Significant differences ($p=0.05$) between values obtained at specified number of days indicated by *a*, *b*, or *c*. Similar letters indicate nonsignificance while dissimilar letters indicate significance].

sented, burning had very little effect on the pH in O21 and O22 horizons.

Hemlock

Ammonium—Burning and subsequent incubation of hemlock forest floor samples showed a different pattern in NH_4 transformation. Similar to the red pine results, NH_4 concentrations did not change significantly in either hemlock horizon due to burning. When values were corrected for sample weight loss, there was an appreciable loss of NH_4 from the O1 horizon (Fig. 1). However, ammonium concentrations in the burned O1 horizons rose sharply during the first 14 days of incubation and then stabilized at a level significantly higher than in the control. This release of NH_4 is in contrast to the immobilization of NH_4 found in red pine litter. A similar pattern was shown in the O2 horizon but the NH_4 concentration dropped significantly below the control at 35 days.

Nitrate—Nitrate concentrations were significantly higher due to burning in both O1 and O2 horizons (Fig. 2). However, when the O1 samples were corrected for weight loss during the fire, the NO_3 concentration was the same as the control. Apparent nitrification patterns were similar to those in red pine but levels were considerably higher.

pH—The rise in pH due to burning hemlock organic horizon was about the same as found with red pine (Fig. 3). Burned O1 horizon hemlock samples showed a two pH unit increase over the unburned. The pH in the O2 horizon was not affected by the burn but rose in relation to increased ammonification after wetting.

Douglas-fir/Western Larch

Ammonium—The pattern of NH_4 concentrations in the Douglas-fir/western larch O1 samples was similar to that found with the red pine and hemlock. No significant differences in NH_4 concentration was evident between the burned and control pots (Fig. 1). When weight-corrected NH_4 concentrations were calculated, the burned O1 horizon was significantly lower than control for the entire study. However, in contrast to the other results, there was a gain of nearly 100 ppm of NH_4 in the O2 horizon. This increase turned to a decrease by the 3-day sampling time and was probably due to microbial assimilation rather than nitrification since there was no increase in NO_3 levels.

Ammonium levels in the O1 horizon of burned samples rose in the following 2 weeks to near control levels. The O2 horizon showed a similar pattern but at a higher level.

Nitrate—Nitrate levels in both the O1 and O2 horizons increased dramatically due to burning with the O1 being affected to a greater degree (Fig. 2). Even when corrected for weight loss, the NO_3 concentrations in the burned O1 horizon was significantly greater than the control. This effect was temporary with values approaching control levels within 2 weeks. The NO_3 incubation pattern differs somewhat from both the red pine and hemlock samples.

pH—The rise in pH of the burned Douglas-fir/western larch samples was less than either red pine or hemlock (Fig. 3). Levels in the O1 horizon rose over 1 pH unit due to burning and remained significantly higher than control for the entire incubation period. The pH of the O2 horizon rose slightly in response to burning but returned to control levels within 3 days.

Nitrogen Losses

One of the most important environmental effects of fire on soil is the potential loss of N through volatilization. Large losses in total N occurred in the O1 horizon in all forest floor samples at time 0 (Table 2). However, this contrasts with some N gains in the O2 horizon. When data from the O1 and O2 horizon are combined, N loss from the O1 are partially offset. An examination of N changes for each pot shows general increases in available N losses in total N for red pine

Table 2—Nitrogen changes in forest floor horizons as affected by burning.

Nitrogen	Control		Burned	
	O1	O2	O1	O2
	mg			
	Red pine			
$\text{NH}_4\text{-N}$	0.39	0.25	0.20	0.93
$\text{NO}_3\text{-N}$	0.55	0.78	0.47	1.35
Total-N	110.00	102.00	66.00	124.00
	Hemlock			
$\text{NH}_4\text{-N}$	0.90	1.36	0.29	2.02
$\text{NO}_3\text{-N}$	0.42	0.83	0.40	1.47
Total-N	147.00	345.00	87.00	369.00
	Douglas-fir/western larch			
$\text{NH}_4\text{-N}$	3.37	3.21	1.86	3.59
$\text{NO}_3\text{-N}$	2.72	0.38	2.29	1.56
Total-N	330.00	600.00	270.00	630.00

Table 3—Nitrogen changes/sample pot as affected by burning.

Nitrogen	Control	Burned	% Change	Significance of F
Red pine				
NH ₄ -N	0.64 mg	1.13 mg	+76.6	†
NO ₃ -N	1.33 mg	1.82 mg	+36.8	†
Total-N	212.00 mg	190.00 mg	-10.4	NS
% Available-N	0.93%	1.55%		
Hemlock				
NH ₄ -N	2.26 mg	2.31 mg	+ 2.2	NS
NO ₃ -N	1.25 mg	1.87 mg	+49.6	NS
Total-N	492.00 mg	450.00 mg	- 8.5	NS
% Available-N	0.71%	0.93%		
Douglas-fir/western larch				
NH ₄ -N	6.58 mg	5.45 mg	-17.2	†
NO ₃ -N	3.10 mg	3.85 mg	+24.2	†
Total-N	930.00 mg	900.00 mg	- 3.2	NS
% Available-N	1.04%	1.03%		

NS = No significant difference, $p < 0.05$.

† Significant difference $0.05 < p < 0.001$.

and hemlock samples (Table 3). However, Douglas-fir/western larch samples showed a lower percent change in total N than the other forest floor types, but the actual N loss was comparable due to a high N content in the O1 horizon. An analysis of variance, however, determined that these changes in total N were not significant. Changes in available N were significant for red pine and Douglas-fir/western larch but not for hemlock.

One striking feature of the Douglas-fir/western larch litter is the high amounts of total N as compared to the red pine and hemlock. Levels of available N were also higher in Douglas-fir/western larch litter.

DISCUSSION

Direct Effects of Fire on Soil Nitrogen

Many studies have shown a loss of total N from the forest floor due to burning while others have reported gains in N (Ahlgren and Ahlgren, 1960). Forest floor sampling pattern may affect these results for several reasons. Significant losses of N from the O1 horizon occurred in this study. This horizon was reduced to a white ash at a high temperature and is similar to the findings of Metz et al. (1961). However, total N content in the O2 horizons, which were merely charred at a lower temperature, increased. When the data from both horizons were combined, loss of total N became nonsignificant. Therefore, if only the ash material is sampled after a fire, there would be an over estimation of N loss from the site.

An increase of N in the O2 horizon is of particular importance because it illustrates how important experimental methodology is when designing a burning experiment. For example, Knight (1966) showed a large loss in total N from L, F, and H layers to conifer litter due to burning. We showed only small nonsignificant losses from similar organic material. Knight (1966) burned individual organic horizons separately at high temperatures in a muffle furnace. This method eliminates temperature gradients by heating the sample from all sides and gives a more complete burn. This contrasts with our study which used a furnace that heats only from the top and

more closely simulated field conditions. Using a similar device, DeBano et al. (1970) found that some vaporized organic compounds migrated downward in the soil along temperature gradients and condensed in cooler soil layers. This downward movement of organic compounds may account for the N gains in the lower horizons as observed in this study. Other investigations have also reported N gains in underlying soil layers (Barnette and Hester, 1930; Lunt, 1951; Metz et al., 1961; Wells, 1971), but it could not be determined whether these gains were due to movement of volatilized N, leaching of N from the upper burn layer, or microbial N fixation. However, others have shown that increases in total N in underlying soil layers do not always occur after burning (Isaac and Hopkins, 1937).

Ammonium concentrations were generally unaffected in all horizons immediately after burning. Weight-corrected values for the O1 horizon showed significant losses of NH₄. This differs from reports of NH₄ gains after burning probably because earlier authors had not expressed both burn and control concentrations on an original weight basis (Neal et al., 1965; Christensen, 1973). Corrected nitrate values for burned red pine and hemlock O1 horizons were not significantly different than control. However, the Douglas-fir/western larch litter showed gains in nitrate for the same horizon. This discrepancy is probably due to the difference in the amount of N present in each litter type as the Douglas-fir/western larch litter had a much higher N content than the hemlock or red pine.

Nitrate concentrations increased in all horizons due to burning; this confirms the work of Lewis (1974) and is probably due to the oxidation of organic nitrogenous compounds. Dunn and DeBano (1978), however, working with ceanothus and chaparral soils, found little or no effect of fire on NO₃-N. This discrepancy may be due to the nature of the soil. This study dealt with organic litter which would have a higher content whereas Dunn and DeBano (1978) used organic material and mineral soil.

INDIRECT EFFECTS OF FIRE ON SOIL NITROGEN

Ammonium and NO₃ concentrations in the three forest floor types showed marked differences during an incubation period following the burn. Both red pine and hemlock organic horizons had increases of NO₃ and NH₄ within 7 days after burning. However, Douglas-fir/western larch litter showed decreases in both NH₄ and NO₃ levels. These changes in available N are probably due to increased microbial activity with resultant ammonification and nitrification in red pine and hemlock samples. In the Douglas-fir/western larch litter, NH₄ and NO₃ were apparently assimilated in the first 3 days. However, after this period, ammonification began as shown by an increase in NH₄. The NH₄ levels subsequently dropped off as nitrification took place.

Ahlgren and Ahlgren (1965) observed sharp increases in soil microbial populations within 4 days following fire and attributed them to higher pH levels. The rise in pH is accompanied by a release of mineral

nutrients from the burned horizons (Lewis, 1974; Row and Hogel, 1974), which may affect nitrification rates (Clark, 1967; Wollum and Davey, 1975). Further, microbial activity and subsequent N transformations may also be favored by a lowering in the C/N ratio and increased structural accessibility of litter to soil organisms may occur after burning (Neal et al., 1965; Christensen, 1973).

Changes in available N following burning were temporary, as levels generally returned to near control after 5 weeks of incubation. This increased N availability for such a short period suggests little advantage is gained for subsequent regeneration, especially since some of the increased NO₃ could be lost to leaching. This same information indicates that sampling time following fire is extremely important because of the time-related changes in available N levels.

SUMMARY AND CONCLUSIONS

Data on individual organic horizons showed that both total and available N were lost from burned forest floor but increased in the underlying unburned layers. This increase of N in the underlying horizons was probably caused by the downward movement of N compounds during the burn.

None of the forest floor types examined showed significant changes in total N levels. This occurred because either small amounts of N were lost compared to the total present or the number of replicate samples was too small to detect the differences.

Ammonium and NO₃ concentrations during incubation were extremely variable with each forest floor type exhibiting its own characteristic N transformation pattern over time. Changes in available N levels due to burning and subsequent incubation are probably due to differential volatilization rates of C and N in the organic material, and to increased microbial activity because of higher pH and lower C/N ratios.

These findings have presented several implications on the evaluation of N levels after fire. Studies that examine only the burned materials will tend to overestimate N losses. Available N concentrations are extremely variable after fire, making the time of sampling critical in obtaining an accurate estimation of fire effects. Litter types in this study which were selected on the basis of high, medium, and low N content showed only limited similarities in their overall reaction of burning. This indicates that any generalization about fire effects on soil N over wide areas and different forest floor materials may not be valid.

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