EFFECTS OF PRESCRIBED FIRE ON FOREST SOILS

by
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RR89001-PR

RESEARCH REPORT

Internal Reports of the Ministry of Forests
Research Program

BC
Ministry of Forests
and Lands

Effects of Prescribed Fire On Forest Soils

A Training Manual
Prepared for the Protection Section,
Prince Rupert Forest Region

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August1989

Ministry of Forests

This publication is RR89001-PR

Copies of this report may be obtained, depending upon supply, from:

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Citation:

Macadam, A. Effects of Prescribed Fire on Forest Soils B.C. Min. For. Research Report 89001-PR.

PREFACE

The following report was prepared at the request of the Prince Rupert Forest Region's Protection Section for the annual Burn Boss Field Training Course. The fire management philosophy in our Forest Region supports the concept that staff should base management decisions on a sound understanding of the principles involved, and be able to integrate their own knowledge and experience into decision making.

The report should be read before the class presentation and discussion. The first section covers general concepts of soil properties and their relationship to site productivity. This material is the basis for understanding the effects of fire on soils, which is discussed in the second section.

ACKNOWLEDGEMENTS

I wish to thank M.C. Feller, Faculty of Forestry, University of British Columbia, R.N. Green, Vancouver Forest Region, E. Hamilton, Research Branch, Victoria, and R. Trowbridge, Prince Rupert Forest Region, who reviewed the report and contributed many useful suggestions. I also wish to acknowledge the assistance of G. Montgomery, who edited the final manuscript.

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Forest renewal depends on the ability of the soil resource to support reasonable rates of growth during successive rotations of crop trees. Some practices associated with harvesting and site preparation and deplete site nutrient capital, cause structural damage to the soil and accelerate erosion, reducing productive potential to the point that years are added to the rotation and the value of the crop is compromised. More often than not, damage can be avoided or minimized through awareness and planning.

To understand the effects that burning or any other management activity can have on forest soils, it is necessary to appreciate the nature of the soil environment and its relationship to above-ground components of the forest ecosystem.

1.1 The Role of Soil Organisms

Soils are an integral component of the forest ecosystem.

It is a common mistake to think of the soil as “just dirt”, a lifeless conglomeration of sand, silt, clay, and gravel. In reality, soils are complex ecosystems teeming with organisms whose activities are essential to the maintenance of plant and animal life.

Soil fertility and plant growth hinge on the presence and activity of soil organisms.

The role of earthworms in mixing the soil and improving soil structure is well known, but it is the billions of microscopic organisms—fungi, bacteria, and actinomycetes—that perform the most dramatic and crucial roles in the cycling of plant nutrients. In fertile soils, populations of these microorganisms commonly exceed 1000000/g of dry soil.

Most of the nitrogen (N) and other nutrients required by trees comes from the decomposition of plant and animal remains by soil organisms. Many microorganisms live in symbiotic association with plant roots, providing benefits such as increased access to moisture and nutrients and protection from disease organisms. Microorganisms are highly sensitive to environmental conditions such as aeration, moisture, temperature, and soil pH. When changes occur in the soil environment due to activities such as harvesting or site preparation, microbial populations are affected. Populations may increase or decrease, and some species may become favored over others. As a result, microbially mediated processes may be inhibited or accelerated.

Mycorrhizae: symbiotic associations between fungi and plant roots

Certain species of fungi form associations called mycorrhizae with plant roots, including those of coniferous trees, that are highly beneficial. In exchange for the carbon compounds which are their energy source, the fungi provide the tree with improved access to soil moisture and nutrients, by forming a network of fine filaments which permeate the soil and act much as extensions of the roots. This is particularly important to the ability of trees to survive and grow where soils are nutrient-poor or where root growth is hampered by environmental conditions, such as low soil temperatures or frequent moisture deficits. The activity of these mycorrhizal fungi is concentrated in the forest floor and in decayed wood.

Some microorganisms convert N from the air into mineral-N that is usable by plants.

Some nitrogen-fixing organisms live in symbiotic association with the roots of a host plant, for example, the bacterium *Rhizobium* with leguminous plants such as lupines and clover and the actinomycete Frankia with alder and ceanothus. Amounts of N added to the system in this manner depend on the species involved and soil and climatic conditions (e.g., *Rhizobium* is more active at pH>5 and requires adequate levels of phosphorus and other elements). Rates of symbiotic N-fixation have been estimated at 10 - 100+ kg/ha per year. Amounts fixed by free-living N-fixing microorganisms tend to be relatively small (< 1 kg/ha per year).

1.2 Soil Nitrogen

Nitrogen differs from other nutrients in the soil in that it is not a product of the decomposition of rock and minerals; the ultimate source of soil nitrogen is the atmosphere. Virtually all of the nitrogen that we now find in our soils has accumulated gradually since the retreat of the glaciers, through the fixation of atmospheric nitrogen by soil microorganisms and from the small amounts of ammonium and nitrate dissolved in rainwater.

Nitrogen is the nutrient most often limiting to growth in forest ecosystems in British Columbia.

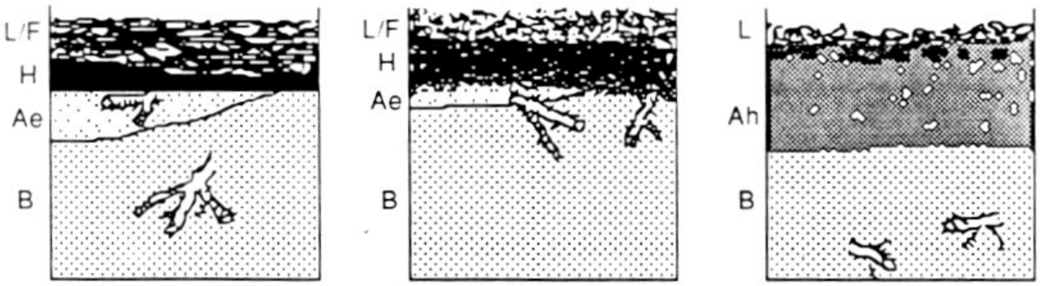
Nitrogen is one of the nutrients that trees require in relatively large amounts. Partly because British Columbia's soils are relatively young, nitrogen deficiencies are common on some medium and poorer sites in the Prince Rupert Forest Region, as well as in the rest of the province. Management practices such as slashburning can potentially aggravate deficiencies on such sites by further reducing N capital. Since natural rates of N accrual are extremely slow on most of these sites, it is important to prevent or minimize losses. Otherwise, chemical fertilizers or the introduction of nitrogen-fixing species may be required to offset losses.

Most of the nitrogen used by trees has been recycled from plant and animal remains.

More than 90% of the N contained in forest soils is associated with organic materials, which are concentrated in the forest floor and the top 15-20 cm of mineral soil. On average sites, the forest floor contains about 20-30% of the total soil N. However, trees may depend on forest floor N for an even greater proportion of their N requirements. In general, the drier and poorer a site, the higher the proportion of total site N contained in the forest floor, and the more important it is to conserve it.

At any given time, less than 2% of the total content of N in the soil is in a form that can be used by plants.

The rate at which N becomes available depends on levels of microbial activity in the soil. This in turn depends on soil moisture, temperature, pH, and the presence and quality of organic materials. The humus form (Fig. 1) reflects these conditions and is a good indicator of the rate of nutrient cycling and nutrient availability on the site.



Mor

- matted F horizon
- abrupt boundary between mineral soil and organic layer

Moder

- loosely structured F horizon
- more gradual boundary between mineral soil and organic layer

Mull

- F and H horizons thin or absent
- organic-enriched mineral soil horizon (Ah) present

FIGURE 1. Differentiating characteristics of mor, moder, and mull humus forms.

• Mor humus forms are most common under pure coniferous stands on medium and poorer sites in the Prince Rupert Forest Region. These have F horizons that are matted rather than loose, and the boundary between the forest floor and underlying mineral soil tends to be abrupt, with little mixing of organic and mineral materials.

- Moder humus forms are indicative of better-than-average rates of nutrient cycling, usually associated with mixed deciduous and coniferous stands. The F horizon has a loose rather than matted structure. If there is an H (well-decomposed) horizon, there will often be some intermixing of mineral particles. However a well developed Ah horizon is lacking.
- Mull humus forms are indicative of relatively rapid rates of nutrient cycling and a high degree of nutrient availability. Mulls have well-developed Ah horizons (dark-colored, organically enriched mineral soil horizons), and usually relatively thin L (litter) and F (slightly decomposed) horizons. These are often found in relatively warm locations associated with seral, primarily deciduous, vegetation.

1.3 Mechanisms for Nutrient Conservation

The ability of a site to retain nutrients depends on soil organic matter and clay content.

Nutrients in plant-available, water-soluble forms are highly susceptible to loss from the soil through leaching. Fortunately, the bulk of the site nutrient capital is stored in forms that are released only very gradually into soluble forms which are available to plants. The binding of nutrients within organic compounds is a key mechanism for nutrient retention.

Another important mechanism is the temporary bonding of nutrient ions to the surfaces of organic compounds and fine clay particles. These materials have a slight net negative electrical charge and can therefore attract and hold onto nutrients which are in forms that have a positive charge (e.g., NH4+, Ca++, Mg++, K+). The capacity of the soil to bind nutrients in this manner is referred to as “cation exchange capacity” (CEC). Soils with a high organic matter and or clay content have a high CEC, and are therefore much less vulnerable to nutrient losses following burning than are soils with low organic matter and clay contents.

1.4 Soil Texture

Soil texture affects a soil’s nutrient and water storage capacity, susceptibility to erosion, and sensitivity to compaction.

Mineral soil materials are mixtures of particles of different sizes. A soil’s physical and chemical properties depend largely on the relative proportions of fine, medium, and coarse particles and coarse fragments present. Susceptibility to nutrient losses associated with burning, and ecological sensitivity to such losses, are two important interpretations based largely on soil texture.

The temporary bonding of water molecules and nutrients in ionic forms to the surface of soil particles is a crucial mechanism for the retention of moisture and nutrients in the soil. The total surface area available for this temporary storage is far greater in fine-textured materials. Clay particles, for example, have up to 10000 times the total surface area of an equal weight of medium sand.

The relationship of soil texture to available and total soil moisture storage capacity is illustrated in Figure 2. Available moisture is that portion of the total soil moisture content that can be extracted by plant roots. Although clayey soils have a very high storage capacity, almost two thirds of that moisture is held so strongly by the soil that it is not available for plant use. Sandy soils have a low total moisture storage capacity, but a high proportion of that total amount is available for plant use.

1.4.1 How to assess soil texture

For general purposes, you do not have to be extremely precise in estimating proportions of sand, silt and clay particles. However, it is important to develop the ability to differentiate among very fine textured (i.e., clayey), fine loamy, loamy, coarse loamy, coarse textured (i.e., sandy), and very silty soils. Dig a shallow pit (30-50 cm in depth) and “hand-texture” mineral soil samples from within the rooting zone. Remove coarse fragments (>2 mm diameter) and add water to a few tablespoons of soil until a putty-like consistency is achieved. Note the predominant consistency of the material in terms of its stickiness, plasticity, cohesiveness, and grittiness:

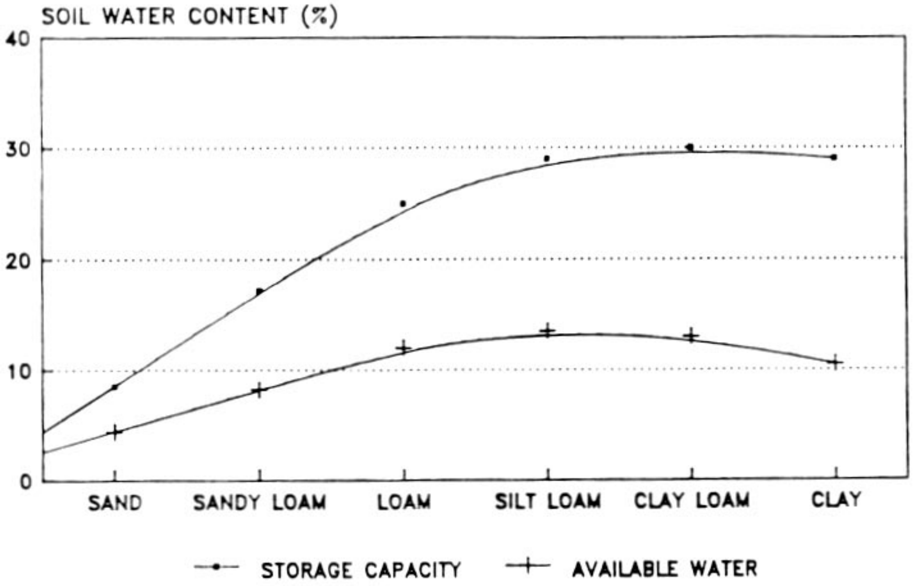


FIGURE 2 Relationship of soil texture to available and total moisture storage capacity.

CLAYEY (very fine textured soils): extremely cohesive and plastic when moist; very sticky when wet; hard when dry.

SILTY: slightly cohesive and slightly to moderately plastic when moist; non-sticky, rather smooth and soapy when wet; more friable than clay when dry.

SANDY (very coarse textured soils): non-cohesive and non-plastic when moist; non-sticky when wet; loose when dry; grains which are large enough to see and feel individually predominate.

LOAMY: contains balanced proportions of clay, silt, and sand-sized particles. Slightly to moderately sticky, moderately plastic, moderately gritty.

CLAY LOAMS, SANDY LOAMS, SILT LOAMS: intermediate between loam and strongly clayey, sandy, or silty textures, respectively.

Commonly used terms:

FINE TEXTURED	increasing clay content
FINE LOAMY	⇧
LOAMY	balanced mixture
COARSE LOAMY	⇩
COARSE TEXTURED	increasing sand content

1.4.2 Interpretation of soil texture

Fine textures

Because fine textured soils have a large total particle surface area, they tend to have a large nutrient and moisture storage capacity. For this reason they are often richer and more productive than coarse textured soils. However, they tend to be relatively dense and are extremely susceptible to compaction, particularly when moist or wet. Also, because of their denseness and high moisture storage capacity, poor aeration is a common problem in very fine textured soils.

Loamy textures

Loams tend to be relatively fertile and porous. They contain sufficient clay to retain moisture and nutrients, and yet have a large enough proportion of coarser particles and pore space to allow for adequate drainage, aeration and root penetration.

Coarse textures

Because they have a small total particle surface area, the ability of coarse textured soils to store nutrients and moisture is limited. They tend to be particularly susceptible to nutrient losses because of leaching following burning. Unless seepage or rainfall is plentiful, moisture deficits may occur during the growing season. For these reasons, the role of the forest floor as a reservoir of moisture and nutrients is particularly important in coarse textured soils.

Effect of coarse fragments

A high proportion of coarse fragments in the soil similarly diminishes moisture and nutrient storage capacity. Sandy soils with > 35% and loamy and finer textures with > 70% coarse fragments by volume are extremely sensitive.

Effect of incorporated organic matter

Organic matter that is incorporated into the mineral soil modifies and improves the soil's characteristics irrespective of texture. Nutrient content as well as nutrient and moisture storage capacity are increased and soil structure is improved, aiding in the formation and maintenance of a porous structure.

1.5 Soil Structure and Porosity

Soil porosity is essential to the functioning of tree roots and soil organisms.

In addition to nutrients, plant roots and soil organisms need air and moisture in adequate amounts to thrive. The free movement of air and water into the soil, and the extension of plant roots depend on a soil structure that comprises adequate numbers of large pores or voids. In productive soils, voids filled with air and water account for approximately one half of the total soil volume, while mineral material generally represents somewhat less than half (Figure 3).

Heavy equipment traffic during harvesting and site preparation activities (including fireguard construction) can cause surface soils to be compacted, resulting in the destruction of these pores, and consequently:

- decreased permeability to air and moisture;
- slower infiltration rates;
- increased overland flow of rainwater and snowmelt;
- accelerated surface erosion;
- a greater physical barrier to root extension; and
- decreased productivity.

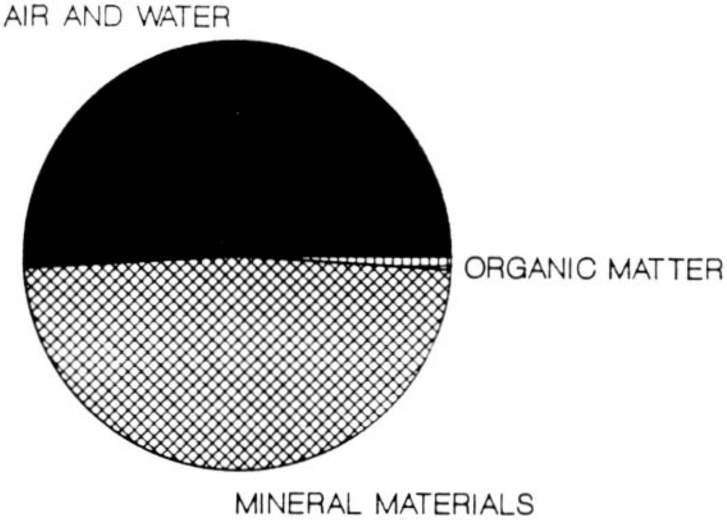


FIGURE 3. Typical proportions of pore space (air and water), mineral materials, and organic matter in productive soils by volume.

Reductions in volume growth on compacted soils have been estimated to be in the range of 45 - 70+% (B. C. Ministry of Forests Timber Harvesting Subcommittee, and Lewis 1989; Corns 1988).

It is difficult and expensive to rehabilitate compacted soils.

Soil texture and coarse fragment content are important risk factors: susceptibility and sensitivity to damage increases with clay content and decreases with increasing coarse fragment content.

Soils are most vulnerable to structural damage when they are moist or wet. Damage can be minimized by scheduling operations when soils are dry, frozen to a depth of > 15 cm, or covered with > 1 m of snow.

The most serious damage occurs during the first few passes of the equipment. Once the soil has been compacted, further increases in density tend to be small. It is best therefore to concentrate activities in as small an area as possible.

1.6 Conclusion

The careful management of soil organic matter is essential to the maintenance of forest soil productivity.

In most forest soils, the bulk of nutrients (particularly nitrogen) and the activity of soil organisms (such as mycorrhizae) are concentrated in the forest floor and the upper 15 cm of mineral soil, which contains most of the organic matter. Soils that are stony or coarse textured have an extremely limited ability to store nutrients and moisture in the absence of organic matter. On dry sites, the forest floor stores moisture and helps to conserve it by slowing evaporation from the surface. The presence of an intact forest floor layer protects the soil from surface erosion and from the breakdown of mineral soil structure and porosity, which is essential to the movement of air and moisture into the rooting zone. When forest soils are scalped or severely burned to the point that little organic matter remains, their productivity can be severely impaired.

To prevent damage to soil productivity, managers must be:

1. aware of the short- and long-term consequences of harvesting and site preparation activities.
2. alert to site and soil characteristics associated with susceptibility to various kinds of damage.
3. willing to adjust prescriptions accordingly. ***Timing of activities is of key importance.***
4. available to supervise operations staff (particularly equipment operators) to ensure that they know how to avoid damaging effects such as compaction, widespread scalping or soil displacement, and burning treatments that are too severe.

2 EFFECTS OF FIRE ON FOREST SOILS

Wildfire has played an important historic role in the development and maintenance of natural forest ecosystems throughout much of British Columbia. As the intentional use of fire as a tool for site preparation following logging has gained popularity, legitimate concerns have been raised about possible detrimental effects of burning on site productivity. Burning is a radical treatment with destructive potential. However, when fire is used intelligently and responsibly, positive effects are likely to outweigh negative effects on most medium and better quality forest sites in the Prince Rupert Forest Region.

Fire may, in many cases, be the least damaging treatment option, short of no treatment at all. Current levels of technology and expertise give forest managers considerable control over the severity of burning treatments. The application of this skill, coupled with a knowledge of site sensitivity to fire and the careful consideration of management goals, will minimize the risk of damage to site quality while optimizing treatment effectiveness.

All fires, including wildfires and broadcast slashburns, result in similar types of changes in forest soils. Some of these changes may be beneficial, while others are potentially damaging. Whether the net effect, in terms of short- and long-term site productivity, is beneficial, negligible, or damaging depends on the character of the site, soil, and climate, and on the severity of the burn.

2.1 Effects of Fire on Site Nutrients

Nutrients are lost from the site in various ways during the fire and for some time after burning. Some nutrients are simply transferred from slash materials into the forest floor and from the forest floor into the mineral soil. The proportion of site nutrients in plant-available forms usually increases immediately after burning because of the addition of nutrient-rich ash to the soil, and through the enhanced microbial activity that results from changes in soil chemistry associated with burning.

Changes in soil contents of available and total soil nutrients observed after operational broadcast burning on mesic sites in the SBSmc (formerly SBSe) subzone are shown in Figure 4. The greatest changes in nutrient content and availability occur within the forest floor. Changes within the upper mineral soil horizons tend to be less substantial and less consistent. The content of nitrogen in the forest floor tended to decrease significantly after burning, and the magnitude of losses was closely tied to forest floor consumption. Amounts of exchangeable (i.e., available) Ca and Mg tended to increase in the forest floor, but were occasionally lower following burning in the underlying mineral soil. The reverse trend was observed for exchangable K, which decreased in the forest floor, but often increased slightly in the mineral soil. Amounts of available P usually increased significantly in the forest floor and upper mineral soil horizons after burning. Similar trends have been observed following broadcast burns in the ESSFk and ICHmc (formerly ICHg) subzones in the Prince Rupert Forest Region (Macadam, unpublished data).

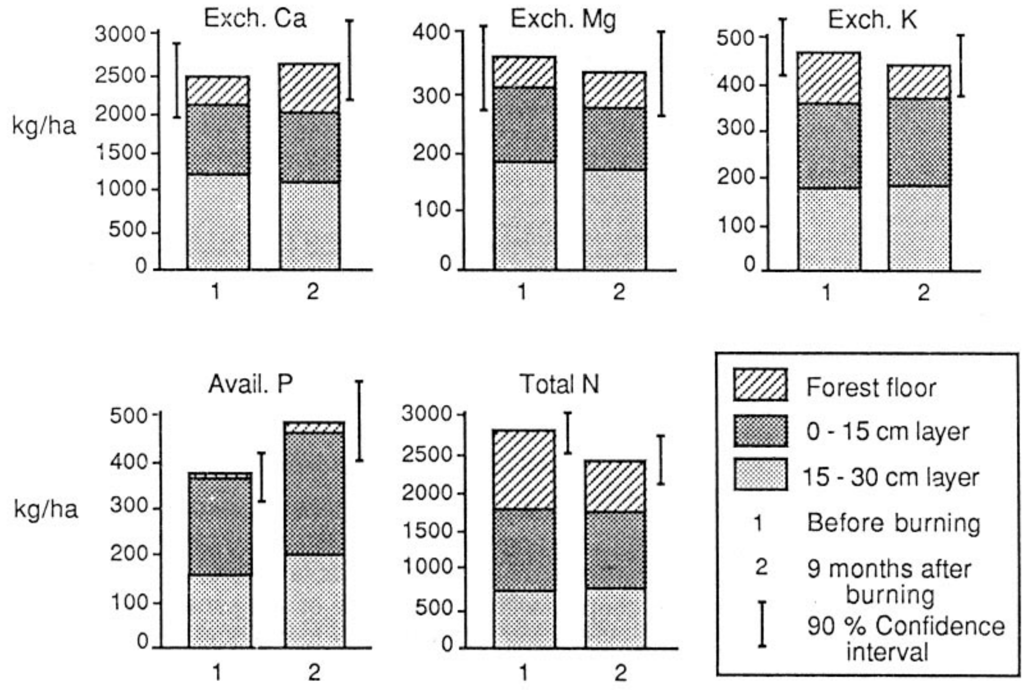


FIGURE 4. Changes in levels of available Ca, Mg, K, and P and total N following moderate-impact broadcast burns on mesic sites in the SBSmc subzone (Macadam 1987).

2.1.1 Nutrient losses

When slash and forest floor materials are consumed by fire, a large proportion of the N and sulfur (S) contained in them is lost from the site into the atmosphere.

This happens because N and S become volatile (vaporized) at relatively low temperatures (200-500_ C). The amounts lost to the atmosphere increase with the intensity of the burn and the degree of consumption of fuels. Nitrogen losses during burning are roughly proportional to the amount of forest floor consumed: 100-150 kg/ha are lost for each centimeter of forest floor consumed (Macadam, unpublished data; Feller 19891). Higher temperatures (> 774_ C) are required to vaporize phosphorus (P) and potassium (K) are higher, but these do occur during very intense burns (Grier 1975; Raison *et al*. 1985). Magnesium (Mg) and calcium (Ca) become volatile only at very high temperatures (1100-1900_ C), so volatile losses of these elements are negligable.

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1 Feller, M. C. 1989. Estimation of nutrient loss to the atmoshpere from slashburns in British Coulumbia. Paper presented at the 10th conference of Fire and Forest Meteorology, April 17-21, 1989, Ottawa.

Some nutrients are carried off as particulates in smoke.

During the fire, nutrient-rich ash and particles of partially burned materials are transported off the site in smoke. Calcium, in particular, is highly concentrated in ash, and losses of Mg, K and P can also occur in this manner. The amounts of these nutrients lost through the convection of ash are generally not large. However, losses may become much greater where ash is carried off in high winds or in runoff if there is a heavy rainfall immediately after a burn.

The bulk of nutrients released into the ash (P, Mg, Ca, K) are leached into the residual forest floor and the underlying mineral soil.

Once in the soil, these nutrients in water-soluble forms become adsorbed to clay or organic matter surfaces. If the amount of nutrients added to the soil is greater than can be accommodated by storage mechanisms, the surplus will be leached out of the soil into the groundwater and lost from the site.

Gravelly, coarse textured soils, low in organic matter and with thin forest floors, have a very limited ability to store nutrients and are most susceptible to losing nutrients through leaching following burning. Rapid revegetation of the site with species such as fireweed is an important mechanism for minimizing leaching losses following burning.

2.1.2 Relationship of slash and forest floor consumption to nutrient losses

The results of fire-effects research indicate that nutrient losses are closely related to the moisture content of the slash and forest floor, and to slash loading. These factors largely determine slash and forest floor consumption (Little *et al.* 1986; Feller 1988), which are closely correlated to nutrient losses and changes in soil chemistry.

A highly significant correlation between forest floor consumption and soil nitrogen losses has been observed on operational broadcast burns in the ESSFk, SBSmc, and ICHmc of the Prince Rupert Forest Region (Fig. 5)(Macadam, unpublished data). Feller (1988) and Little and Ohmann (1988) observed

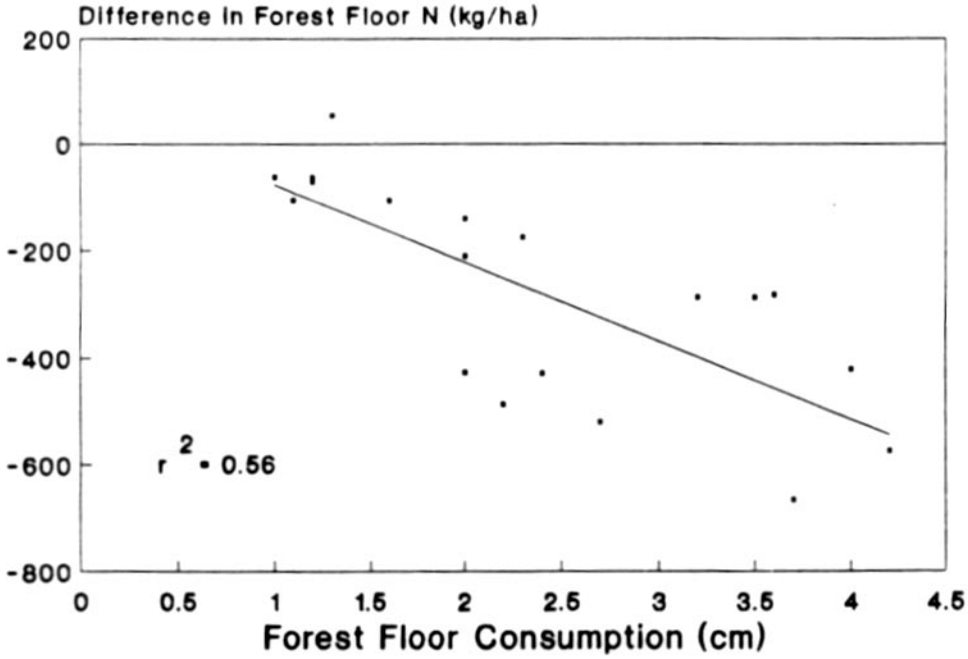

FIGURE 5. Relationship of forest floor consumption to differences in forest floor in nitrogen content following operational broadcast burns in the Prince Rupert Forest Region.

similar trends in the CWH Zone of southwestern British Columbia and the U.S. Pacific Northwest, respectively. Feller (1988) found that the response of sulfur was similar to that of nitrogen. Forest floor consumption depends strongly on the moisture content of the slash and forest floor, and on total slash loading. Another important factor is the density, or compactness, of the forest floor (E. Hamilton, pers. comm., April 1989). Loosely compacted forest floor materials are more readily consumed than more dense layers.

2.1.3 Assessing site sensitivity to nutrient depletion

1. How nutrient-rich is the site to begin with? Is the loss of nutrients likely to create deficiencies or aggravate existing deficiencies?

If a relatively nutrient-rich site loses 400 kg/ha of nitrogen as a result of burning, the consequences may be negligible if the loss represents only a small proportion of the total site nitrogen capital. However, a loss of this magnitude from a poorer site could cause a serious reduction in long-term productivity if the amount of N remaining is too low to support tree growth.

To assess site nutrient status, consider the following:

1. *soil texture and coarse fragment content*

Coarse-textured soils are usually relatively nutrient poor unless there are mitigating features such as a high organic matter content or seepage within the rooting zone. Soils containing a high proportion of coarse fragments (> 35% in a sandy soil or > 70% in a loamy soil) also tend to have a low nutrient content.

2. *soil organic matter content*

Mineral soil materials that are rich in organic matter are also rich in nutrients. They are dark in color, usually brown or black. An Ah horizon is an upper mineral soil horizon enriched with organic matter > 2 cm in depth. Soils that are light in color, or bright-colored (e.g. yellow or reddish) have a low organic matter content. A well-developed Ae horizon is an upper mineral soil horizon, > 2cm in thickness, that is strongly leached, and very low in organic matter and nutrients. These are usually white to greyish in color.

3. *seepage*

Moving groundwater, termed seepage, that is present within the rooting zone during the growing season enhances soil nutrient levels. Seepage may be permanent or temporary, and is often indicated by mottled soil horizons.

4. *humus form*

As discussed in section 1.2, the humus form is a good indicator of nutrient status. Mulls tend to be associated with soils that are very nutrient rich, moders with medium to rich sites, and mors with poor to medium nutrient levels.

5. *soil depth*

The nutrient content of soils that are < 30 cm in depth is limited because of the low soil volume available for nutrient storage. Depending on texture, organic matter content, etc., the soil nutrient content may be rated medium to low.

6. *indicator plants*

Certain species of shrubs, herbs and mosses are good indicators of soil nutrient levels. These can be used in conjunction with soil properties to assess nutrient content. Refer to Pojar *et al*. (1982) and Klinka *et al*. (1989) for information on interior and coastal species respectively.

2. What proportion of the site's total nutrient capital is contained in materials that are vulnerable to combustion?

If the depth of the forest floor before burning averages 15-20 cm, and the amount removed is unlikely to be greater than 3-4 cm, then the proportion of the total site nutrient capital that is at risk is very minor and the sensitivity rating low compared to a site that has only 4-6 cm of forest floor (assuming there is no Ah horizon). Soils with well-developed Ah horizons are not likely to sustain serious nutrient losses, because a large proportion of the nutrient capital is contained in materials that are not likely to burn.

3. What is the capacity of the soil to store nutrients made mobile by burning? Would you expect serious leaching losses?

Gravelly or sandy soils with little incorporated organic matter and thin forest floors have a very limited capacity to store nutrients released by burning. To assess the potential for nutrient loss through leaching, consider soil texture, coarse fragment content, soil depth, and organic matter content.

2.1.4 Increased nutrient availability

The ash from burned slash and forest floor materials is rich in soluble forms of Ca, Mg, K, and P. These are nutrients that would otherwise become available to plants only very gradually through microbially mediated decomposition processes.

Ash from burned slash and forest floor is strongly alkaline. As a result, soil pH typically increases following burning. Increases in soil pH observed following operational broadcast burns in the Prince Rupert Forest Region ranged from 1 to 2 units in the forest floor, and from 0.2 to 0.5 units in the upper 15 cm of mineral soil (Macadam, unpublished data). Increased pH in otherwise relatively acid forest soils can improve the availability of some nutrients and stimulate microbial activity, resulting in increased rates of nutrient cycling and nitrogen fixation following burning.

2.2 Soil Organisms

Following burning, numbers of soil microorganisms decrease sharply due to the combustion of forest floor materials and high temperatures close to the soil surface. Changes in populations and the species composition of soil microorganisms have been observed following burning, probably due in part to decreased soil acidity (Bisset and Parkinson 1980). While bacterial populations tend recover rapidly, often to levels higher than those observed before burning, actinomycetes are much slower to recover, and the activity of fungi may be reduced for more than a year (Raison 1979). Burning may increase or decrease the occurrence of mycorrhizal fungi, depending on the species involved (Pilz and Perry 1984). Beese (1987) found no significant differences in the frequency of mycorrhizal colonization of Douglas-fir or western red cedar seedlings planted in burned compared to unburned soils on Vancouver Island.

2.3 Mineral Soil Exposure

Some localized mineral soil exposure associated with intense burning under large fuels is common following broadcast burning. However, high impact burns resulting in wide-scale mineral soil exposure can have serious negative effects on site productivity because of:

- loss of nutrient capital and decreased soil moisture
- drastic increases in soil pH
- damage to surface soil structure, resulting in increased runoff and accelerated soil erosion.

A study on Vancouver Island (Beese 1987) demonstrated greater height growth among Douglas-fir, western redcedar, and yellow-cedar where some forest floor was present, compared to areas where only mineral soil remained following burning.

Exposure of mineral soil is particularly damaging on sites that are susceptible to surface erosion. The following factors contribute to a high degree of surface erosion hazard: high rainfall (> 50 mm per year), slopes > 30%, depth to restricting soil layer < 60 cm, upper soil horizons low in clay, subsoil horizons high in clay and low in coarse fragments (B.C. Ministry of Forests and Lewis 1989).

2.4 Soil Moisture

The reduction of forest floor depth may significantly reduce the water storage capacity of dry sites with thin forest floor layers and coarse textured mineral soils. In addition, complete removal of the forest floor increases the loss of soil moisture through evaporation from the surface.

2.5 Water Repellent Layers

Burning can cause the formation of a water repellent layer, usually within a few centimeters below the forest floor. This is caused by the downward movement and condensation of volatile organic compounds. A study in the CWH Zone (Henderson and Golding 1983) found that this occurred in 35% of the burned and only 21% of the unburned clearcuts sampled. These differences were significant for a period of up to 2 years following burning.

2.6 Soil Temperature

The degree of soil heating during burning depends on the amount of fuel consumed at the surface and the depth and moisture content of the forest floor (Raison 1979). Heat transfer in soils is mainly by thermal conduction, and conductivity increases with moisture content. Therefore, the heating of dry soil causes greater rise in temperature at the surface but less penetration of heat compared to a moist soil. Extreme temperatures at the time of burning are generally confined to the top few centimeters below the surface of the burned forest floor (Hamilton 1988), but this can be sufficient to kill underground parts of some species of vegetation, preventing resprouting.

High soil surface temperatures observed following burning are due to the blackening of the surface and increased absorption of solar energy. This may damage newly planted seedlings under some circumstances, particularly during the first season after burning on exposed south-facing slopes. The problem has not been reported in north-central British Columbia, but it may occur in warmer parts of the province.

Soil temperatures in the rooting zone may be increased in some, but not all, cases following burning. This is potentially a very beneficial effect at higher elevations and higher latitudes, especially in the Interior where cold soils are a serious limitation to growth. Soil temperatures are kept low by deep forest floor layers (>15 cm in depth), which have a strong insulating effect when dry and a high heat capacity when wet, causing heat to be transmitted only very slowly from the surface. Soils that are poorly drained are often cold because wet soils have such a high heat capacity: they require a large input of heat to raise temperatures even slightly.

Burning can increase growing season soil temperatures by increasing the amount of heat absorbed by the forest floor and by decreasing its insulating effect. This depends not only on the depth of burn, but also on the depth of forest floor remaining and the depth of planting. If the remaining forest floor is > 10 - 15 cm in depth, temperatures in the underlying mineral soil may not be much affected. Also, if soils remain very moist or wet through the growing season, temperatures are unlikely to be increased significantly by burning alone. Mechanical treatments that improve soil drainage result in much greater improvements in soil temperature on moist-wet sites than can be achieved by burning alone (Macadam 1989).

2.7 Windrowing

In cases where broadcast burning is not feasible, slash is frequently piled in windrows before burning. This practice has some potential disadvantages. The concentration of slash in piles tends to result in more intense burning and increased fuel consumption, resulting in greater losses of nutrients through volatilization. Over the short-term, however, nutrient-rich ash deposited within windrows may enhance seedling growth relative to that between rows (Ballard 1986).

As with any treatment involving the use of heavy machinery, the importance of closely supervising piling operations cannot be over-emphasized. In the process of moving slash into piles, nutrient-rich forest floor and surface mineral soil materials may be displaced into windrows along with logging debris. This is potentially very damaging to site productivity, particularly on medium and drier sites. Growth reductions of 30-40% have been reported on sites that have been scalped (Binkley 1986; Minore 1986; Weber *et al*. 1985).

2.8 Effects on Seedling Survival and Establishment

Burning often favors seedling survival and early growth on plantations. This is most likely to occur when some serious limiting factor is alleviated as a result of burning. However, short-term benefits such as improved planter access, vegetation control, and improvements in soil temperature regimes may frequently be achieved at the cost of nutritional problems later in the rotation. For example, in a study of some white spruce plantations in north-central British Columbia, Ballard (1986) found better height growth but more frequent N, copper and iron deficiencies on burned than on unburned sites. On medium and poorer sites it may be necessary to plan for ameliorative measures to restore nitrogen levels following burning. The application of a nitrogen fertilizer is one option. Seeding with legumes such as clover or lupines or planting with alder is another possibility that is currently being investigated in the Prince Rupert Forest Region.

2.9 Conclusion

In planning any site preparation treatment it is essential to:

1. carefully assess site and soil properties and management goals;
2. weigh the probable short- and long-term costs and benefits of available treatment options;
3. establish specific treatment goals; and
4. time the treatment to coincide with fuel or soil moisture conditions required to achieve treatment goals with a minimum of damage to the soil.

Effects of burning on nutrient losses, soil temperature, and soil erosion are directly related to the amount of forest floor consumed and the depth remaining. Moderate-impact broadcast burns appear to have largely positive effects on soil productivity on medium and better quality sites in the Prince Rupert Forest Region, at least over the short term. Nutrient deficiencies, particularly of nitrogen, may result later in the rotation after burning on sites with medium and poorer nutrient regimes. Severe burning treatments or burning on very sensitive sites can damage the soil by accelerating rates of surface erosion and depleting nutrient capital. Particular caution should be exercised on poor, dry sites with coarse soils and thin forest floors, on steep slopes, and on shallow soils.

3 OPERATIONAL PRESCRIBED FIRE ASSESSMENTS

A standard methodology has been developed for monitoring the impacts of broadcast burns. Its purpose is to allow field staff to quantify the results of operational burns so that prescription making can be fine tuned based on local experience. A handbook describing procedures, and forms for collecting data on fuel loading and consumption, site characteristics and fuel moisture conditions are available from the Protection Branch in Victoria. The title is: Field handbook for prescribed fire assessments in British Columbia: Logging slash fuels. B.C. Ministry of Forests, Land Management Handbook No. 11.

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