Sustaining
Minnesota Forest Resources:
Voluntary Site-Level
Forest Management Guidelines
for Landowners,
Loggers and Resource Managers

The Minnesota Forest Resources Council (MFRC) was charged under the Sustainable Forest Resources Act of 1995 with coordinating the development of site-level timber harvesting and forest management guidelines. In response to this mandate, the MFRC convened four multi-disciplinary technical teams to develop guidelines for riparian zone management, wildlife habitat, historic/ cultural resources and forest soil productivity. The technical team guidelines were developed through consensus over a two-year period and then integrated to produce a single set of guidelines.

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The Value of Forest Soil Productivity

Sustainable Soil Productivity

Soil productivity is defined as the capacity of soil, in its normal environment, to support plant growth. Soil productivity is reflected in the growth of forest vegetation or the volume of organic matter produced on a site. In forest management, soil productivity is most often measured in volume of trees produced; however, other methods of determining productivity exist, including forest community assessments.

"Minnesota's forest soils are a fundamental resource on which rests the ability of our forests to provide a wide variety of benefits."

Jaakko Pöyry 1992

The goal of these guidelines is to maintain the productive capacity of forest soils in Minnesota. A decrease in soil productivity could affect the level of timber harvesting the forest can sustain, as well as other forest values, such as wildlife habitat and biodiversity. Identifying and reducing impacts to this resource should be an essential part of any strategy to achieve sustainable forest management.

A certain amount of soil impact is inevitable when conducting some forest management activities. Many of the recommended practices are aimed at keeping this impact to a minimum level and affecting only a small percentage of a forest site.

Benefits of Forest Soil Productivity

Soil is the fundamental resource of the forest. Without it or its productive capacity, the other resources of the forest are diminished. Primary benefits of soil productivity include the following:

❒ Maintaining soil productivity is an important consideration in determining the level of timber harvesting the forest can sustain, as well as other forest values, such as wildlife habitat and biodiversity.

❒ Maintaining soil productivity sustains forest soils in a condition that favors regeneration, survival and long-term growth of desired forest vegetation.

❒ Maintaining soil productivity is key to sustainable forest management.

❒ Maintaining forest soil productivity is less costly than correction or mitigation, such as trying to fix damaged soils after the fact.

❒ Soil productivity influences what plants can grow on a site (or in the forest) and how well they grow.

❒ Maintaining the sustainability of forest soils is key to meeting society's need for forest products and other amenities of the forest.

Using Guidelines To Maintain Soil Productivity

Desired Overall Outcomes

These guidelines have been designed to lead to the following outcomes for all forest management activities:

❒ Increasing awareness and understanding of soil impacts caused as a result of forest management activities among forest landowner, resource managers, loggers, equipment operators and others involved in forest management.

❒ Maintaining forest soil conditions to favor regeneration, survival and long-term growth of desired forest vegetation.

❒ Minimizing the forest area occupied by roads, landings and primary skid trails.

❒ Encouraging the use of alternate equipment and operating techniques that avoid or reduce impacts to soils, so that forest management activities can be conducted with little or no reduction in soil productivity.

Soil Productivity and Sustainable Forest Management

Soil plays an important role in forest growth and management. It provides moisture and nutrients for tree growth, serves as a medium for root growth, and physically supports the equipment used in harvesting, yarding and other operations.

Maintaining soil productivity is critical to sustainable forest management. A decrease in soil productivity could affect the level of harvesting the forest can sustain, as well as other forest values, such as wildlife habitat and populations, and biodiversity.

Disturbances initiated by intensive forest management can have diverse impacts on the physical, chemical and biological characteristics of soils, which can, in turn, impact long-term productivity. For example:

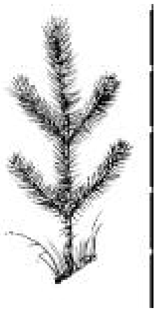
❒ Features such as access roads, landings and primary skid trails result in significant reduction of the productive capacity of the soils directly beneath them.

❐ Severe nutrient depletion reduces soil fertility, directly affecting vegetation growth.

❐ Soil compaction and associated disturbances reduce and disrupt soil porosity, thereby restricting water and air movement into and through the soil. This results in poor soil aeration, which negatively affects root growth and the activity of soil organisms involved in nutrient cycling and other processes.

❐ Compaction also increases soil resistance to root penetration, thus limiting the volume of soil available for root exploitation.

❐ Accelerated soil erosion leads to the removal of surface soil material and increased sedimentation of surface waters.



Some of these impacts (such as the development of roads, landings and skid trails) are an unavoidable consequence of forest access and utilization. These guidelines are intended to minimize negative impacts to soil productivity and ensure the continued sustainability of forest management in Minnesota.

When planning forest management activities, prevention of negative impacts is more desirable than correcting impacts after they have occurred. Mitigation of impacts to the soil after they have occurred can be costly and may not be very effective. It is more effective to prevent impacts from occurring than to resort to such mitigation measures as deep subsoiling, constructing erosion control devices, fertilization or filling in ruts.

Pre-planning and on-site soil investigation are good tools for avoiding negative soil impacts. Soil conditions should be evaluated to determine suitable species, preferred seasons of operations, and preferred site preparation and regeneration techniques.

For example, soils susceptible to severe compaction or rutting under typical climatic conditions should be identified as requiring harvest under frozen ground conditions or with specialized equipment.

Predicting the operability of a site will help protect the site, as well as save operators from the costly process of moving equipment off a site after discovering that negative impacts are occurring. If unique weather conditions occur or specialized equipment is available, these soils may be operable under non-frozen conditions.

Applying Guidelines to Varying Site Conditions

Forests in Minnesota grow on a wide variety of soils and site conditions:

❒ **Hundreds of different "soil types" have been identified** in the forested portions of Minnesota. These soils include deep organic soils in peatlands; shallow soils over bedrock; dry sandy soils formed in outwash or beach deposits; deep moist loamy and clayey soils formed in rolling glacial till; and poorly drained fine loamy and clayey soils formed in level lake plains.

❒ **Topography also varies greatly** in Minnesota forest regions, from steep long valley slopes in the southeast to nearly flat lake plains or short steep irregular slopes of the northern forests. Each site presents unique conditions and opportunities.

Because of the great variety of soils and site conditions in Minnesota's forested areas, it is impossible to develop guidelines that cover every situation. These guidelines are intended as a set of general recommendations to be applied to forest management in Minnesota.

Because site conditions vary, it is very important that individuals making forest management decisions evaluate the soil conditions on the site they are considering. Specific soil conditions will allow the manager to develop specific prescriptions for a given site that will ensure that the productive capacity of a site is not reduced due to forest management.

Soil Characteristics and Potential Impacts

Three Related Groups of Soil Characteristics

These guidelines refer to physical, chemical and biological aspects of soils. These three characteristics are closely interrelated, and impacts on one aspect may influence others:

- ❐ The physical properties of soil include such factors as soil texture, structure, porosity, soil density, drainage and surface hydrology.
- ❐ The chemical properties of soil include nutrient status (inputs and outputs) and pH.
- ❐ The biological properties of soil include the multitude of organisms that thrive in soil, such as mycorrhizae, other fungi, bacteria and worms.

Because of the nature of forest management activities in Minnesota, the risk or significance of impacts to soil properties appears to be highest for physical properties, followed by chemical properties, and finally by biological properties.

For example, in Minnesota, forest management sites with reduced growth because of nutrient loss due to timber harvesting are relatively uncommon, while sites that have suffered due to physical impacts are more common. Impacts to physical characteristics also appear to be more long lasting.

In addition, it appears that, if care is taken not to negatively impact the physical and chemical properties of the soil, then the biological aspects take care of themselves. However, if a soil is severely compacted, then forest plants cannot utilize nutrients because of the poor physical rooting environment, and the soil organisms responsible for nutrient cycling are limited as well.

Physical Characteristics of Soil and Potential Impacts

Soil physical properties include soil texture, structure, porosity, soil density, drainage and surface hydrology. These properties are very important in influencing what plants can grow on a site and how well they grow.

The physical soil properties determine the ease of root penetration, the availability of water and the ease of water absorption by plants, the amount of oxygen and other gases in the soil, and the degree to which water moves both laterally and vertically through the soil.

Soil Compaction

According to Jaakko Pöyry (1992), "Soil compaction is one of several types of closely related physical soil disturbances that can occur during timber harvesting and forest management activities. The other types of physical soil disturbance include puddling, rutting and scarification. These disturbances often occur simultaneously and are almost exclusively caused by:

1) Trafficking by heavy equipment during felling, forwarding, skidding and site preparation operations

2) The dragging action of logs as they are moved from the stump to the landing

3) Slash disposal and the creation of planting or seeding sites during site preparation

"It is difficult to distinguish between each type of disturbance in terms of their effect on site properties, and all of these disturbances are often referred to generically as soil compaction.

"Soil compaction is the increase in soil density resulting from loads applied to the soil surface. During the compaction process, soil volume is decreased primarily through the elimination of macropores (pores > 0.002 inches in diameter). Pore volume and pore size are key properties that govern gas and water relations in the soil. Because of their relatively large diameter, macropores are particularly important in regulating the rates of water and gas movement."

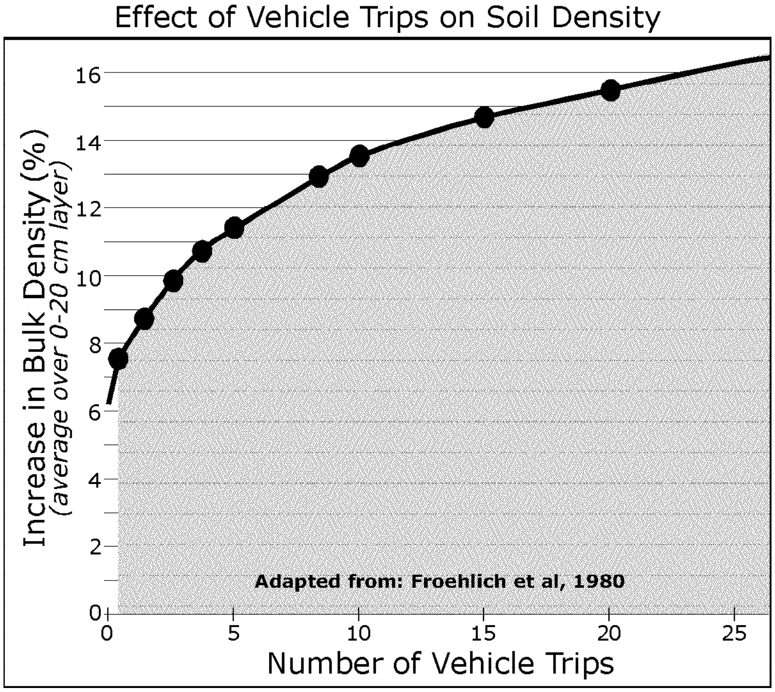


Figure S-1

The first few trips (with heavy equipment) over the soil surface produce the greatest increase in soil density. A large percentage of the increase in soil density occurs during the first six trips on some soils (Froehlich et al 1980). (See Figure S-1.) Machine vibration may also contribute to compaction.

Recovery of compacted soil is variable depending on the severity of the compaction and local conditions. Most studies, however, indicate that recovery from compaction and its effects is long term rather than short term.

Severely compacted soils may require up to 40 years or more to recover naturally, according to Hatchell and Ralston (1971). Froehlich and McNabb (1984) state that "...the effects of soil compaction should be assumed to persist for several decades on forest sites."

Even in cold climates, where the action of freezing and thawing presumably loosens soils quickly, the density of compacted soils decreases slowly (Voorhees 1983 and Corns 1988). In an ongoing study in Minnesota and the Lake States (Stone and Elioff 1998), no reduction in soil density has been measured 5 years after intentional compaction.

"Soil compaction affects site quality and tree growth through its effect on the rooting environment....Reduced aeration significantly decreases the respiratory activity of plant roots and their capacity to supply the plant with adequate moisture and nutrients" (Jaakko Pöyry 1992).

"Compaction also increases soil strength, which reduces root growth by increasing soil resistance to root penetration....The decrease in porosity associated with compaction also reduces soil infiltration capacity or the rate of water movement in the soil....In addition to reducing the amount of soil water available for plant growth, slower infiltration capacities result in increased amounts of over-land flow, which can lead to increased erosion rates" (Jaakko Pöyry 1992).

Rutting

Rutting is the creation of depressions made by the tires of vehicles such as skidders, log trucks and pickup trucks, usually under wet conditions. Rutting occurs when the soil strength is not sufficient to support the applied load from vehicle traffic. A few examples of the effects of rutting:

❒ Rutting affects the surface hydrology of a site as well as the rooting environment. The process of rutting physically severs roots and reduces the aeration and infiltration of the soil in the rut itself, thereby degrading the rooting environment.

❒ Rutting also disrupts natural surface water hydrology by damming surface water flows, creating increased soil saturation up-gradient from ruts, or by diverting and concentrating water flows, creating accelerated erosion.

❒ Soil rutting is also an important indication that other physical soil impacts may be occurring on a site.

Protecting Soil Resources

Timing of forest management activities, development of infrastructure, and selection of equipment and operating techniques are all critical components contributing to the effectiveness of forest management activities, as well as the protection of the soil resource. It is important to avoid operating heavy equipment on a site when adverse soil impacts are likely, and to limit direct trafficking of a site to the smallest area possible.

The susceptibility of soil to compaction and rutting is primarily dependent on soil texture and moisture content. Soils are most susceptible to compaction, puddling and rutting during spring/ early summer months, immediately following heavy rains, and in the fall after transpiration has ceased and before freeze-up.

Soils most susceptible to compaction and rutting include fine-textured soils (silty clay, sandy clay and clay) and medium-textured soils (fine sandy loam, very fine sandy loam, loam, silt loam, silt, silty clay loam, clay loam, and sandy clay loam). Poorly and very poorly drained soils of any texture are susceptible to compaction and rutting during most years when not frozen.

The preferred operating season for any one site may vary depending on local climatic conditions, equipment being used and operating techniques. The use of low ground pressure (LGP) equipment and such operating techniques as the use of slash mats to drive on can extend operating seasons on low-strength soils. Infrastructure, such as roads, landings and skid trails, directly impacts the soils that it is developed on; therefore any reduction in the area occupied by infrastructure reduces the impact to soil productivity. For more information on how to obtain soil interpretations relating to equipment operation, see *Resource Directory.*

Peatland Timber Harvests

Peatlands are a unique ecosystem producing valuable wood products. These soils pose specific management concerns and harvesting issues, including low soil strength and low nutrient status.

Typically these sites are harvested when soils are frozen. New technologies and equipment allow harvesting on theses sites under non-frozen conditions with minimal impact. LGP equipment, including eight-wheeled tracked forwarders, portable artificial mats, natural slash mats and cable logging systems, are all options for completing harvesting with an impact on soil productivity that is similar to conventional winter harvest methods.

These technologies are especially suitable for shallow organic soils adjacent to high land (likely to a maximum of 500 feet) and on pockets of organic soils within highland soils. Timber harvesting on deep peat soils under non-frozen conditions in large peatlands is not practical because of low soil strength and lack of truck access.

Soil Erosion

Soil erosion is another type of physical soil impact that can occur as a result of soil disturbance during timber harvesting, site preparation and other forest management activities. Soil erosion is the process by which soil particles are detached and transported by water, wind and gravity to some downslope or downstream point. Erosion is a natural process. Increased erosion that occurs due to human activity is considered to be accelerated erosion.

Almost all accelerated erosion on forested lands in Minnesota follows major disturbances that increase the exposure of soil to water (Patric and Brink 1977, as cited in Jaakko Pöyry 1992). Several factors can influence the rate of soil erosion on a site: rainfall intensity and duration, slope steepness and slope length, erodibility of the soil on the site, and soil cover (overstory and surface cover) (Dissmeyer and Foster 1980).

When all other factors are held constant, surface erosion rates increase with increasing rainfall intensity, increasing slope steepness, and increasing slope length (Jaakko Pöyry 1992). Perhaps the greatest factor controlling surface erosion in forests is the amount of vegetative cover and forest litter protecting the soil surface (Megahan 1990, as cited in Jaakko Pöyry 1992).

Soils with the highest inherent erodibility contain high proportions of fine sand and silt, low amounts of soil organic matter, and slow permeability. Table S-1 shows the relative erodibility hazard for different soil textures. Extra care should be taken on silt, silt loam, loam, very fine sandy loam, sandy clay loam, silty clay loam and clay loam soils, as these soils tend to erode easily when disturbed or exposed, especially on long slopes or slopes greater than 10%.

Table S-1

Soil Erosion Susceptibility of Texture Classes

Surface Soil Texture	Susceptibility to Erosion
Silt, silt loam, loam, very fine sandy loam	1 (highest)
Sandy clay loam, silty clay loam, clay loam	2
Clay, silty clay, sandy clay, very fine loamy sand, fine sand loam	3
Sandy loams	4
Loamy sands, sands	5 (lowest)

According to the 1994 Generic Environmental Impact Statement Study on Timber Harvesting and Forest Management in Minnesota (GEIS), the greatest erosion rates in Minnesota were estimated to occur in southeastern Minnesota. The potential for erosion in this part of the state is approximately two to three times the estimated rates of the rest of the state. This landscape has the steepest slopes (averaging 45% in many areas), and the southern portion of the state also has the highest rainfall intensity (Jaakko Pöyry 1994).

Soil erosion impacts the long-term productivity of a soil by removing nutrients and surface soils (which contain a high percentage of nutrients and water-holding capacity of soil). This eroded material (sediment) is then deposited on top of downslope soils, covering up richer surface soils with less productive material. Erosion on skid trails and roads reduces the ability of the soils in the trail or road to revegetate. It also tends to create a poor transportation system that encourages the creation of more trails and roads to replace the eroded ones.

Accelerated erosion is caused by forest management activities that result in the following:

- ❒ Removal of vegetation and litter, or disturbance of surface soil, which exposes mineral soil to rain and water.
- ❒ Soil compaction, which decreases the rate of water infiltration into the soil.
- ❒ Concentration of surface runoff (Jaakko Pöyry 1992). Areas of soil disturbance, such as roads, landings, skid trails, fire lines and site prep areas, can all create soil erosion problems.

For timber harvest areas, the GEIS suggests that mitigation strategies be concentrated around forest roads, skid trails and landings. If the guidelines for reducing compaction and related disturbances are followed, erosion will be reduced. Soil compaction, puddling, rutting and scarification decrease the rate of water movement into the soil, which increases overland flow, channels and concentrated surface runoff, and reduces protective surface cover (Jaakko Pöyry 1992).

One of the most effective means of reducing erosion is to reduce the volume, velocity or distance of travel that water flows down a road, landing or skid trail. This reduction can be accomplished using various water diversion techniques identified in *Protecting Water Quality and Wetlands in Forest Management: Best Management Practices in Minnesota* (1995).

Implementing practices identified in the BMP guidebook will prevent erosion concerns in most situations. However, erosion control practices as stated in the guidelines should be applied to all sites, not just those sites with direct impact to water quality.

Chemical Characteristics of Soil and Potential Impacts

Soil chemical properties include nutrient status of a soil and soil pH. Soil chemical characteristics are influenced by many things, including soil origin, soil texture and drainage, degree of soil weathering and development, and organic matter type and content. These characteristics vary widely in Minnesota's soils. Forest management affects the nutrient status of a soil/site through 1) removal of nutrients in forest products and 2) disturbance of surface soils through harvesting and site preparation activities.

Nutrient Cycling

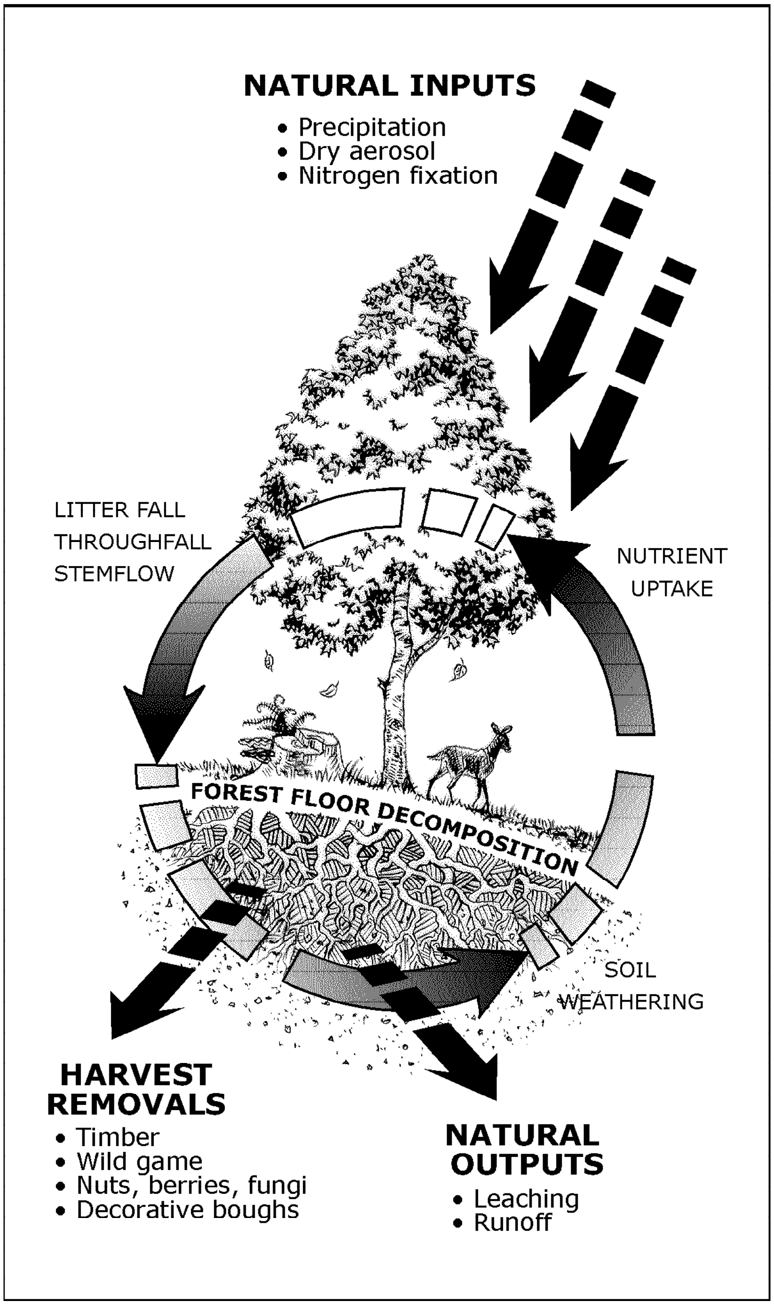
Nutrient cycling is the process by which nutrient elements move into, out of, and within an ecosystem. The forested ecosystem in Minnesota receives natural inputs of nutrients through atmospheric deposition and geologic weathering. See Figure S-2.

Through the life of a stand, these inputs can be significant. Outputs of nutrients occur through timber harvesting or other practices (such as site preparation) and through soil leaching and surface runoff (Jaakko Pöyry 1992).

In Minnesota and adjoining areas, nutrients that are of primary concern for forest growth are nitrogen (N), phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg). Complete understanding of nutrient use and sustainability requires not only knowledge of the amount of nutrients removed during the harvest (or through poor site preparation techniques), but also knowledge of the nutrient capital of the soil and the rates of natural additions and losses of those nutrients.

Figure S-2

Nutrient Cycling



In contrast to the annual harvests associated with agriculture, forest harvest—and hence nutrient removal—typically occurs only once per rotation or every 40 to 120 years. This not only reduces the rate of removal, but the long-time interval makes natural additions of nutrients by atmospheric deposition and by weathering of soil minerals very important in maintaining nutrient status.

In agriculture, deficiencies of macronutrients have occurred when the rate of nutrient removal via harvest exceeds the reserves in the soil and the annual replenishment through natural processes.

In forest ecosystems, timber harvesting and some site preparation practices remove nutrients and have the potential to create deficiencies if the removal of nutrients through these practices is greater than the replenishment through natural processes during the time between harvests and the amount of nutrients removed from harvest represents a large portion of the soil reserves.

The Balance of Inputs and Outputs

“A long-term view of forest nutrient status of an ecosystem must focus on the balance of inputs and outputs as they affect the nutrient capital. The nutrient capital can be considered to be a resource that can be used by trees, but whose availability depends on the internal dynamics of the system. If inputs of nutrients to a forest ecosystem exceed outputs from that system, then the nutrient capital in the system will increase. Conversely, if outputs exceed inputs, nutrient capital will decrease” (Jaakko Pöyry 1992).

The initial nutrient capital of a site varies widely by soil type. For example, a fine loamy soil formed in lacustrine sediment may contain four times the amount of calcium in the rooting zone than a well-drained sandy soil formed in outwash deposits (Jaakko Pöyry 1992).

Outputs can occur through timber harvesting, removal of slash or surface soil during site preparation, burning, leaching or surface runoff. Most macronutrients that are removed from a site through timber harvest are replaced over the period of the rotation by nutrient inputs through such processes as precipitation, dust deposition and nitrogen fixation. Some notable exceptions are calcium after harvesting aspen stands, and phosphorous and potassium after harvesting on organic soils (Jaakko Pöyry 1992).

Different nutrients are stored in different parts of a tree, and different tree species store the nutrients in different relative abundances throughout the tree. For example, aspen utilizes a relatively high amount of calcium and stores roughly 50% of the calcium in the bole-wood and bark of the tree. Because nutrients that are contained within the harvested portion of a tree are removed from a site, species that store high amounts of nutrients in the bole-wood and bark result in higher amounts of nutrient removed when harvested.

Nutrient removal associated with timber harvest is very dependent on the species being harvested and on the components, or parts of the trees, being removed. For example, a full-tree harvest during the growing season will remove virtually all the nutrients stored in the above-ground part of the trees.

In the case of merchantable bole harvest, with limbing at the stump, the nutrients in the crown and in the upper portion of the woody stem (above the merchantable top diameter) are retained on the site. If trees are skidded to a landing before limbing, then the nutrients in the crown are removed from the actual site of growth as well (Jaakko Pöyry 1992).

Mineral Soils

An analysis of data that were available at the time of the GEIS indicated that, on some sites, some nutrients were being removed by the harvest at a greater rate than the rate of natural additions (defined as *mining* by the GEIS). On mineral soils, the nutrient that was most often of concern was calcium; other nutrients were seldom lost at greater rates than additions.

This caused concern about the relationship of calcium loss to sustainability of forest production. Recent studies have produced additional information indicating that the issue of calcium depletion is less significant than indicated in the 1992 GEIS (Wilson and Grigal 1995).

In summary, the mineral soil sites for which nutrient depletion may become a concern after two or three rotations include aspen (or other hardwoods) on well-drained sandy soils and aspen (or other hardwoods) on shallow (8 inches or less) to bedrock soils.

Aspen grow poorly on these soils, and are often termed "off-site aspen." A rational management strategy for these sites is conversion to pine (red or jack pine) where appropriate. Both pines are more productive on these sites, and they demand much less calcium. On other upland sites, nutrient depletion is usually not an acute problem, but one that can be further studied and dealt with in the future without affecting sustainability.

Other nutrient-retention strategies for these sites include the following:

❐ Retaining or redistributing slash on the site

❐ Avoiding full-tree harvesting or full-tree skidding that piles slash without redistributing it

❐ Addition of nutrients to the site

❐ Avoiding shortened rotations

Many modern harvesting systems require full-tree skidding for efficiency of the operation. In these situations, slash can be redistributed out to the site from the landing. Caution should be exercised during non-frozen seasons to avoid trafficking additional areas while redistributing slash. The negative effects of soil compaction due to increased trafficking could outweigh the positive benefits of redistributing slash. It may be advantageous to leave clumps of slash (drags left along skid trails) or leave slash in the skid trails.

Organic Soils

Most deep organic soils in Minnesota (soils with greater than 24 inches of organic surface) contain a relatively low amount of phosphorus (P) and potassium (K) in the rooting zone of the organic soil surface. Deep organic soils do not have a nutrient input of mineral weathering to replenish nutrients; instead, these soils depend solely on atmospheric deposition.

Black spruce is the major species harvested on peatland soils, and many harvesting techniques remove the full tree from the site, including branches and needles. In the case of organic soils, available evidence indicates that this removal of the full tree leads to removal of a large proportion of the potassium and a relatively large proportion of the phosphorus from the site. Rates of replenishment for P and K are low; about 100 years are required to rebuild K reserves to their original level after harvest.

Removal of only the woody bole and associated bark does not lead to these large losses of potassium and phosphorus. Thus, full-tree harvest may be inappropriate without corrective measures such as fertilization. Site preparation techniques that pile or windrow slash result in a similar removal of nutrients from the general area of a site. These practices have an effect similar to full-tree harvesting.

Mechanical Site Preparation

Many mechanical site preparation techniques involve the disturbance, redistribution and possibly the removal of surface soils. The surface horizons of most forest soils are very important to the productivity of the soil. These horizons are rich in organic matter; they contain the bulk of the soil's nutrient and moisture-holding capacity; and they provide a source of mychorrizae. Surface horizons also cushion soil from traffic and buffer extremes in temperature. Severe treatments that remove or displace the surface organic and mineral soil layer may result in nutrient removal and other site degradation, such as soil erosion and compaction.

It is important to remove the surface soil as little as possible from the immediate area of the seedling. Practices that remove surface soil from the general vicinity of a seedling (such as dozing soil into windrows) should be avoided, as these practices remove the many benefits of surface soil from the area utilized by a seedling.

The removal of surface soil is exaggerated with extremes of soil types. In other words, coarse dry soils and wet fine soils, or soil shallow to bedrock, are most likely to be severely impacted from surface soil removal. "Extremely shallow soils have a limited store of nutrients and are sensitive to disturbance, as are coarse-textured, excessively well-drained soils, whose limited nutrient reserves resides principally in the surface organic layer and in logging debris. Any treatment of such sites should retain as much of the organic layer and any logging debris as possible or mix the organic and mineral layers together" (Sutherland and Foreman 1995).

Slash provides shelter that mediates climatic extremes and contributes organic matter (nutrients and water-holding capacity) to forest soils. Although slash may create some hardship when planting a site, windrowing or piling of slash should be avoided, and scattering of slash should be encouraged. This is particularly important on coarse droughty soils.

According to the forest soils technical paper of the GEIS (Jaakko Pöyry 1992): "There is virtually no justification, from the standpoint of nutrient status, for use of any site preparation technique that displaces material. Site preparation techniques that incorporate materials (such as disking) or only displace materials short distances (such as the Brakke scarifier) do not have negative impacts on nutrients."

Prescribed fire is used to reduce slash for ease of planting, setting back or killing competing vegetation, or exposing mineral soil for seeding. "Hot" slash burns on dry sandy soils have the potential to reduce soil productivity by consuming the forest floor, which reduces the water-holding capacity of these sites, volatilizes some nutrients, and makes nutrients rapidly available to plant uptake, runoff or leaching.

Biological Characteristics of Soil and Potential Impacts

Biological characteristics of soil include the population of plants and animals that thrive in a particular soil, including microflora (fungi, bacteria, algae) and microfauna (worms, arthropods, protozoa). Forest soils contain a multitude of microorganisms that perform many complex tasks relating to soil formation, slash and litter disposal, nutrient availability and recycling, and tree metabolism and growth. Generally the number of organisms are greatest in the forest floor and the area directly associated with plant roots (Pritchett 1979).

The population of soil organisms (both density and composition) and how well that population thrives is dependent on many soil factors, including moisture, aeration, temperature, organic matter, acidity and nutrient supply (Pritchett 1979).

These physical and chemical soil characteristics are influenced by forest management as previously indicated. Impacts to these soil properties may directly impact the soil biology, thereby impacting the functions of the organisms, many of which are beneficial to plant growth. Implementation of practices that protect the physical and chemical properties of the soil, also protect the "habitat" of the soil organisms and result in sustaining these populations.

Enhancement of Soil Productivity

In addition to guidelines to mitigate against potential negative impacts to soil productivity, opportunities exist to enhance soil productivity. In these guidelines, the term **enhancement** is defined as **improving the current productive potential of a site or fully expressing the productive capacity of a site.**

To sustainably meet society's need for forest products and other amenities of the forest, intensive management of a portion of the forest resource may be necessary. The following section describes some of the available options to improve productivity.

Fertilization

Fertilization is often used in agriculture to improve outputs of a particular crop and maintain productivity. In forestry, opportunities exist to increase fiber outputs through fertilization.

Limited research has been done on fertilization of species common in Minnesota. Recommendations for forest fertilization need to be better refined in order to understand situations in which this practice is biologically beneficial and economically effective.

Generally speaking, returns on investment in forestry are greater when made on sites closer to markets, due to transportation costs. Fertilization treatments made later in the rotation have the benefit of reducing carrying costs of money and increasing growth when trees are adding merchantable volume.

Detailed nutrient analysis of the soil and fertilizer should be done before application. Water quality guidelines related to pesticides use should be followed when applying fertilizers.

Genetic Improvement

Capturing a site’s potential can often be improved by using improved genetic material. In Minnesota, seed orchards have been developed through concentrated cooperative breeding efforts over the past 20 years. These efforts have been focused on improving growth, tree form and insect and disease resistance.

Seedlings grown from improved seed are available commercially. Currently the most widely-planted species in forested environments are Norway (red) pine, jack pine and white spruce. These species have different opportunities for improved growth. For example, Norway (red) pine has a narrow genetic variability, whereas jack pine has a wide genetic variability.

Shortened Rotation

On those sites where nutrient depletion is not a concern, it may be possible to increase fiber production by reducing rotation age. Given the age distribution of Minnesota’s forest resources, capturing production of a portion of these stands may be useful to stabilize the flow of available timber in the future. Feasibility of reducing rotation age will depend on several factors, including end-product, harvesting equipment and nutritional status of the site. Research is needed to better understand the ramifications of reduced rotation on other site factors and to develop guidelines for identifying sites on which reduced rotations could be implemented.

Preventing Flooding

In some cases, increases in tree growth are possible through maintenance of proper drainage. Maintaining proper drainage may include controlling beaver populations to prevent flooding of forested areas and maintaining natural drainage, where consistent with landowner and landscape objectives.

Bedding, mounding and other site preparation methods that modify microsite conditions for tree establishment may also be beneficial for tree growth on saturated soils. These techniques are effective in improving aeration in the root zone immediately after planting, thereby improving early tree growth and survival. It is important on these sites to plant and manage species suitable to the poorly drained conditions.

Competition Control

Controlling competing vegetation has significant positive effects on survival and growth of trees. Various methods, including herbicide use, should be used to control competing vegetation early in the rotation to achieve maximum fiber productivity.

Thinning/Timber Stand Improvement

Commercial and pre-commercial thinning may be useful to capture the productive capacity of a stand. Thinning concentrates growth on fewer stems, thereby increasing the recovery of usable fiber. In addition, thinning can have the effect of shortening rotations by increasing the growth rate of individual trees, thus producing larger trees at an earlier age.

Thinning also allows selection of the most desirable trees in a stand on which to concentrate volume growth. This technique has the effect of increasing the overall value of the stand and presenting the opportunity to provide higher economic returns to landowners by increased product value at an earlier age.

Species/Site Matching

Matching the appropriate species to specific site conditions has the ability to increase forest productivity. For example, aspen growing on coarse-textured soils (“off-site”) may decrease the nutrient capital of these sites over time and produce lower yields compared to other species. To increase productivity on these sites, pine species will generally be a more efficient species, both from the perspective of fiber production and nutrient conservation.