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Fire and Stand Nutrition in Canadian Boreal Forests

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Highlights

- Fire can result in short-term increases in nutrient abundance and availability. These nutrient flushes are not found in harvested forests.
- Nutrient removals are higher after whole tree harvesting than after fire.
- Fire can result in a loss of nutrients via gases released to the atmosphere or through leaching (especially in coarse textured soils). Some of these losses can be mitigated through informed and careful planning.

Forest fire! The words conjure up visions of leaping flames, incinerated houses and vistas filled with the charred skeletons of trees. For forest managers, the words mean disrupted operations, salvage logging and gaps in future wood supply. For governments, they mean skyrocketing fire-fighting costs, dislocated communities and claims for compensation. It is not surprising then, that fire in the forest has historically been seen as something to eliminate and to protect the forest against.

In recent years, however, the way we think about fire in the forest has changed. Research has shown that fire is a natural and important part of the ecology of many forests, and policy makers and managers have begun to take a broader view. This change in perspective can be seen in forest management policy throughout Canada.

Fire is now known to play several key roles in forest ecosystems. Fire stimulates the release of seed from the cones of some tree species and produces good conditions for germinating seeds. Ash from fire fertilizes the soil and reduces soil acidity. Warmer soil temperatures and increased soil moisture following fire provide a good rooting environment, and stimulate microbial activity and decomposition that increase nutrient availability. Plants and animals that live in forests where fire is a regular occurrence are adapted to the conditions produced by fire. When fire is eliminated from the forest, habitat quality for these species may decline.

As our knowledge of fire ecology has grown, so has our interest in the possibility that harvesting can mimic the effects of fire. This paper reviews how fire affects soil properties and nutrient cycles in forests and explores the ways that the effects of fire can be more closely imitated by adding them to forestry practices.

Fire and nutrient cycling in boreal soils

Benefits of fire to nutrient cycling

Fire can have significant effects on nutrient availability and cycling in boreal forest soils. Cold soil temperatures in the boreal forest usually result in slow decomposition and a build up of organic matter in the forest floor. Fire can help decomposition by increasing soil temperatures in several ways. First it can remove forest floor cover, exposing lower layers of mineral soil to solar heat. Second, it can result in a layer of black ash or charred ground which is more able to absorb and retain solar heat. Each of these stimulates biological decomposition and makes essential nutrients such as nitrogen (N), sulfur (S), and phosphorus (P) available for plant usage. Fire has also been found to increase the availability of base-forming

cations such as calcium (Ca), magnesium (Mg), and potassium (K) through the conversion of plant material to ash. These nutrient additions can create a pulse of nutrients. An increase in cations raises the pH of the forest floor which can be considered a good thing because it increases the buffering capacity of soils. Buffering capacity, in turn, prevents drastic changes in acidity, which can be detrimental to plant growth.

Adverse affects of fire on nutrient cycling

Fire can also have less desirable impacts on forest ecosystems. N, P, and sulfur in the organic matter on the soil surface and in the living plants can be lost in large quantities to the atmosphere when they volatilize (transform into a gaseous state) during fires. This is especially true for N, which volatilizes at a relatively low temperature (200°C). S and P are lost at temperatures of 375°C and 700°C, respectively. These losses are commonly related to the severity of the burn, which is usually defined by the amount of forest floor removal. Temperatures of 700°C can be reached in moderately severe fires, indicating that N and S are lost even in low severity fires.

Atmospheric losses

To date, there has been little research into the actual amount of nutrients lost during fires. The few studies that do exist have recorded N and P losses from the forest floor and vegetation of nearly all forest types. For example, a loss of 350 kg/ha of forest floor N was recorded in an eastern Ontario jack pine ecosystem, while N losses after slashburns in coastal temperate forests in British Columbia have ranged from 10-1000 kg/ha.[2]

N, S, and P are three essential nutrients that can be lost to the atmosphere via volatilization during fires such as this one in Chisholm, Alberta. Photo courtesy of EMEND.

Leaching and Erosion

As discussed above, fire deposits ash on the surface of the soil. This ash contains high levels of nutrients, which can be lost from the ecosystem via surface erosion. Fire can increase the erodibility of soils by exposing mineral soil or by (indirectly) diminishing the water holding capacity of soils. When a fire burns a forest, it can expose mineral soil. If heavy rains follow this exposure, soil pores can become clogged or saturated, leaving them unable to accept more water. The result is water pooling on the soil surface and, eventually, running out of the forest (taking nutrients with it).

Leaching can also result in nutrient losses from both ash and remaining forest floor. The amount of nutrients leached depends on several things, one being soil texture. A sandy soil, with large pore size, will leach nutrients more readily than a clay-dominated soil. The amount of live vegetation either surviving or regenerating on soils after fire can also affect leaching losses. If vegetation is present shortly after a fire, nutrients run a better chance of being taken up by growing plants rather than being lost to leaching. The movement of nutrients into lower soil horizons can eventually lead to nutrients leaching into groundwater. This can be a problem for both the forest soil (nutrient deficiency) and for the surrounding water bodies (increased nutrient levels can be toxic to aquatic species).

Fire vs. harvesting effects

Most studies to date have concluded that clearcutting does not result in the same initial flush of nutrients that fire does. This is partly due to the fact that no ash is produced and partly to the fact that soil temperatures are not raised enough to enhance nutrient release. On the other hand, tree-length harvesting—whereby branches

and foliage are left onsite--can add organic matter to the forest floor, which can serve as a long term nutrient reservoir. This nutrient reservoir is usually burned off by fire and is often removed with whole tree harvesting.

Comparisons have been made between burned and harvested sites in several boreal ecosystems. In black spruce forests of Quebec, lower concentrations of N, P, K, Ca, and Mg were observed in the forest floor of clearcut stands than in burned stands. This difference could be seen for at least 14 years after fire. However, the differences had disappeared 21 years after fire.[4] This supports the notion that differences between fire and harvesting, in relation to soil nutrient cycling, usually disappear after a certain time period following disturbance. Fire provides a quick flush of available nutrients while tree-length harvesting can result in greater total nutrient supply over the long-term.

It is important to note that no studies, to date, have looked at nutrient cycling over more than one harvest rotation. Furthermore, there are very few studies that have looked at the impacts of harvesting-associated activities (e.g. road building or landings) on soil nutrient cycling. These gaps in knowledge are significant. They indicate a lack of understanding of long-term effects of harvesting on forest soil nutrient cycling. Investigating these issues should be a focus of future research if we are to better understand the differences between forest harvesting and fire insofar as nutrient cycling is concerned.

Should fire be used in forest management?

Prescribed fire has been used as a management tool for several decades in Canadian forests. Prescribed fire has been used perhaps most extensively in British Columbia, which has resulted in a fairly comprehensive set of guidelines for determining when, where, and how much to burn. Prescribed fire can aid in the removal of forest floor and can expose mineral soil. In addition, it has been used to manage competing vegetation. In most cases, regeneration has been found to be favorable following prescribed burning. With regards to soil nutrition, there are some important considerations that must be accounted for when using prescribed fire.

Fire Severity

Fire severity is partially defined by the amount of forest floor and/or mineral soil burned. It seems to be the key factor in regeneration success and nutrient cycling. The severity of a fire determines the amount of remaining live roots and, hence, to some extent the resultant vegetation. Additionally, fire severity affects the amount of mineral soil exposure and nutrient cycling within a forest. Depending on the objectives of the burn, fire severity can be calculated for—and adjusted appropriately—to achieve prescribed burning goals. For example, a burn with the goal of removing all fine fuels in order to minimize wildfire hazards will have a much lighter severity than a burn with the goal of burning all fuel and some of the forest floor in order to expose mineral soil.

In jack pine and black spruce forests in northwestern Quebec, forest floor nutrient content was reduced significantly on severely burned (i.e. all vegetation charred) sites. Nutrient content was not significantly reduced on light/moderately burned (i.e. most vegetation intact or understory and canopy leaves and twigs singed) sites.[1]

Vegetation Considerations

In a Coastal Western Hemlock forest in British Columbia, it was found that the species of slash affected nutrient losses during fire. These losses were attributed to the amount of slash consumed by the fire which, in turn, was related to species type.[3] Different types of slash have different chemical properties that can result in different burning characteristics. To date there have been no studies comparing different types of slash with nutrient loss in boreal forests. This would be an informative and interesting focus of research in the future.

Summary

Fire plays a natural and important role in forest soil nutrient cycling. Fire can improve regeneration and nutrient cycling by exposing mineral soil, aiding in microbial decomposition, and converting essential nutrients from unusable to available forms. Fire can also result in “nutrient pulses” whereby essential nutrients

are available in quantities larger than those found in pre-fire conditions. However, these pulses are usually short lived, and it is unknown at this time what the long-term effects of fire on soil nutrition are.

Fire can result in a loss of nutrients, especially N, which is easily volatilized. It can also decrease the abundance of microbial communities and can result in an increase in leaching. Future research into the differences in nutrient losses due to fire between different species would be a worthwhile focus of data collection in the future. Such research will help identify what (if any) steps need to be taken to bring management practices into the range of variability found in un-managed forests. Several ongoing studies, namely the Chisholm and EMEND projects, are good examples of the type of research that needs to be done.

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Several useful management implications can be garnered from our research here. From the point of view of soil nutrition in boreal forests, effective sustainable management will be promoted if forest managers adhere to the following ideas:

- Ecosite characteristics should be taken into account when planning for prescribed burns. Ecosystem attributes such as forest floor cover, tree species type, and soil type can influence the success of prescribed burning in meeting management goals.
- The maintenance of forest floor after burning and/or encouraging the quick re-establishment of ground cover after burning can mitigate nutrient losses due to excessive leaching and/or erosion.
- Fire in jack pine and mixedwood forests can be beneficial since it exposes mineral soil and can increase mineralization of nutrients. However, coarser textured soils could result in nutrients being leached after fire. Determining appropriate fire severity, as well as recognizing site specific soil texture properties, should be a priority when using fire for nutrient cycling purposes in these forests.

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