Soils and Nutrient Considerations

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Abstract—Fire suppression has resulted in a buildup of forest litter and an accumulation of organic nitrogen, and a decrease in available potassium. This has changed the historic structure of soils and their nutrient content. Studies at 15 sites in Montana have looked at a wide range of changes in soil productivity following prescribed fire. Results indicate obvious benefits to the soils from reduction in fuel loading through fire, and renewed growth of desirable understory plants.

Restoration of ponderosa pine (*Pinus ponderosa*) forests to more closely resemble pre-1900 stand structures and species compositions generally involves some form of harvest along with use of prescribed fire (Arno and others 1995; Fiedler and others 1996). These Ecosystem-based Management (EM) approaches are aimed at the reduction of surface and ladder fuels that have accumulated as a result of decades of fire suppression. EM is also intended to stimulate herbaceous and shrubby vegetation, to prepare mineral-soil seedbeds, and to kill undesirable conifers (see Harrington, this issue). Although historic stand structures can be quickly envisioned following these prescriptive treatments, there is only limited understanding of how these treatments influence soil processes and nutrient availability and how these influences compare to those of the historic disturbance regime of frequent, low-intensity fires.

Ponderosa pine and Douglas-fir (*Pseudotsuga menziesii*) forests of the inland Northwest commonly accumulate little inorganic nitrogen (N) in the mineral soil because of slow decay rates and rapid uptake by plants and microorganisms. These forests are generally assumed to contain suboptimal N levels (Mandzak and Moore 1994). This N limitation is thought to be due to the accumulation of organic matter composed of low N woody residues within the forest floor and mineral soil of coniferous forests, resulting in little or no N release from the organic reservoir that houses soil N (Keeney 1980). Fire suppression has resulted in a buildup of forest litter (Covington and Sackett 1993), accumulation of inhibitory compounds (terpenoids) associated with pine needles (White 1986), and accumulation of N in living forest biomass (Hungerford and others 1991). Many forests of the inland Northwest are also considered to be potassium (K) deficient, depending upon the type of geologic material from which the soils formed (Mandzak and Moore 1994).

The significance of low N and other aspects of apparent infertility in these forests are not clear. We do know that historically many (perhaps most) of these forests were maintained in multi-aged stands, which included very large long-lived ponderosa pines, maintained by frequent low-intensity fires. It is likely that there were relatively small quantities of duff, humus, and coarse woody debris associated with the historic conditions. Annual precipitation and available moisture in these ecosystems are so low that, in some regions of the world, areas having comparable moisture do not support large trees. Perhaps these semiarid ponderosa pine ecosystems functioned naturally at low levels of certain nutrients.

Wildfire and prescribed fire in ponderosa pine forests generally result in an increase in plant available N due to removal of forest floor (Covington and Sackett 1992), volatilization of terpenoids (White 1986), denaturation of organic N compounds, and killing of soil microbial biomass (Hernandez and others 1997). The resulting release of inorganic N immediately following burning of ponderosa pine forests has been reported in numerous papers (Kovacic and others 1986; Covington and Sackett 1992; Monleon and others 1997). This increase in immediately available N is considered to improve N fertility in ponderosa pine forests. However, productivity of ponderosa pine forests may decline following first-entry fire treatments as a result of root kill (Grier 1989) or perhaps due to a reduction in N mineralization potential (Monleon and others 1997).

We have been investigating the effect of forest restoration efforts (harvest with and without prescribed burning) as well as wildfire with and without previous prescribed fire on nutrient availability, microbial activity, and soil organic matter quantity and quality. Studies have been carried out at 15 sites in western Montana, including the Lick Creek Demonstration Area on the Bitterroot National Forest and at the University of Montana's Lubrecht Experimental Forest.

Our investigations have demonstrated that prescribed fire following selection or shelterwood harvest results in a short term increase in mineral N followed by a long term decline in available N (DeLuca and Zouhar 2000; Newland and DeLuca 2000). The higher severity fires (such as the 1994 Willow Creek Wildfire on the Bitterroot National Forest) result in the greatest N loss from the ecosystem (Choromanska and DeLuca 2000). When prescribed fire precedes a wildfire, the N loss is lower than if the site experiences wildfire alone. These declines in available N are paralleled by a decrease in microbial activity wherein microbial biomass and basal respiration rates are reduced following fire and are reduced to the greatest degree on high severity fire sites.

The connection between a reduction in mineralizable N levels following fire and an increase in site productivity may seem difficult to reconcile; however, it must be stressed that we do not have a historic reference site with which to compare the fire treatments. The composition and function of understory plants may play an important role in maintaining long term productivity of sites with low levels of

In: Smith, Helen Y., ed. 2000. The Bitterroot Ecosystem Management Research Project: What we have learned—symposium proceedings; 1999 May 18-20; Missoula, MT. Proceedings RMRS-P-17. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

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mineralizable N. Sites with well developed understory communities in ponderosa pine forests in central Oregon showed increased long term growth of trees, total organic matter, and microbial biomass compared to sites in which understory vegetation had been excluded for 35 years (Busse and others 1996). Fire exclusion has clearly altered understory plant communities. In our studies, N fixing plant species were in low numbers on all sites, but were more common on sites exposed to fire and most common on sites that had been repeatedly opened by harvest prior to reintroduction of fire.

Our studies suggest that ponderosa pine forests with frequent low-intensity fires may have once had higher densities of N-fixing plants, including legumes (e.g., lupine [*Lupinus* spp.]) or actinorrhizal species (e.g., bitterbrush [*Purshia tridentata*]) (Newland and DeLuca 2000). The paucity of remaining old growth stands and the fact that these have been altered by fire suppression make repeatedly opened sites in ponderosa pine forests the best representation of historic forest structure in western Montana (Arno 1996). Efforts to restore historic ecological function in these forests may allow managers to increase the density of N-fixing plants while meeting other management objectives. It is important to learn more about the contribution of N-fixing plants to the N cycle of western Montana forests. If N-fixing plants become more common with increasing disturbance and available soil N becomes lower, input of N from N-fixing plants may become very important in maintaining forest productivity.

Obvious benefits realized from prescribed fire include a reduction in fuel loading, thereby reducing the potential for a high severity wildfire that would lead to (1) greater losses of N, phosphorus, and sulfur, (2) greater microbial mortality, and (3) greater potential for post-fire erosion events (Hernandez and others 1993). Such treatments also allow for growth of understory plants that had been out-competed and excluded as a result of eliminating frequent fires. These understory species may directly or indirectly influence nutrient availability.

At first glance, a decrease in total mineralizable N in forests that have generally been considered N deficient may seem like a negative impact of re-introducing fire. However, the reduced stand density following fire has lower N demand, and the decline in available N may actually have several positive effects, such as:

1. Reduced available N and increased or static concentrations of exchangeable K resulting in a more balanced ratio of N:K, thereby resulting in lower susceptibility to disease or insect attack (Mandzak and Moore 1994).

2. Reduced levels of mineralizable N resulting in greater ability of native N fixing species to colonize sites following fire (Leach and Givnish 1997), thus providing a more labile form of N compared to the recalcitrant N associated with duff or resident soil organic matter.

3. Reduced levels of mineralizable N may decrease the ease with which non-native plant species compete with native species (Wedin and Tilman 1996).

Further studies are being conducted on the Bitterroot National Forest to assess some of the interactions of fire and N. Those studies are investigating the following effects of fire on:

1. N turnover rates and plant uptake rates of N, and how that may influence productivity.

2. N:K and how this influences root phenolic concentrations.

3. The change in understory vegetation (from ericaceous shrubs to graminoids) and how this change in plant species influences soil organic matter quality as it relates to nutrient turnover.

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