MICROBIAL PROCESSES ASSOCIATED WITH NITROGEN CYCLING IN NORTHERN ROCKY MOUNTAIN FOREST SOILS

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ABSTRACT

The soil microflora is of critical importance for the cycling of nitrogen (N) in forest ecosystems. Forest management practices such as timber harvesting, residue removal and prescribed burning greatly affect the activity of these microorganisms. N fixation by free-living soil bacteria in the Northern Rocky Mountain region was reduced following harvesting. This was particularly true in the surface organic horizons and appeared related to low moisture levels on the surface of cleared sites. Decaying wood incorporated in the soil was a major site of N fixation. The establishment of N-fixing plants, such as Alnus, Ceanothus, Lupinus, and Astragalus on logged areas could more than compensate for the lower N fixation rates by soil bacteria. However, the occurrence of these plants are habitat-type related, and most of the sites studied did not have a significant N-fixing plant component. Increases in ammonium and nitrate concentrations occurred in the soil following logging, especially when the sites were burned. Such increases in available soil N levels could be beneficial for subsequent regeneration establishment and growth. However, both ammonium and nitrate concentrations returned to their original levels within several years after cutting. Higher nitrate concentrations after harvesting could increase leaching losses of N from the site. Changes in soil organic matter content must be considered when evaluating the effects of harvesting methods on soil N strata.

KEYWORDS: nitrogen fixation, nitrogen mineralization, ammonium, nitrate, timber harvesting, fire, litter
Nitrogen (N) is normally the soil nutrient most limiting the productivity of forest stands. Since nearly all N in forest soils is present as a component of various types of organic matter, the activity of the soil microflora is particularly important for N availability and subsequent uptake by tree roots. It is this biological decomposition of organic matter which make soil N levels more susceptible to modification by silvicultural practices than any other nutrient. Timber harvesting, residue removal and post-logging site preparation, such as burning and soil scarification, may directly modify the soil N status. Less conspicuous, but in many instances just as important, are the soil chemical and physical changes following these operations which affect the soil microorganisms active in the N cycle (Harvey and others, 1976).

Much has been written about the various aspects of the N cycle and how it may be altered by forest management activities. A comprehensive treatment of N relationships in forest soils is given in an excellent review by Wollum and Davey (1975). Rather than try to cover all facets of this complex subject, only the effects of timber harvesting on biological N fixation and mineralization of organic N in various northern Rocky Mountain forest ecosystems will be discussed. Five experimental sites were used in this study:

Idaho - Old growth western cedar - western hemlock stand (Tsuga heterophylla/Pachistima habitat type) located near the Priest River Experimental Forest, northern Idaho Panhandle.

Montana - 200-year old western hemlock stand (Tsuga heterophylla/Clintonia uniflora habitat type), Coram Experimental Forest in northwestern Montana.

Montana - 250-year old Douglas-fir, western larch, subalpine fir stand (Abies lasiocarpa/Clintonia uniflora habitat type) in the Coram Experimental Forest, northwestern Montana.

Montana - 250-year old Douglas-fir stand (Pseudotsuga menziesii/Physocarpus malvaceus habitat type) in the Coram Experimental Forest, northwestern Montana.

Wyoming - Overmature 175-year old lodgepole pine stand (Abies lasiocarpa/Vaccinium scoparium habitat type) located near Union Pass, northwestern Wyoming.

Detailed information on stand characteristics, soil properties and harvesting treatments on these sites are given in other papers of this symposium or have been published elsewhere (Harvey and others, 1979).

DINITROGEN fixation

Timber and/or residue removal results in a direct loss of N from a site. This N loss is further increased if prescribed fire is used for site preparation (Wells and others, 1979). Natural replacement of this soil N capital in the Intermountain West comes from small amounts of N (1-2 kg/ha/yr) present in rainfall (Tiedemann and others, 1978), and from the biological conversion or "fixation" of inert atmospheric N\textsubscript{2} into usable forms by select microorganisms free-living in the soil or present in plant roots. It is these biological N fixation processes which are affected by various forest management practices. Such N inputs by soil microorganisms are important for long term site productivity and should be considered when evaluating the environmental impact of timber removal.

\footnote{Habitat type designation according to Pfister and others, (1977) or Daubemire and Daubenmire (1968).}
Free-living N-fixing microorganisms, with the exception of the autotrophic blue-green algae, are dependent on a source of organic matter to satisfy both energy and carbon requirements. With this nutritional constraint, greater activity of the N-fixing microflora might be expected in soil substrates high in organic matter. Such a relationship was evident in all of the northern Rocky Mountain soils examined. In the example shown in Figure 1, the highest N fixation rates on this Douglas-fir/western larch site were associated with decaying logs. When decayed wood is eventually incorporated into the soil profile, it normally retains a higher N-fixing capacity than the surface litter, humus, or mineral soil. However, these N fixation values may be misleading when trying to estimate the relative contribution of each soil component to total N input. The actual amounts of N fixed depends on the weight/volume relationship of each soil fraction on the site.

Figure 1.-- Amounts of N fixed in various forest floor and soil components (Montana).

Nonsymbiotic N fixation in Intermountain forest soils is also related to stand productivity. As the timber yield potential of a site increased, so did the N fixation rates (Figure 2). However, the drier and poorer the site, the greater the importance of decayed wood to overall soil N fixation capacity (Figure 3). It seems likely that at least some of the increased productivity of the higher quality sites is related to a greater N input from the N-fixing microflora.
Figure 2.-- Relationship of forest site productivity to amounts of N fixed in the forest floor and top 5 cm of mineral soil (Montana).

Figure 3.-- Relative daily N Fixation rate by soil component on three different habitat types (Montana).
In a previous paper (Jurgensen and others, 1979a), we speculated that timber harvesting would alter the soil chemical and physical properties to favor the activity of N-fixing microorganisms. Preliminary sampling in a Douglas-fir/western larch stand in northwestern Montana tended to substantiate this hypothesis. However, more intensive sampling throughout the growing season on several other sites indicated that N fixation rates were actually lower on harvested sites as compared to uncut controls, especially when a post-harvest fire treatment was used (Figure 4).

Figure 4.-- Effects of harvest treatment on N fixation in the surface 30 cm of forest floor and mineral soil (July).

All harvested sites and the controls showed a general lowering of N fixation rates in the summer months. This was due to a drying out of the surface soil layers during this period, especially on the exposed clearcut areas (Hungerford, 1980). The small amounts of N fixed in the O$_2$ horizon on the intensive utilization and burned site reflected these low soil moisture levels (Figure 5). A lowering of N fixation rates on these burned sites contrast with several other studies which indicated a stimulation of N-fixing microorganisms following fire (Wells and others, 1979). Differences in soil, timber type, climate, severity of burn, and method of measuring N fixation rates could account for such variable results.

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Changes in nonsymbiotic N fixation rates due to timber removal also reflect differences in site productivity. The amounts of N fixed in a highly productive, northern Idaho cedar-hemlock soil were much greater than in a cold, high altitude lodgepole pine soil regardless of harvest treatment. Conservatively assuming that the N-fixing bacteria would be active for only 100 days/yr, N added to the cedar-hemlock soil would amount to slightly over 1 kg/ha/yr on the prescribed burned sites to nearly 2.3 kg/ha/yr in the uncut stands. However, as the stands on these cut and burned areas become reestablished, the N fixation rates would likely increase to preharvest levels. The length of the recovery period is unknown. While these N gains are small on an annual basis, the significance over a stand rotation of 100–150 years would be appreciable. In contrast, N added to the lodgepole pine soils would be much lower. Again assuming a 100 day activity period for the N-fixing microflora (a possible overestimation), less than .25 kg/ha/yr of N would be added to the burned sites, and only .5 kg/ha/yr in the undisturbed stands. N fixation rates should also increase as this site regenerates, but the recovery time would probably be longer than on the more favorable cedar-hemlock site.

More immediate N gains on poorer sites could be obtained by converting unused logging residues into chips. N fixation rates associated with wood chip decay were the highest found in any of the wood or soil substrates examined (Jurgensen and others, 1979b). The insulating properties of the chips and the heat and moisture generated during fermentative and decay processes would favor the activity of N-fixing organisms throughout the year (Larsen and others, 1980). While the economic or practical feasibility of conducting such chipping operations is questionable, it is one way by which logging residues could be more rapidly decomposed and overall site productivity improved.
Symbiotic N Fixation

The establishment of N-fixing plants such as *Alnus*, *Ceanothus*, *Lupinus*, or *Astragalus* on logged sites could more than compensate for the low N additions by the free-living soil bacteria. For example, Youngberg and Wollum (1976) reported that in a ten year period *Ceanothus* fixed over 1,000 kg N/ha in an Oregon Douglas-fir stand after harvesting and slash burning. Applicable amounts of N are also added to forested sites by other N-fixing plants (Youngberg and Wollum, 1970).

Most of the forests in the northern Rocky Mountains do not have a significant N-fixing plant component in pole-size stands or larger (Jurgensen and others, 1979b). When these stands are logged, N-fixing plants may become established, but their development is habitat-type specific. For example, *Ceanothus* is favored on warm, dry Douglas-fir sites following logging and prescribed burning, while on cooler, wetter sites, much less development is found. Stickney (1980) observed that *Alnus* was greatly reduced on several clearcut and burned subalpine fir sites in western Montana. However, *Alnus* is abundant on road cuts and other scarified sites in many subalpine fir habitat types. In the southeastern U. S. timber harvesting and prescribed burning frequently increases the legume component in the ground vegetation (Cushwa and others, 1966). In the generally drier Intermountain region, no such consistent post-harvest pattern of legume development is evident (Jurgensen and others, 1979b).

The use of N-fixing plants to replace N losses due to harvesting or fire offers considerable management potential. Youngberg and Wollum (1976) have recommended using *Ceanothus* for early seedling shade protection and soil N enrichment following logging operations in Oregon. Grier (1975) believes most of the N lost from a severe wildfire in Washington can be replaced by *Ceanothus* becoming established on the site. The use of legumes as a cover crop in southern pine stands following harvesting is being considered for site N additions and weed control (Haines and DeBell, 1979). Native and introduced legumes are an integral part of erosion control efforts on logged or burned sites (Monsen and Plummer, 1978). However, much more information is needed on the response of these plants to stand manipulation and the successional roles they play on disturbed sites.

**N MINERALIZATION**

Timber harvesting has pronounced effects on N transformations within a soil. Increases in ammonium (NH$_4^+$) and nitrate (NO$_3^-$) concentrations were found in the soil following clearcutting and prescribed burning on a subalpine fir site at the Coram Experimental Forest in western Montana. The patterns of N release from the humus (O$_2$) horizon for two years after logging is shown in Figure 6. Similar changes in available N levels were recorded for the mineral soil horizons but the amounts were much lower than found in the organic layer. Clearcutting and intensive residue removal increased NH$_4^+$ and NO$_3^-$ concentrations over those found in an uncut stand during the following growing season. These higher N values on the cleared sites could have resulted from both accelerated organic matter decomposition and a lack of vegetation to take up the N as it was mineralized. The greatest effect on available N levels occurred when the site was clearcut and burned. Such gains in available N after fire have also been reported for conifer sites in Idaho (Orme and Leege, 1976), Wyoming (Skujins, 1977), Oregon (Neal and others, 1965), Arizona (Campbell and others, 1977), and Europe (Tamm and Popovic, 1974; Viro, 1974).

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A clearer picture of the N mineralization changes which occur in soil following fire was given by Mroz and others (1980) in a laboratory experiment using forest floor material from the Coram site (Figure 7). This study showed an immediate release of N when the organic layers were burned, a rapid immobilization of the available N within three days following the burn, and a gradual mineralization of the organic N to NH₄ in the succeeding five weeks. These N fluctuations are likely due to a rapid expansion of the soil microflora after the fire in response to increases in available
carbon and NH$_4$ (Ahlgren, 1974). Microbial activity may also be stimulated by a re-
lease of mineral cations from the burned organic matter and a decrease in soil acidity
(Wells and others, 1979). Soil reaction increased over one pH unit in the organic
horizon of the burned site at Coram (Figure 8). A sampling of the areas four years
after burning showed that the pH of the 0$_2$ horizon had not yet returned to preburn
levels.

Figure 7.-- Ammonium concentrations in the forest floor layers of Douglas-fir/
western larch/subalpine fir stand following burning (Mroz and others, 1980).
The effects of post-harvest burning treatments on the levels of available N show a definite relationship to the soil component examined (Figure 9). These results from the Coram study show that before the prescribed fire, total amounts of NH$_4$ and NO$_3$ in the organic layers were approximately equal to that present in the surface 30 cm of mineral soil. After the fire, available N levels in the surface organic horizons and decayed wood increased to double the amount present in the mineral layer. Total N availability in the surface 30 cm of soil was highest in November-December, followed by a steady decrease during the winter and spring months to preburn levels (Figure 10).
Figure 10.-- Effects of harvest treatment on available N content of the surface 30 cm of forest floor and mineral soil in a Douglas-fir/western larch/subalpine fir stand (Montana).

Immobilization and denitrification by the soil microflora as well as NH$_4$ and NO$_3$ leaching by snowpack melt would account for these winter and spring N losses. Appreciable losses of N have been reported from some eastern hardwood forests due to NO$_3$ leaching after timber harvesting (Hornbeck and others, 1975). While increased NO$_3$ losses have been reported following logging operations in the west, the amounts are usually too low to affect site productivity (Fredrikse and others, 1975).

Higher levels of available soil N following clearcutting (Figure 10) could be beneficial for subsequent regeneration establishment and growth on harvested sites. Total amounts of available N present in humus layers and in decayed wood are of special significance for tree uptake, since mycorrhizal root activity is concentrated in these soil strata (Harvey and others, 1980). However, the potential effects of this additional N would be of short duration. Available N levels in soil on both the intensive utilization and burned sites were comparable to uncut stands by the second year after harvesting.

CONCLUSIONS

The dynamics of N fixation and N mineralization in northern Rocky Mountain forest soils are strongly affected by timber harvesting. The impact of these operations was most evident on N transformations occurring in organic soil components. Changes in soil organic matter content must be considered when evaluating the effects of logging methods on soil N levels. However, the significance of such harvest-related N changes to overall site productivity in this region is unknown.
The caution given by Harvey and others (1980) in this symposium on applying mycorrhizae results from the Intermountain region to other forested ecosystems is equally valid for soil N relationships. Differences in climate, stand properties and soil type are only several of the variables which could alter the intensity and direction of microbiological processes occurring on a site.

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