EFFECTS OF TIMBER HARVESTING ON SOIL BIOLOGY

M.F. Jurgenson, M.J. Larson, and A.E. Harvey

Department of Forestry, Michigan Technological University, Houghton;

Institute for Forest Mycology, Forest Products Laboratory, Madison, Wisconsin; and Forestry Sciences Laboratory, Missoula, Montana.

The impact of timber harvesting on soil biological processes has received considerably less attention than its effects on soil physical and chemical properties. This is due largely to the lack of obvious correlations between microbial activity and environmental change, and to the difficulty in obtaining meaningful estimates of soil biological activity. Most investigations on the effects of timber harvesting on soil biology have been conducted in Europe, particularly in Russia (Bell et al., 1974). Recently with the controversies over clearcutting, interest has developed in North America on this subject.

The manner by which harvesting operations affect soil microflora and their activities may be grouped into two categories: (1) direct effects by the removal of carbon and nutrient supplies (logs, pulp sticks, chips, etc.), and (2) indirect effects related to changes in the chemical and physical properties of the soil (water content, temperature, oxygen–CO₂ levels, pH and bulk density).

Biomass Removal

Removal of wood is an obvious influence of harvesting on heterotrophic soil organisms. This loss of carbon, nitrogen, and associated minerals has a pronounced effect on the microbial complex dependent on this material as an energy and nutrient source. Thus, the removal of woody substrates would drastically alter the activity of wood decay fungi and other microorganisms associated with decay. Similarly, the removal of tree foliage in total fiber harvest operations would affect the microbial processes occurring in the 0 horizon.

Alteration of Soil Properties

The most widespread effects of timber harvesting on the soil organisms are due to changes in the soil physical and chemical properties. Tree removal generally increases the levels of available water in the soil and raises soil temperatures (Debye, 1976). Since soil aeration is inversely related to moisture content, oxygen levels are reduced. Changes in soil pH also result from harvesting, especially if fire is used for a slash disposal or site preparation. These changes in soil properties can greatly affect the numbers, diversity, and activity of the various soil organisms (Harvey et al., 1976a).

IMPLICATIONS FOR FOREST MANAGEMENT

Of the many important activities of soil organisms likely to be influenced by timber harvesting, several seem of special significance to forest management. These are: (1) soil nutrient levels and availability, (2) decay of woody plant material, and (3) activities of plant pathogens. Each of these is related to the level and type of timber operation and to possible site preparation practices. Fire is an integral part of post harvest operations, but due to its large impacts on soil properties it will be discussed separately.

SOIL NUTRIENT LEVELS AND AVAILABILITY

Organic Matter Mineralization

Particular attention has been given to harvesting effects on the nutrient release from non-woody residue, the litter layer or soil organic matter. This release or "mineralization" of nutrients from organic materials by soil microorganism supplies a large portion of the nutrients required for tree growth. This is particularly true for nitrogen, phosphorus, and sulfur, since nearly all of the nitrogen and approximately half of the phosphorus and sulfur are present in the soil as organic complexes (Mulder et al., 1969). The availability of most other
Soil nutrients are at least partially dependent on the activity of the soil microflora. Therefore, changes in soil microbe populations may have important consequences for nutrient availability and subsequent site productivity.

Studies such as those by Cole and Gessel (1965) and Likens et al. (1970) on nutrient release from litter have shown that the removal of forest vegetation increased forest floor decomposition. This increased nutrient availability is apparently related to increased activity of the soil microflora. Numbers of heterotrophic soil organisms have been shown to increase after clearcutting, as has the level of carbon dioxide in the soil (Piene, 1974). This increased carbon dioxide production by the soil microflora would increase nutrient movement through the profile and contribute to leaching losses from the site (Cole et al., 1975).

Increased microbial activity after logging is associated with increased soil temperature and/or moisture levels in the cleared area. However, in certain instances where timber harvesting has raised the ground water level to near or at the soil surface, the reduction in soil oxygen levels may be severe enough to decrease organic matter decomposition (Bell et al., 1974). In operations where the litter is incorporated into the soil, such as in diskng or bedding, the decomposition of organic materials is greatly accelerated.

The significance of increased litter decomposition to soil nutrient availability and possible losses due to leaching depends on the site and the type of harvesting operations. Cole and Gessel (1965) found that the nutrients released after clearcutting a Douglas fir stand in Washington remained in the root zone. Conversely, Pierce et al. (1972) in their hardwood clearcutting study in New England found significant increases of nutrients in the ground water and neighboring streams. Other investigators have reported increased nutrient losses after harvesting (e.g. Hart and Debye, 1975). However, these accelerated losses of nutrients are generally of short duration and only continue until the understory and herbaceous plants reestablish on the site, usually within several years.

Nitrogen Availability

Nitrogen is present in the soil almost entirely as organic forms and is usually the most limiting nutrient in soil. Consequently, harvesting effects on the soil microflora would likely have their greatest impact on nitrogen cycling. These effects on soil nitrogen can be broadly classified as follows: the biological conversion or "fixation" of atmospheric N\textsubscript{2} into organic complexes, the nitrification of NH\textsubscript{4} to NO\textsubscript{3}, the losses of NO\textsubscript{3} from the soil by denitrification. The mineralization of NH\textsubscript{3} from organic N complexes was discussed earlier.

Dinitrogen Fixation

In natural ecosystems the atmosphere supplies nitrogen to the soil through the fixation of inert nitrogen gas (N\textsubscript{2}) into forms useful to plants. Most research on nitrogen fixation has centered in agricultural areas, such as in the much publicized attempts to develop nitrogen-fixing strains of corn and wheat. However, nitrogen fixation in forest ecosystems may be significant, particularly for replacing nitrogen losses from a site due to harvesting or fire.

Symbiotic

The best known symbiotic nitrogen-fixing relationship is between the bacterial genus Rhizobium and leguminous plants. Commercially important legumes such as soybeans, peas and alfalfa have been found to add up to 200 kilograms of nitrogen/hectare/year to the soil. Most work has centered on agricultural systems and with the exception of black locust, very little is known regarding the extent or significance of the Rhizobium-legume association in forest ecosystems (Wollum and Davey, 1975).

Other symbiotic nitrogen-fixing relationships are found in a wide variety of non-leguminous plants. Over 100 plant species, including alder (Alnus) and snowbush (Ceanothus) have been reported to form nitrogen-fixing root nodules (Youngberg and Wollum, 1970). Appreciable amounts of N can be fixed by these non-leguminous plants. Field studies on snowbush and red alder have reported nitrogen additions of over 100 and 300 kilograms/hectare/year respectively (Wollum and Davey, 1975).

Timber harvesting would seem to increase the contribution of nitrogen-fixing plants to soil nitrogen levels in the post harvest period. Clearcutting in the Douglas-fir region of western Washington and Oregon favors the development of alder and snowbush in the subsequent stand. Opening of the forest canopy drastically alters the composition of the understory and most likely
increases the representation of shrub and herbaceous nitrogen-fixing plants (Schultz, 1976). The use of clovers as a cover crop after harvesting is a being attempted in Southern pine stands. Additional information is needed on the distribution and activity of nitrogen-fixing plants in forest stands and how their occurrence is affected by management practices.

Non-symbiotic

In contrast to the symbiotic nitrogen-fixing plants, the significance of free-living nitrogen-fixing microorganisms in soil is unclear. It has been generally found that little non-symbiotic nitrogen fixation occurs in agricultural soils (Jensen, 1965). However, appreciable nitrogen gains have been reported from certain prairie, forest and peat soils where organic matter is not routinely removed from the site (Moore, 1966).

Most of the soil and stand changes resulting from timber harvesting would favor non-symbiotic nitrogen-fixing organisms (Table 1). Preliminary results from a study we are conducting in Montana indicate at least a slight increase in nitrogen-fixation after clearcutting. However, the amounts of nitrogen added to the soil are still quite low. How long this increase in fixation rates will continue is unknown.

Table 1. -- Potential Harvesting Effects on Dinitrogen Fixation

<table>
<thead>
<tr>
<th>Decrease N-Fixation:</th>
<th>Increase N-Fixation:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Higher levels of soil NH(_4^+) or NO(_3^-)</td>
<td>1. Higher H(_2)O level → less O(_2)</td>
</tr>
<tr>
<td>2. Increase soil temperature</td>
<td>2. Increase soil temperature</td>
</tr>
<tr>
<td>3. Raise pH</td>
<td>3. Raise pH</td>
</tr>
</tbody>
</table>


Nitrification

The effects of forest practices on nitrification are receiving considerable attention due to the role of nitrates in ground water, stream and lake pollution. In contrast to the positively charged ammonium ion, the nitrate anion readily moves through the soil profile. The organisms generally assumed to be most active in the nitrification process are a select group of autotrophic bacteria. These nitrifying bacteria are not directly affected by the soil organic matter because they obtain their energy solely from the oxidation of nitrogen compounds and use carbon dioxide as a carbon source. However, organic matter indirectly affects nitrification by influencing soil moisture levels, soil temperature and cation exchange capacity.

Timber harvesting, particularly clearcutting, has been found to drastically increase the populations of nitrifying bacteria in certain soils. This was shown by Likens et al. (1970) in New Hampshire and resulted in much higher levels of nitrate in neighboring watersheds. However, the loss of nitrate after clearcutting has been found to be much lower in other parts of the country (Reinhart, 1973). These variable effects of harvesting seem to be related to stand differences in organic matter accumulation, soil temperature/moisture pattern and soil texture (Stone, 1973).

Denitrification

The effect of timber harvesting on losses of nitrogen through denitrification is unknown. In fact, the extent of this nitrogen transformation occurring under forest conditions has hardly been investigated (Wollum and Davey, 1975). However, logging operations have the potential to increase denitrification rates. Since denitrification is carried out by anaerobic bacteria, the increases in soil water content after harvesting and the resultant lowering of oxygen levels would favor such organisms. An increase in soil temperature or pH could also stimulate the denitrifying microflora (Broadbent and Clark, 1965).

Of particular importance to the activity of the denitrifying bacteria is an adequate supply of nitrate. As noted earlier, nitrification rates in certain soils may be enhanced after removing the overstory. Such higher levels of soil nitrate may lead to greater denitrification and resultant nitrogen loss. However, at present this is only speculation.
Rhizosphere Interactions

In addition to the symbiotic nitrogen-fixing relationships discussed earlier, other more subtle root-microbe interactions may also be affected by timber removal. The rhizosphere, or that portion of the soil immediately adjacent and directly under the influence of the plant root, is a site of enhanced microbial activity. The metabolic products both from the roots and its associated microflora have been shown to be active in mineral weathering. Boyle and Voigt (1973) attributed increased potassium availability and subsequent plant uptake to rhizosphere nutrient release. The rhizosphere also exhibits higher rates of nitrogen fixation and denitrification.

Rhizosphere differences occur among various plant species and site differences affect the microbial populations. Changes in both the overstory and understory composition could alter the rhizosphere and impact nutrient availability. As of yet, this effect of timber harvesting has not been explored.

WOODY RESIDUE DECAY

We are considering timber harvesting effects on the incidence of woody residue separately from leaves, twigs or bark. This is due to the distinctive chemical composition of wood, the unique microflora active in its breakdown and the possible role it may have in maintaining site quality. Depending on the type and past history of a site, woody materials in various amounts and in different stages of decay may be found at the soil surface or partially imbedded in it.

Large woody residues, depending on size, may persist on a site for several hundreds of years. McFee and Stone (1966) found in Northern New York that up to 30% of the surface foot of soil volume was made up of decayed wood. Harvey et al. (1976b) demonstrated similar volumes of woody residues in a Montana soil. These persistent woody materials are formed mostly from conifer residue by the activity of brown rot fungi. Wood decomposed by white rot fungi does not persist and appears to be more characteristic of hardwood stands.

The Function of Residue Decay

The most important effect of brown cubicle decayed wood (BCD) on site quality seems to be in its moisture-holding properties. Decayed wood has a larger water-holding capacity and dries out more slowly than other soil components (Table 2). A more favorable moisture regime in BCD makes this substrate important for seedling establishment and subsequent stand growth. It is a common observation to find seedlings of certain trees on decaying logs, e.g. birch and hemlock.

Table 2.--Nitrogen fixation rate (grams N/gram dry soil) and moisture content (percent dry weight) from various forest sites, July 24, 1976.

<table>
<thead>
<tr>
<th>Site</th>
<th>Moisture (%)</th>
<th>Nitrogen fixation (grams N/day/gram dry soil)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B. for (FES/PIKA)</td>
<td>15.6</td>
<td>21.8</td>
</tr>
<tr>
<td>W. Larch/D. fir (ABAN/COAN)</td>
<td>12.0</td>
<td>15.0</td>
</tr>
<tr>
<td>H. Larch/D. fir (ABAN/COAN)</td>
<td>14.0</td>
<td>17.0</td>
</tr>
</tbody>
</table>

$1^1$ $O_2$: humid, $O_2$: dry.

Decayed wood is also a site of nitrogen fixation both in or on the soil (Table 2). Of particular significance is that on a dry site it was a more active site for nitrogen fixation than either the litter or mineral soil. In the Southeast both decaying chestnut logs and the leaf litter layer had comparable fixation rates (Cornaby and Wade, 1973).
The impact of timber harvesting on the amounts of decayed wood on a site is obvious—the greater the timber removed, the less residue remains on the site to be incorporated into the soil. The trend toward more intensive residue utilization, coupled with fire as a slash disposal method could drastically alter this woody soil component. It appears that on certain sites some woody material should be left after harvest to guard against a long term reduction in site productivity. This may be especially true for those soils characterized by prolonged droughty conditions or having low levels of soil nitrogen.

ACTIVITIES OF PLANT PATHOGENS

The very nature of forest harvesting imposes radical changes on the ecosystem which, in turn, directly or indirectly affect forest pathogens. Whether related to natural forces, or to man's activities, tree residues left in place can pose disease problems. Stumps of fallen trees, other woody residue or roots in the soil are essential for the fruiting and survival of cull-causing and root-rotting fungi (Boyce, 1961). Diseases that attack foliage, and produce spores on dead and fallen needles, such as Lophodermium or Neopeckia, may also represent residue hazards (Hepning, 1971). Thus, adequate reduction of logging residues can suppress many types of diseases. Conversely, allowing residues to accumulate may intensify these problems.

Disease incidence may also be affected by the increases in soil nutrient availability after logging. Fertilizer applications have been found to aggravate some disease problems, both in nurseries and in the field (Hesterberg and Jurgensen, 1972). These nutrient additions influence disease incidence by changes in the physiological conditions of the fertilized tree. However, certain nutrients, particularly nitrogen, may also affect the survival and growth of the saprophytic stage of many root pathogens (Huber and Watson, 1974). It seems unlikely that the increased nutrient availability following harvesting is sufficient to cause disease responses similar to fertilizer application. However, this question needs to be further investigated.

FIRE

Considerable research has been done on the effects of both prescribed and wild fire on soil biology. Fire drastically reduces microbial populations, particularly the bacteria, in the surface soil horizons (Neal et al., 1965. Usually the soil microflora recovers quite rapidly, frequently to population levels far greater than the original. In severe habitats, such as chapparral stands in California, the recovery may be delayed.

The increased microbial activity can be related to the increased soil pH, carbon availability and ammonium levels found after fire. Soil nitrification rates would likely increase since ammonium is normally the limiting factor for the nitrifying population. The rise of soil pH after a fire would also favor these organisms.

Organisms active in the nitrogen cycle have been of special concern since substantial losses of organic nitrogen can occur via volatilization during a fire (Knight, 1966). However, gains of over 20 kg of nitrogen/hectare/year were found on some sites in the Southeast which were burned annually over a 20-year period (Jorgensen and Wells, 1971). Nitrogen gains after fires have been attributed to an increased legume component in the ground vegetation or to a greater activity of non-symbiotic nitrogen-fixing organisms.

Prescribed fire may also have an effect on disease problems in subsequent stand development. As noted above, fire can sterilize and change the physical-chemical characteristics of the upper soil horizon. Frequently feeder-root pathogens, such as Fusarium and Phytophthora, are well adapted to these new soil conditions (Wright and Bollen, 1961). The root pathogen Rhizina undulata, whose spores are activated by exposure to heat, is often active on young conifer seedlings after burning (Morgan and Drier, 1972). However, thus far, disease problems related to fire incidence have not been significant.

SUMMARY AND CONCLUSIONS

Interactions between logging systems, silvicultural treatments and their respective residues will bring about changes in the soil microflora. Many studies have shown enhanced microbial decomposition with resultant increases in nutrient availability and leaching of nutrients through the soil. For most sites these losses are small and usually last for only a few years.

A different situation seems to prevail after logging cool, wet sites where a large buildup of surface organic litter has occurred. Here increased microbial activity, coupled with adequate rainfall for leaching, causes appreciable nutrient losses. Of particular significance are possible increases in the
nitrifying populations which can bring about high losses of nitrate nitrogen.

Interest is developing with regard to harvesting effects on the microorganisms which function in the cycling of nitrogen. Post harvest operations which include fire as part of site preparation have more effect on these organisms than those without burning. As of yet, an insufficient data base prevents definite conclusions.

Harvesting affects on disease problems appear to be mostly related to the level and type of residue remaining on the site. As more of this material is removed through greater utilization standards, general disease incidence should decrease. The application of fertilizers is known to favor certain disease organisms. Whether the increase in soil nutrient availability after fire or timber harvesting would cause a similar effect is unclear.

Most studies on the environmental impact of timber harvesting stress the amounts of various nutrients removed and their relation to the total nutrient budget. From a soil biological standpoint, the loss of wood as a physical entity may be equally or more important for site quality. The trend toward greater use of logging residues and cull timber will dramatically reduce the amounts of woody matter returned to the soil. The long term implications of reducing this woody–organic base in soil is generally unknown. Our studies suggest that on dry sites in the northern Rocky Mountains these materials should remain on the site if they do not constitute a wildfire hazard.

Most of the information on the biological consequences of timber harvesting is derived from a few studies investigating treatments designed to give the highest possible impact to the site. The infinite variations in harvesting techniques, stand age and condition, post–harvest treatment, soil and climatic differences which characterize forest conditions make it difficult to draw general conclusions. It would seem that no generally detrimental impact on site quality can at this time be directly attributed to harvesting effects on the activities of the soil microflora. This may not remain true as harvesting system emphasize more intensive use of the stand.

**LITERATURE CITED**


In: Convention held in Albuquerque, New Mexico, Oct 2-6, 1977. p. 244-250