INT-69
GTR
41

FOREST SOIL BIOLOGY — TIMBER HARVESTING RELATIONSHIPS

M. F. Jurgensen,
M. J. Larsen,
and A. E. Harvey

FOREST SOIL BIOLOGY —
TIMBER HARVESTING RELATIONSHIPS:
A PERSPECTIVE

M. F. Jurgensen, M. J. Larsen, and A. E. Harvey

THE AUTHORS

M. F. JURGENSEN, Associate Professor of Forest Soils, teaches
and conducts research in Forest Soils-Soil Microbiology,
Department of Forestry, Michigan Technological University,
Houghton. Dr. Jurgensen received the B.S. degree in Forestry
(1961), the M.S. degree in Silviculutre (1965), and the Ph.D.
degree in Soil Science (1967). He was a Research Associate
(1966-1967) and an Assistant Professor (1966) at North Carolina
State University before assuming his present position.

M. J. LARSEN, Mycologist, investigates the taxonomy and ecology of
forest fungi at the Center for Forest Mycology Research,
Forest Products Laboratory, Madison, Wis. Dr. Larsen received
the B.S. degree in Botany (1960), the M.S. degree in Plant
Products Pathology (1963), and the Ph.D. degree in Forest
Mycology (1967). He held a position with the Canadian Forestry
Service from 1966 to 1970 and joined the Center for Foresty
Mycology Research in 1971.

A. E. HARVEY, Plant Pathologist, is responsible for research
investigations on the microbiological impacts of intensive
fiber utilization and prescribed fire at the Forestry Sciences
Laboratory, Missoula, Mont. Dr. Harvey received the B.S.
degree in Biology (1960), the M.S. degree in Plant Pathology
(1962), the Ph.D. degree in Plant Pathology (1968), and
completed an academic year of postgraduate work in Plant
Pathology (1972). He joined the Intermountain Forest and
Range Experiment Station in 1965.

RESEARCH SUMMARY

Timber harvesting has a pronounced effect on the soil micro-
flora by removing essential woody food supplies and by changing
soil chemical and physical properties. Greater activity of micro-
organisms following logging operations may affect site quality
because of increased availability of soil nutrients and accelerated
nutrient movement through the soil profile. Soil micro-organisms
that function in the cycling of nitrogen generally are stimulated
by timber removal, particularly if fire is used as part of post-
harvest site preparations. The effect of harvesting on the incidence
of disease is a potential problem, but seems to be more related to
the levels and types of logging residues on the site than to
changes in soil properties. Decayed wood, as both a physical and
chemical component of soil, appears to be an important factor in
stand development and productivity on dry sites in the northern
Rocky Mountains. The long-term implications of reducing the
amounts of woody materials returned to the soil by increasing
residue utilization is unknown. At present, no detrimental impact
on site quality can be directly attributed to harvesting effects
on soil micro-organisms; however, this may change as forest manage-
ment goals emphasize more intensive use of existing stands.

CONTENTS

INTRODUCTION

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

This paper is intended to acquaint forest managers and research scientists with the functions of micro-organisms in forest soils and to explain how changes in these functions can result from timber harvesting operations. It is not meant to be a comprehensive state-of-the-art survey on this subject (see Harvey, 1976a), but rather a perspective of soil biology-harvesting relationships for the northern Rocky Mountain region based on selected literature and studies currently under way.

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

Biomass Removal

Removal of wood has an obvious influence on heterotrophic soil organisms. This loss of carbon, nitrogen, and associated minerals has a pronounced effect on the complex of micro-organisms dependent upon this material as a source of energy and nutrients. Thus, the removal of woody substrates would drastically alter the activity of fungi and other micro-organisms associated with wood decay. Similarly, the removal of tree foliage in total fiber harvest operations would affect the processes conducted by microorganisms in the soil litter.

Alteration of Soil Properties

The most widespread effects of timber harvesting on soil organisms are due to changes in the physical and chemical properties of the soil. Tree removal generally increases the levels of available water in the soil and raises soil temperatures (DeByle 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 slash disposal or site preparation. These changes in soil properties can greatly affect the numbers, diversity, and activity of the various soil organisms (Harvey and others 1976a).

1

IMPLICATIONS FOR FOREST MANAGEMENT

Of the many important functions of soil organisms likely to be influenced by timber harvesting, several are of special significance to forest management. These have to do with: the levels and availability of soil nutrients, the decay of woody plant material, and the 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 postharvest operations but, because of its large impacts on soil properties, will be discussed separately.

SOIL NUTRIENT LEVELS AND AVAILABILITY

Organic Matter Mineralization

Particular attention has been given to harvesting effects on the release of nutrients from nonwoody tree litter or from soil organic matter. This release, or "mineralization," of nutrients from organic materials by soil micro-organisms supplies a large portion of the nutrients required for tree growth. This is particularly true of 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 and others 1969). Inasmuch as the availability of most other soil nutrients is at least partially dependent upon the activity of soil microflora, changes in populations of soil micro-organisms may have important effects on nutrient availability and subsequent site productivity.

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

Increased activity by micro-organisms after logging is associated with increased soil temperature and (or) moisture levels in the cleared area. In certain instances, where timber harvesting has raised the ground water level to the soil surface or close to it, the reduction in soil oxygen levels can be severe enough to slow decomposition of organic matter (Bell and others 1974). In such operations as disking or bedding, where the litter is incorporated into the soil, decomposition of organic materials is greatly accelerated.

The significance of increased litter decomposition to the availability of soil nutrients and subsequent leaching losses depends on the site and on the type of harvesting operations. After clearcutting a Douglas-fir stand in Washington, Cole and Gessel (1965) found that the nutrients released after harvest remained in the root zone. Conversely, Pierce and others (1972), in their hardwood clearcutting study in New England, found nutrients significantly increased in the ground water and in neighboring streams. Investigators in the northern Rocky Mountain region have also reported increased losses of nutrients after harvesting (Hart and DeByle 1975); however, periods of accelerated nutrient losses are generally of short duration and continue only until the understory and herbaceous plants reestablish on the site, usually within a few years (Packer and Williams 1976).

Nitrogen Availability

Almost all nitrogen in the soil is present as organic forms and usually is the nutrient most limiting plant growth. Consequently, the effects of timber harvesting 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 nitrogen into organic complexes, the nitrification of ammonium to nitrate, the losses of nitrate from the soil by denitrification. The mineralization of ammonium from organic nitrogen complexes was discussed earlier.

Dinitrogen Fixation

In natural ecosystems, the atmosphere supplies nitrogen to the soil through the fixation of inert nitrogen gas into forms useful to plants. With the recent increases in fertilizer costs, greater interest has centered on increasing the amounts of nitrogen added to the soil by biological fixation. Most of this research has been agricultural, such as the much-publicized attempts to develop nitrogen-fixing strains of corn and wheat. Nitrogen fixation in certain forest ecosystems is of considerable importance, particularly for replacing nitrogen losses caused by harvesting or fire.

SYMBIOTIC ORGANISMS

Symbiotic nitrogen fixation is the result of an association between a higher plant and a micro-organism capable of fixing atmospheric nitrogen. The best known relationship of this type is between leguminous plants and the bacterial genus *Rhizobium*. Commercially important legumes, such as soybeans, peas, and alfalfa, have been found to add as much as 175 pounds of nitrogen/acre/year (200 kilograms/hectare/year) to the soil. Most work has centered on agricultural systems and, with the exception of black locust, little is known about the extent or significance of the *Rhizobium*-legume association in forest ecosystems (Wollum and Davey 1975).

Other nitrogen-fixing relationships between symbiotic organisms are found in a wide variety of nonleguminous plants. Over 100 plant species, including alder (*Alnus*) and snowbush (*Ceanothus*), form nitrogen-fixing root nodules (Youngberg and Wollum 1970). Appreciable amounts of nitrogen can be fixed by these nonleguminous plants. Field studies on snowbush and red alder have shown nitrogen additions of over 90 and 275 pounds/acre/year (100 and 300 kilograms/hectare/year), respectively (Wollum and Davey 1975).

Timber harvesting increases the contribution of nitrogen-fixing plants to soil nitrogen levels in the postharvest period. Clearcutting in the Douglas-fir region of western Washington and Oregon favors 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 also being considered in Southern pine stands (Jorgensen 1978). Additional information is needed on the distribution and function of nitrogen-fixing plants in forest stands and how their occurrence is affected by management practices.

NONSYMBIOTIC ORGANISMS

In contrast to the symbiotic nitrogen-fixing plants, the significance of free-living, nitrogen-fixing micro-organisms in soil is unclear. This group of organisms, with the exception of the autotrophic blue-green algae, are dependent on organic matter in the soil as an energy and carbon source. Generally, little nitrogen fixation by nonsymbiotic organisms occurs in agricultural soils (Jensen 1965); however, appreciable nitrogen gains have been reported in certain prairie, forest, and peat soils, where organic matter is not routinely removed form the site (Moore 1966).

Most soil and stand changes resulting from timber harvesting would favor non-symbiotic nitrogen-fixing organisms. The increases in soil temperature, pH, and moisture level after logging would all tend to raise nitrogen-fixation rates. Greater light penetration to the soil surface would also promote the activity of the nitrogen-fixing blue-green algae. Conversely, observed increases in soil ammonium and nitrate concentrations following harvesting could inhibit the nonsymbiotic nitrogen-fixing microflora.

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 after the harvest such increases in nitrogen fixation rates will continue is presently unknown.

Nitrification

The effects of forest practices on nitrification are receiving considerable attention because of nitrate pollution problems in ground water, streams, and lakes. 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 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, will drastically increase populations of nitrifying bacteria in certain soils. Clearcutting increased bacterial populations in New Hampshire and resulted in much higher levels of nitrate in neighboring water-sheds (Likens and others 1970); 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, to soil temperature and moisture pattern, and to soil texture (Stone 1973).

Denitrification

The effect of timber harvesting on losses of soil nitrogen through the biological conversion of nitrate to gaseous nitrogen forms is unknown. In fact, the extent of this nitrogen transformation occurring under forest conditions has hardly been investigated (Wollum and Davey 1975).

Logging operations have the potential of increasing 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).

4

An adequate supply of nitrate is of particular importance to the denitrifying bacteria. 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, but, at present, this is speculation.

INTERACTIONS WITHIN THE RHIZOSPHERE

In addition to symbiotic nitrogen-fixing relationships, other more subtle root-micro-organism interactions may also be affected by timber removal. The rhizosphere, or that portion of the soil immediately adjacent to and directly under the influence of the plant root, is a site of enhanced microbial activity. The metabolic products from the roots and associated microflora are important in mineral weathering. Boyle and Voigt (1973) attributed increased potassium availability and, subsequently, increased plant uptake to nutrient release within the rhizosphere (figure 1). Also, nitrogen fixation and denitrifcation rates are higher in the rhizosphere (Trolldenier 1977).
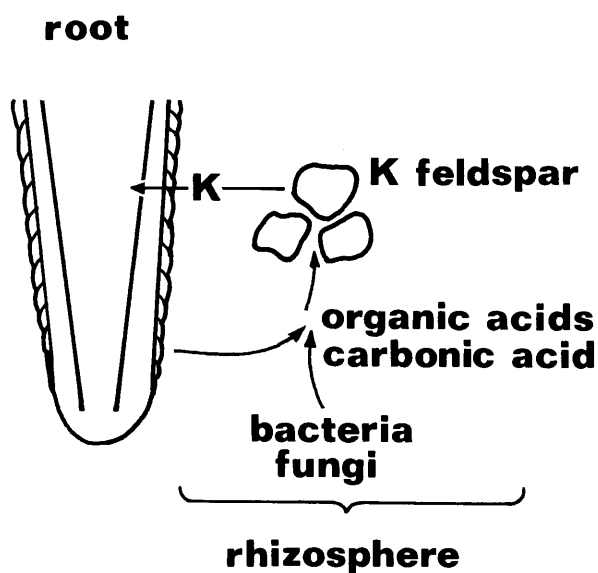
root

Figure 1.--Impact of rhizosphere microflora and plant roots on nutrient availability.

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

5

WOODY RESIDUE DECAY

Timber harvesting effects on the incidence of woody residue, in contrast to leaves, twigs, or bark, are being considered separately. 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 varying amounts and in different stages of decay may be found at the soil surface or partially imbedded in it.

Large woody residues can persist on a site for several hundreds of years. McFee and Stone (1966) found in northern New York that up to 30 percent of the surface foot of soil volume was made up of decayed wood. Harvey and others (1976b) demonstrated similar volumes of woody residues in a western Montana soil. These persistent woody materials are formed mostly from conifer residue by 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 decayed wood 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 1). A more favorable moisture regimen in decayed wood makes this substrate important for seedling establishment and subsequent stand growth. Seedlings of certain trees, such as birch and hemlock, are commonly observed growing on decaying logs.

Table 1.--*Nitrogen fixation rate (grams x 10^{-9} N/day/gram of dry soil) and moisture content (percent dry weight) from various forest sites in Montana, July 24, 1976*[1]

Stand and habitat type designation[2]	:	Humus	:	Decayed wood	:	First 5 cm of mineral soil	
Pseudotsuga menziesii (PSME/PHMA)	5.9	53	22.8	172		2.3	11
Larix occidentalis/P. menziesii (ABLA/CLUN)	15.8	146	32.3	301		3.2	36
Tsuga heterophylla (TSHE/CLUN)	39.5	201	30.6	226		2.1	23

[1]Determined by acetylene reduction technique (Hardy and others 1968).
[2]*Pseudotsuga menziesii/Physocarpus malvaceus*; *Abies lasiocarpa/Clintonia uniflora*; and *Tsuga heterophylla/Clintonia uniflora* are habitat type designations in western Montana (Pfister and others 1977).

Even for an older stand, the decayed wood fraction of the soil may play an important role, particularly on dry sites. Our recent studies in Montana have shown that decayed wood is a major site of mycorrhiza particularly during the dry portion of the growing season (table 2). Higher soil temperatures and reduced moisture levels in the surrounding mineral and litter layers restrict root colonization and growth of mycorrhizal fungi (Harvey and others 1976a). Decayed wood is generally more acid than other soil components, which favors development of mycorrhizal roots (Bowen and Theodorou 1973).

Table 2.--*Active ectomycorrhizal root tips/liter of soil from various forest sites,*
summer 1976[1]

Stand and habitat type designations[2]	:	Humus	:	Decayed wood	:	First 5 cm of mineral soil
Pseudotsuga menziesii (PSME/PHMA)		12.8		17.2		10.2
Larix occidentalis/P. menziesii (ABLA/CLUN)		109.8		26.2		16.7
Tsuga heterophylla (TSHE/CLUN)		203.7		108.4		41.8

[1]From Harvey and others 1978
[2]*Pseudotsuga menziesii/Physocarpus malvaceus*; *Abies lasiocarpa/Clintonia uniflora*; and
Tsuga heterophylla/Clinton uniflora are habitat type designations in western Montana
(Pfister and others 1977).

Our studies have also shown that decayed wood is a site of nitrogen fixation, both
in and on the soil (table 1). Of particular significance is the fact that on a dry
area, decayed wood was a more active site for nitrogen fixation than either the litter
or the mineral soil. In the Southeast, both decaying chestnut logs and the leaf litter
layer had comparable fixation rates (Cornaby and Waide 1973).

The impact of timber harvesting on the amounts of decayed wood on a site is
obvious--the more timber removed, the less residue remains to be incorporated into
the soil. More intensive residue utilization, coupled with fire as a slash disposal
method, could drastically alter this woody soil component; consequently, some woody
material should be left on certain sites after harvest to guard against long-term
reduction in site productivity. This may be especially true for those soils character-
ized by prolonged droughty conditions or by having low levels of soil nitrogen.

ACTIVITIES OF PLANT PATHOGENS

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

Disease incidence can also be affected by the increased amounts of available nutrients after logging. Fertilizer applications have aggravated some disease problems both in nurseries and in the field (Hesterberg and Jurgensen 1972). These nutrient additions influence the incidence of disease by changing the physiological condition of the fertilized tree. Certain nutrients, particularly nitrogen, can also affect the survival and growth of the saprophytic stage of many root pathogens (Huber and Watson 1974). It seems unlikely that the increased amount of nutrients available after harvesting would be sufficient to cause disease responses similar to those caused by fertilizer application, but this question needs to be further investigated.

FIRE

Considerable research has been done on the effects of both wildfire and prescribed fire on soil biology. Fire drastically reduces microorganisms, particularly bacteria in the surface soil horizons (table 3). The soil microflora usually recovers quite rapidly, frequently to a population level far greater than the original. In severe habitats, such as chaparral stands in California, recovery may be delayed (Dunn and DeBano 1977).

Table 3.--*Changes in populations of soil micro-organisms following burning*[1]

Site	Horizon	Sampling (after burn)	Treatment	Bacteria[2]	Fungi[2]
	inches	days			
Pseudotsuga menziesii (Oreg.)	0-1.5	210	Unburned	2,910	6
			Burned	119,500	38
P. menziesii (Oreg.)	0-2.0	2	Unburned	26,000	240
			Burned	60,000	136
	0-2.0	180	Unburned	33,000	570
			Burned	36,000	138
Pinus banksiana (Minn.)	0-1.0	35	Unburned	800	30
			Burned	710,000	100

[1]Ahlgren and Ahlgren 1965; Neal and others 1965; Wright and Tarrant 1957.
[2]Bacterial and fungal populations expressed in thousands/gm of dry soil.

Increased microbiological activity in burned soils can be related to a more alkaline soil pH, to increased carbon availability, and to higher ammonium levels found after fire. Soil nitrification rates are likely to 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 (table 4).

Organisms active in the nitrogen cycle have been of special concern since substantial losses of organic nitrogen can occur through volatilization during a fire (Knight 1966); however, gains of over 18 pounds of nitrogen/acre/year (20 kilograms/ hectare/year) were found on some sites in the Southeast that were burned annually over a 20-year period (Jorgensen and Wells 1971). Nitrogen gains after fires have been attributed to a larger legume component in the ground vegetation or to greater activity of nonsymbiotic nitrogen-fixing organisms (Stone 1971).

8

Table 4.--*Changes in available nitrogen and pH by burning*[1]

Site	Horizon	Sampling (after burn)	Treatment	pH	Ammonium	Nitrate
		days			- - - - p/m - - - - -	
Pseudotsuga menziesii (Oreg.)	0-2 in.	2	[2]Unburned	5.9	3	1
			Burned	5.9	38	4
Chaparral (Calif.)	0-1/2 in.	1	[3]Before	--	1	1
			After	--	7	1
Tsuga canadensis (Mich.)	Litter (0_1)	3	Unburned	4.8	75	27
			Burned	6.9	180	100
Larix occidentalis (Mont.)	Litter (0_2)	1	Before	6.0	15	17
			After	7.0	230	16

[1]Mroz and others 1979; Dunn and DeBano 1976; Neal and others 1965.
[2]Samples taken from a burned area and from an adjacent control.
[3]Samples taken from a particular site before and after a fire.

Prescribed fire can also have an effect on disease problems in subsequent stand development. Fire can sterilize and change the physical-chemical characteristics of the upper soil horizon. Frequently, feeder-root pathogens, such as *Fusarium* and *Phytopthora*, 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 Driver 1972). 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 decomposition of soil organic matter by micro-organisms with resultant increases in nutrient availability and in the leaching of nutrients through the soil. For most sites, these losses generally are small and last only a few years.

A different situation prevails 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 that can bring about high losses of nitrate nitrogen.

Interest is developing in the effects of tree harvesting on microorganisms that function in the cycling of nitrogen. Postharvest operations that include fire as part of site preparation have more effect on these organisms than do nonburning operations. As yet, an insufficient data base prevents definite conclusions as to whether these effects are generally detrimental or beneficial.

Harvesting effects on disease problems appear to be related to the amount and type of residue on the site. As more of this material is removed because of more intensive utilization standards, the incidence of disease should decrease. Fertilizers are known to favor certain disease organisms. Whether the increase in the availability of soil nutrients after fire or timber harvesting would cause a similar effect is unclear.

Most studies describing the impact of timber harvesting on the environment stress the loss of various nutrients in wood and their relation to the total nutrient budget; however, from the standpoint of soil biology, the loss of wood as a soil component may be of equal or of more importance to 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 these materials should remain on dry sites in the northern Rocky Mountains 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, postharvest treatment, soil and climatic differences that characterize forest conditions make it difficult to draw general conclusions; however, at this time, no widespread detrimental impact on site quality can be directly attributed to harvesting effects on the soil microflora. These environmental effects may change as harvesting systems emphasize more intensive use of the stand.

PUBLICATIONS CITED

Ahlgren, I. F., and C. F. Ahlgren.
  1965. Effects of prescribed burning on soil microorganisms in a Minnesota jack pine
    forest. Ecology 46:304-310.
Bell, M. A. M., J. M. Beckett, and W. F. Hubbard.
  1974. Impact of harvesting on forest environments and resources. Pac. For. Res. Cen.,
    Can. For. Serv., Victoria, B. C.
Bowen, G. D., and C. Theodorou.
  1973. Growth of ectomycorrhizal fungi around seeds and roots. In Ectomycorrhizae--
    their ecology and physiology, p. 107-150. G. C. Marks and T. T. Kozlowski, eds.
    Academic Press, New York.
Boyce, J. S.
  1961. Forest pathology. Third ed. 572 p. McGraw-Hill, New York.
Boyle, J. R., and G. K. Voigt.
  1973. Biological weathering of silicate minerals. Implications for tree nutrition
    and soil genesis. Plant and Soil 38:191-198.
Broadbent, F. E., and F. E. Clark.
  1965. Denitrification. In Soil Nitrogen, Agron. Monogr. 10, p. 347-362., W. V.
    Bartholomew and F. E. Clark, eds. Amer. Soc. Agron., Madison.
Cole, D. W., W. J. B. Crane, and C. C. Grier
  1975. The effect of forest management practices on water chemistry in a second-
    growth Douglas-fir ecosystem. In For. Soils and For. Land Manage., p. 195-208.
    B. Bernier and C. H. Winget, eds. Laval Univ. Press, Quebec.
Cole, D. W., and S. P. Gessel.
  1965. Movement of elements through forest soil as influenced by tree removal and
    fertilizer additions. In Forest Soil Relationships in North America, p. 95-104.
    C. T. Youngberg, ed., Oregon State Univ. Press, Corvallis.

Cornaby, B. W., and J. B. Waide.
  1973. Nitrogen fixation in decaying chestnut logs. Plant and Soil 39:445-448.
DeByle, N. V.
  1976. Fire, logging and debris disposal effects on soil and water in northern
    coniferous forests. *In* Proc. VII, IUFRO World Cong., Oslo, Div. 1, p. 201-212.
Dunn, P. H., and L. F. DeBano.
  1976. Effects of burning on chaparral soils. II. Soil microbes and nitrogen
    mineralization. Paper presented Ann. Meet. Soil Sci. Soc. Amer. Houston,
    December, 1976.
Dunn, P. H., and L. F. DeBano.
  1977. Fire effects on biological and chemical properties of chaparral soils.
    In USDA For. Serv. Gen. Tech. Rep. WO-3, p. 75-84.
Hardy, R. W. F., R. D. Holsten, E. K. Jackson, and R. C. Burns.
  1968. The acetylene-ethylene assy for N_2 fixation: laboratory and field evaluation.
    Plant. Physiol. 43:1185-1207.
Hart, G. E., and N. V. DeByle.
  1975. Effects of lodgepole pine logging and residue disposal on subsurface water
    chemistry. Watershed Management Symp., Amer. Soc. Chem. Eng., p. 98-109.
Harvey, A. E., M. F. Jurgensen, and M. J. Larsen.
  1976a. Intensive fiber utilization and prescribed fire: Effects on the microbial
    ecology of forests. USDA For. Serv. Gen. Tech. Rep. INT-28, 46 p.
Harvey, A. E., M. J. Larsen, and M. F. Jurgensen.
  1976b. Distribution of ectomycorrhizae in a mature Douglas-fir/larch forest soil in
    western Montana. For. Sci. 22:393-398.
Harvey, A. E., M. F. Jurgensen, and M. J. Larsen.
  1978. Role of residue in and impacts of its management of forest soil biology.
    Eighth World For. Congr. FAO Special Pap. 11 p.
Hepting, G. H.
  1971. Diseases of forest and shade trees of the United States. USDA For. Serv.
    Agric. Handbk. 386, 658 p.
Hesterberg, G. A., and M. F. Jurgensen.
  1972. The relation of forest fertilization to disease incidence. For. Chron.
    48:92-96.
Huber, D. M., and R. D. Watson.
  1974. Nitrogen form and plant disease. Anu. Rev. Phytopath. 6:139-166.
Jensen, H. L.
  1965. Nonsymbiotic nitrogen fixation. *In* Soil nitrogen, Agron. Monogr. 10,
    p. 436-480. W. V. Bartholomew and F. E. Clark, eds. Am. Soc. Agron., Madison.
Jorgensen, J. R.
  1978. Growth of legumes on forest soils fertilized at low rates. USDA For. Serv.
    Res. Note SE-251, 7 p.
Jorgensen, J. R., and C. G. Wells.
  1971. Apparent nitrogen fixation in soil influenced by prescribed burning. Soil
    Sci. Soc. Amer. Proc. 35:806-810.
Knight, H.
  1966. Loss of nitrogen from the forest floor by burning. For. Chron. 42:149-152.
Likens, G. E., F. H. Bormann, N. M. Johnson, D. W. Fisher, and R. S. Pierce.
  1970. Effects of forest cutting and herbicide treatment on nutrient budgets in the
    Hubbard Brook watershed ecosystem. Ecol. Monogr. 40:23-47.
McFee, W. W., and E. L. Stone.
  1966. The persistence of decaying wood in humus layers of northern forests. Soil
    Sci. Soc. Amer. Proc. 30:513-516.
Moore, A. W.
  1966. Nonsymbiotic nitrogen fixation in soil and soil-plant systems. Soils Fert.
    29:113-129.

Morgan, R., and C. H. Driver.
  1972. *Rhizina* root rot of Douglas-fir seedlings planted on burned sites in Washington. Plan Dis. Rep. 56:402-409.
Mroz, G., M. F. Jurgensen, A. E. Harvey, and M. J. Larsen.
  1979. Effect of fire on total and available nitrogen in forest soils. Soil Sci. Soc. Amer. J. (Accepted for Publication).
Mulder, E. G., T. A. Lie, and J. W. Woldendorp.
  1969. Biology and soil fertility. *In* Soil biology, reviews of research. Nat. Resour. Res. UNESCO 9:163-208.
Neal, J. L., E. Wright, and W. B. Bollen.
  1965. Burning Douglas-fir slash. Physical, chemical, and microbial effects in soil. Oregon State Univ. For. Res. Paper 1, 32 p.
Packer, P. E., and B. D. Williams.
  1976. Logging and prescribed burning effects on the hydrologic and soil stability behavior of larch/Douglas-fir forests in the Northern Rocky Mountains. Proc. Tall Timbers Fire Conf. 14:465-479.
Pfister, R. D., B. L. Kovalchik, S. F. Arno, and R. C. Presby.
  1977. Forest habitat types of Montana. USDA For. Serv. Gen. Tech. Report INT-34, 174 p.
Piene, H.
  1974. Factors influencing organic matter decomposition and nutrient turnover in cleared and spaced, young conifer stands on the Cape Breton Highlands, Nova Scotia. Can. For. Serv. Inf. Rep. M-X-41, 31 p.
Pierce, R. S., C. W. Martin, C. C. Reeves, G. E. Likens, and F. H. Bormann.
  1972. Nutrient loss from clearcuttings in New Hampshire. *In* Watersheds in transitions, p. 285-295. Amer. Water Res. Ass. Proc. Ser. 14.
Reinhart, K. G.
  1973. Timber-harvest clearcutting and nutrients in the northeastern United States. USDA For. Serv. NE-170, 5 p.
Schultz, R. P.
  1976. Environmental change after site preparation and slash pine planting on a flatwoods site. USDA For. Serv. Res. Pap. SE-156.
Stone, E. L.
  1971. Effects of prescribed burning on long-term productivity of coastal plain soils. *In* Proc. Prescribed Burning Symp., p. 115-127. USDA For. Serv., Southeast For. Exp. Stn.
Stone, E. L.
  1973. The impact of timber harvest on soils and water. *In* Report of the President's Advisory on Timber and the Environment, p. 427-467, April 1973.
Trolldenier, G.
  1977. Influence of some environmental factors in the rhizosphere of rice. Plant and Soil 47:203-218.
Wollum, A. G., II, and C. B. Davey.
  1975. Nitrogen accumulation, transformation, and transport in forest soil. *In* Forest Soils and Forest Land Management, p. 67-106. B. Bernier and C. H. Winget eds. Lavel Univ Press, Quebec.
Wright, E., and W. B. Bollen.
  1961. Microflora of Douglas-fir soil. Ecology 42:825-828.
Wright, E., and R. F. Tarrant.
  1957. Microbiological soil properties after logging and slash burning. USDA For. Serv. Pac. NW Forest and Range Exp. Stn. Res. Note 157, 5 p.
Youngberg, C. T., and A. G. Wollum II.
  1970. Non-leguminous symbiotic nitrogen fixation. *In* Tree growth and forest soils, p. 383-395. C. T. Youngberg and C. B. Davey, eds. Oregon State Univ. Press, Corvallis.

Jurgensen, M. F., M. J. Larsen, and A. E. Harvey
    1979. Forest soil biology-timber harvesting relationships: a
    perspective. USDA For. Serv. Gen. Tech. Rep. INT-69, 12 p.
    Intermt. For. and Range Exp. Stn., Ogden, Utah 84401.

    Timber harvesting has a pronounced effect on the soil micro-
flora by wood removal and changing properties. This paper gives a
perspective on soil biology-harvesting relationships with emphasis
on the northern Rocky Mountain region. Of special significance to
forest management operations are the effects of soil micro-organisms
on: the availability of soil nutrients, particularly nitrogen; the
decay of woody plant material; and tree disease incidence. At
present, no widespread detrimental impact on site quality in the
northern Rocky Mountain region can be directly attributed to
harvesting effects on the soil microflora.

Headquarters for the Intermountain Forest and Range Experiment Station are in Ogden, Utah. Field programs and research work units are maintained in:

Billings, Montana

Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Provo, Utah (in cooperation with Brigham Young University)

Reno, Nevada (in cooperation with the University of Nevada)