

EFFECTS OF FIRE ON THE LONG-TERM MAINTENANCE OF FOREST PRODUCTIVITY

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ABSTRACT

The maintenance of long-term productivity in forest stands is highly dependent upon the continued input of plant nutrients and their conservation within the ecosystem. Although fire has many beneficial uses within the forest environment, it also has potential negative effects. Among these are reduced protection of the soil by removal of the forest floor, volatilization of nitrogen and sulfur, transformation of phosphorus, potassium, calcium, and magnesium to soluble oxide and carbonate forms, thus increasing potential for leaching loss, and deleteriously altering a variety of other physical, chemical, and biological soil properties. The effective magnitude of these transformations depends almost entirely upon fire intensity. However, one of the major research difficulties in interpreting long-range effects of fire on the productivity of Pacific Northwest forest soils is the unknown or incomplete documentation of fire intensity on sites being studied for fire effects.

INTRODUCTION

Forest managers trying to increase wood fiber production on a limited land base have become increasingly interested in the effects of fire on the long-term productivity of forest lands. Although fire has played a major historic role in forming the present forest ecosystems of the Pacific Northwest, a rather small effort has gone into studying specific effects of fire on long-term site productivity. Variability in forest productivity and possible needs for forest fertilization brought about by fire effects are difficult to explain from results of current research. This can be attributed to both an incomplete understanding of how Pacific Northwest conifers respond to mineral fertilization and the ecosystem dynamics affecting the total amount of organic matter produced (Grier and Klock 1980).

Thus with the present state of knowledge we could easily argue either that fire affects productivity or that it does not. The limited literature shows both viewpoints. Stark (1977) points out, using one site as a reference, that fire will not affect productivity over tens of thousands of years. On the other hand, Jorgensen et al. (1975) contend that because of the physical and chemical processes that plant nutrients are subjected to in burning, future productivity must be reduced. We take the

position that fire may affect site productivity, but the magnitude of its effect depends upon (1) the ecosystem, (2) the intensity of fire, and (3) the frequency of fire.

EFFECTS OF FIRE ON SOILS

Before we discuss the ecosystem, treatment, and frequency consequences of fire on site productivity, however, we should review the primary effects of fire on soils. Wells et al. (1979) recently prepared an excellent state-of-knowledge report on the effects of fire on soil. They pointed out that the generally accepted negative effects of fire on soil are: (1) Removal or decreases in protection of soil by forest floor, (2) volatilization of large amounts of certain plant nutrients (mainly N, S), (3) transformation of less volatile plant nutrients to soluble mineral form that are easily absorbed by plants or lost by leaching, and (4) heating the soil, thus altering its physical, chemical, and biologic properties.

Although well documented, it is often difficult to predict either immediate or long-term fire effects because of large variations among and within fires. These variations are often attributed to differences in fire intensity, temperature, vegetative type and amount, and soil moisture (Wells et al. 1979).

Removing the protective forest floor by fire exposes the mineral soil to the destructive forces of erosion by wind and water. Klock (in press) showed that loss of the upper few centimeters of mineral soil by erosion may have a serious impact on soil productivity, particularly in ecosystems occupying harsh or steep sites. Erosion is not only promoted by exposure, but also by decreased water retention capacity created by loss of the forest floor organic material and increased surface runoff. Increased surface runoff may also be created by loss of the transpiration draft on soil water leading to reduced mantle capacity for the storage of future precipitation input.

Of all the potential effects of fire on soil, the loss of valuable plant nutrients, particularly those which may be limiting to future productivity, is of greatest concern. DeBano and Conrad (1978) reported that up to 10% or 146 kg/ha of N was lost through volatilization during prescribed burning in a southern

California chaparral ecosystem. Welch and Klemmedson (1975) reported a 20% loss of ecosystem N capital during a wildfire in ponderosa pine. Within the Pacific Northwest, Grier (1975) reported at least 39% or 907 kg/ha of ecosystem N capital was lost by volatilization and possible ash convection in the 1970 wildfire in the Entiat Valley of eastern Washington. In this case, the dominant vegetation was mixed ponderosa pine and Douglas-fir. Zavitzkovski and Newton (1968) estimated N loss from Douglas-fir slash burning in western Oregon to be 750 kg/ha. Generally, these values appear to be near the upper limit of N loss by fire and subsequent volatilization. Volatilization losses of N and S can be expected any time organic matter is heated in excess of 200°C (White et al. 1973).

Nitrogen is not a nutrient normally present in rock minerals, thus it is not released by weathering. For this reason, ecosystem nitrogen capitals represent accumulations of inputs whose source is outside the ecosystem. Two important outside sources are recognized: atmospheric deposition by precipitation and fallout, and fixation of atmospheric dinitrogen. In the United States, atmospheric deposition ranges from 1 to 12 kg/ha. Although this appears to be the major source of N in nonfire-perpetuated ecosystems, it is insufficient to balance N losses by volatilization in ecosystems with significant fire frequency.

In fire-perpetuated ecosystems, fixation of atmospheric dinitrogen appears to be important in the N economy of an ecosystem and equally important in maintaining site productivity. Many species of *Alnus*, *Ceanothus*, *Purshia*, *Lupinus*, and *Shepherdia* harbor N-fixing symbionts in root nodules—these species are common in fire-type communities. Moreover, these species appear to play an important role in fixing N in Northwest conifer forests following fire (Waring and Franklin 1979).

An extended period of vegetative N-fixation activity may be required to rebuild N capital lost through fire-induced volatilization. This important biologic N input to forest systems is not as prevalent in ecosystems in many other forested regions of the United States. Thus the detrimental effect of fire on long-term site productivity may be greater in forest regions lacking significant vegetative N-fixation. Introduction of N fertilizers can reduce the time period necessary for the reestablishment of N levels in these ecosystems.

Sulfur, another important plant nutrient, is lost in fires by volatilization in much the same way as N. However, relatively little research has been done on S losses in fires. The ratio of N to S in the protein molecule is about 10:1. Sulfur losses during combustion should be 7% to 10% of N losses when forest fuels are burned. Thus S losses can be significant if N volatilization losses are any indication.

The major exogenous source of S appears to be atmospheric pollution. In the past, levels of atmospheric pollution in the Pacific Northwest were probably low. But, the much greater frequency of fire may have led to the S deficiency observed within some of our fire-perpetuated ecosystems. Increased use

of fire with intensive management could also lead to increased S deficiencies if not corrected by fertilizer amendments. Increased input of S in acid rain from coal burning could help counter this trend.

One of the important objectives of rehabilitating areas burned by wildfire through vegetative establishment is to immediately immobilize the P, K, Ca, and Mg in rapid regrowth by living vegetation. Otherwise these elements, having been mineralized in the fire, may be subject to leaching losses. Although the loss of these elements by leaching is highly dependent upon climate, and more particularly on precipitation chemistry and intensity, their loss is also dependent upon levels of mobile anions (bicarbonate, nitrate, and sulfate) and organic acids in the soil solution.

Since the ionic charge of cations and anions must be equal in solution, increased concentration of anions in the soil solution will displace greater quantities of cations from the ion exchange complex in the soil to the leaching soil water flux (McColl and Cole 1968). Grier (1972) observed from laboratory leaching studies that 31% of the Ca, 80% of the Mg, 84% of the K, and 75% of the Na could be leached from the ash layer left by the Entiat wildfire, described earlier in this paper, by less than 30 cm of precipitation. Although much of the potential loss will be absorbed by the mineral soil, the possibility exists for plant nutrients to be lost from the rooting zone along this pathway.

Changes in the physical, chemical, and microbiologic properties of the soil are highly dependent on fire intensity. As noted earlier, fire can remove the protective forest floor exposing the mineral soil to erosion and surface water runoff. In extreme cases, exposure of the mineral soil can lead to dispersion of soil aggregates by raindrop impact leading to the clogging of pores and a resultant decrease in macro pore space, infiltration, and aeration. Fire has been reported to induce water repellency in soils at depths ranging from the surface to 20 cm; this phenomenon appears more prevalent on coarse textured soils (DeBano et al. 1977, Dyrness 1976). A wider range of soil surface temperatures can be expected following fire due to the loss of the insulating properties associated with the forest floor (Fowler and Helvey 1979).

Also, as noted earlier, the soil chemistry can be modified by fire. For example, P, K, Ca, and Mg can be released from organic complexes and become more available for plant use. Some N-fixation is stimulated by fire. For example, fire activates *Ceanothus* seed and permits its germination. On the other hand, N-fixation can also be inhibited by fire. Heat from fire may have a temporary sterilizing effect altering soil microflora populations including free-living nitrogen fixers. Although microorganism populations, have been observed to be modified by fire effects, no impairment of plant growth has been noted as a result of the effects of fire on soil microorganisms.

As pointed out earlier, we believe the potential effect of fire on the maintenance of long-term productivity is highly depen-

dent upon the ecosystem, the fire intensity or land treatment by fire, and fire frequency. A review of site characteristics and fire history may define the role of fire in the development of a particular ecosystem.

FIRE IN NORTHWEST FOREST TYPES

Lowland Douglas-Fir/Hemlock

Forest ecosystems of western Oregon and Washington have developed under relatively high rainfall and mild temperatures. In spite of this, fire has played a major role in shaping these forests (Waring and Franklin 1979). Fires in this forest zone are rather infrequent, possibly several hundred years apart, but are usually extremely intense. Recent examples of large, intense fires in this region are the Shelton, Tillamook, and Oxbow burns. Forest succession in these fire-affected areas usually follows rapid establishment of herbaceous coverage. The herbaceous cover helps protect the site from erosion and retains readily available plant nutrients initially present in the ash layer.

Establishment of alder often follows development of herbaceous vegetation and N lost in the fire can be in large part replaced by an alder sere. Succeeding conifer stands then benefit from N-fixation by the pioneering *Alnus* species. Introduction of intensive management of conifers may not allow for the 30 to 40 yr required for restoration of N lost in burning. Therefore, N may become limiting to future stand growth and introduction of N fertilizer into the system may relieve this deficiency. Since fires in these ecosystems are infrequent, the probability of S loss and its influence on plant growth should be small under natural conditions.

Montane Douglas-fir

Douglas-fir also dominates large areas of the montane forests on the western slopes of the Cascade Range away from the coastal zone. In contrast to lowland forests, fire frequency here appears to be greater. Both *Alnus* and *Ceanothus* can be found in these forests. In these ecosystems, the two species have been reported to fix 50 to 300 kg/ha of N annually in early stages of forest development (Waring and Franklin 1979).

The increased presence of these pioneer N-fixing species in this ecosystem appears to result from higher frequency of wildfire in the past. Response to N fertilization could be expected by these forests, particularly if N-fixing species are silviculturally suppressed for several rotations. Existing N limitations would be emphasized if fire were used extensively in site preparation following harvest, while development of symbiotic N-fixing species was prevented. Since S inputs are limited in this region, deficiencies causing reduced productivity could appear in some areas within the region.

Eastside Forests

On the eastern Cascade slopes, fire frequency is much greater than observed on the western slopes. Where moisture is adequate, fire-associated N-fixing species, including *Ceanothus* and *Purshia*, are key species in forest succession. Four years after the Entiat Experimental Watershed in north-central Washington was burned by wildfire, *Ceanothus velutinus* covered 10% of the ground surface in the watershed (Tiedemann and Klock 1976). This cover was significantly greater than that of any other native plant species found in the area.

Due to the greater fire frequency, deficiencies in N and S might be expected. Klock et al (1971, 1975) showed significant plant growth response to both N and S fertilization through greenhouse bioassays for soil from the Entiat region and other east Cascade soils. Pumphrey (1971) and Geist (1971) pointed out that the addition of S was particularly important for increasing productivity of forest soils in northeastern Oregon.

SUMMARY

Fire can influence the long-term productivity of Pacific Northwest forest land, particularly if N-fixing species are suppressed in the early stages of plant succession following fire. This may be true both for fire used in site preparation following harvest and for wildfire. Due to the rather small effect of fire on the nutrient pool. The seriousness of the impact depends upon (1) the ecosystem involved, (2) the intensity of fire or land treatment, and (3) the frequency of fire.

It appears possible that response to N and S mineral fertilizer can be expected from forest sites where fire has been more prevalent. Due to large amounts of N potentially available through successional plant pioneers during early stages of forest development, S losses may be more critical in the long-term effect of fire on the maintenance of forest productivity within the Pacific Northwest.

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