The Biogeochemical Effects of Catastrophic Fires and Salvage Logging on Forest Soils in the Fremont-Winema National Forest

Background

On July 23, 2002, lightning struck in southern Oregon, sparking a fire that consumed approximately 42,000 forest acres. After 10 days, the fire crews were able to get it under control but not before losing an estimated total of 88,000 acres.

Importance

Soil nutrient changes brought on by fire can have immense repercussions on future forest development. Vegetation depends on soil nutrients to survive: perennials in the late seral stage of succession, such as mature forests, depend on ammonium-nitrogen; nitrite is an intermediate step between the change from ammonia to nitrate and can be highly toxic; annuals, such as pioneering species, rely on nitrate-nitrogen; phosphates make up the phospholipid bilayer in cell membranes as well as the energy molecule Adenosine Tri Phosphate (ATP); and potassium aids in root osmosis.

Nitrogen

Nitrogen is an inert gas and makes up approximately 78% of the Earth's atmosphere. It can be fixed by lightning but mostly by bacteria living in soil. The bacteria fix the nitrogen for their own use and it is not until their "death" that they release it (Ingham). Because the bacteria have died, the fixed nitrogen is now ammonium-nitrogen. Perennials prefer to utilize ammonia, as can annuals. When the plant dies, it will return to the soil. Ammonia not taken-up can become nitrite-nitrogen, an intermediate step between ammonium-nitrogen and nitrate-nitrogen. Once it becomes nitrate-nitrogen, annuals prefer to take it up and sometimes perennials make use of it. Throughout the cycle, nitrogen can denitrify and change back to inert nitrogen gas. Phosphate and potassium come from volcanic rock; potassium usually in the form of potash.

What happens to these nutrients after a catastrophic fire sweeps through, leaving no vegetation? Any heating of the organic layer and the upper six inches of the mineral soil can have serious repercussions on post-fire forest productivity because the bulk of nutrients and the activity of soil organisms are concentrated there.

Low severity fires heat the soil surface to 400 degrees Fahrenheit or less, leave blackened soil surfaces and minimally impact the soil except on its surface. Fires that reach 550 degrees Fahrenheit or less are considered moderately severe. These fires generally consume all organic material on the soil surface but at a temperature that mineralizes soil macro-nutrients making them available for plant up-take. Moderately severe fires tend to have higher nitrogen concentrations immediately following the fire, but tend to lose most of the nitrogen over the course of the first year. High severity fires cause soils to reach temperatures in excess of 572 degrees Fahrenheit where nitrogen compounds volatilize to nitrogen gas. These soils are nitrogen poor following the fire.

Soil studies detailing soil nutrients trends after the first year are difficult to find. Six years after the fire, raw data was taken from burned areas to be analyzed for this study.

Methods/Materials

Surveyed sites were randomly chosen using GIS layers (ESRI) based on similar characteristics. The 45 sites chosen were west-facing with a 6-15° slope, sandy loam soils lacking abundant boulders and populated with Ponderosa pine and White fir. 70% non-burned, 30% burned, and burned and harvested were randomly selected. The randomly selected sites were visited for closer inspection. The sites were examined for similar pre-burned tree characteristics: densities of 150-200 trees per acre; diameters at breast height averaged 25-40cm; 20 trees or less greater than 45cm; and with 20-30 small trees less than 20cm.

Once the sites were found to be comparable, the center of a stand was found using a compass and a 30m tape, and a random number between 0 and 360° was used for direction to transect. A random number was again selected for the distance in paces to point A of plot. After locating point A, a random number was selected for the direction of the transect line and then the tape was stretched out. Soil data was taken at every 3m mark. Soil temperature was measured with the Weksler soil thermometer; Field Scout Soil Compaction M-900 was used for compaction, AMS Tile Probe for soil depth, Field Scout Soil Moisture Meter 700 for moisture, a caliper to measure rhizome depth, and the Soil Sampling Augur to take soil samples.

Soil samples representative of the site were taken at the A and B stake and bagged for soil testing. Using the LaMotte Smart 2 Soil Spectrophotometer/Colorimeter and protocols developed by LaMotte for soil Ammonia, Nitrite, Nitrate, Phosphate, and Potassium. The samples were analyzed and recorded in parts per million (mg/L).

Results of soil characteristics:

Comparisons between burned areas and unburned areas revealed significant changes:

1. soil depth decreased by 29%,
2. duff depth increased by 94%,
3. rhizome depth increased by 13%,
4. percent moisture decreased by 500%, and
5. soil temperature increased by 12%.

Compaction decreased by 38.6% but this proved insignificant

Comparisons between burned areas and burned areas that were salvaged revealed insignificant changes despite:

1. soil depth increased by 11%,
2. duff depth was similar and mostly absent,
3. rhizome depth increased by 3%,
4. percent moisture decreased by 25%, and
5. compaction decreased by 14%

Temperature increased significantly by 9%.

The following explanations are given concerning changes between the non burned control and burned areas and between the burned areas compared to the burned and salvaged areas:

1. Soil depth decreased due to high temperatures resulting in friable soil peds losing structural integrity and settling over time, Soil depth increasing slightly after logging is confusing though sub-soiling may have been performed in enough areas to statistically show deeper soils
2. Duff depth decreased because the moderately severe fire removed the litter layer leaving a thin layer of ash,
3. Rhizome depth increased as a possible result of the small ash particles from the fire leaching throughout the soil horizons and settling in lower layers causing the rhizomes to move deeper for nutrients,

4. Percent moisture decreased because shade was removed exposing the soil to sunlight drying it out. During salvage the establishing plants were disturbed, again allowing in more sunlight to heat the soil and dry it farther,
5. Compaction decreased as a result of heating water in the soil, expanding water pockets. However the soil becomes very fragile when this happens and is easily compacted when disturbed. The lower compaction values could also result from sub-soiling practices that occurred in some of the areas, and
6. Temperatures increased because soil was exposed due to loss of vegetative cover. This may appear negative but does have some positive implications; higher temperature less than 90° causes microbes in the soil to increase their activity; cycling soil nutrients.

Results of soil chemistry:

Comparisons of unburned with burned areas revealed that nitrogen macro-nutrients decreased while phosphorus and potassium macro-nutrients increased:

1. Ammonia decreased by 43%; nitrite decreased by 50% and nitrate decreased by 53%. Ammonia and nitrate decreasing in the soil could indicate one of two things: the area is recovering and vegetation is utilizing the nutrients; or because there are no vegetation or soil microbes to utilize them, the nutrients have denitrified into inert nitrogen.
2. Phosphate increased by 75% probably due to the lack of plants that utilize it and its ability to be stored in the soil for long periods of time.
3. Potassium is similar at +4% which falls within the relative error of the mean and deviation.

Comparisons of burned areas with burned salvaged areas revealed:

1. Ammonia decreased by another 50%; nitrite decreased by an additional 50%; nitrates by 91%. Ammonia and nitrate decreasing in the soil could indicate one of two things: the area is recovering and vegetation is utilizing the nutrients; or because there are no vegetation or soil microbes to utilize them, the nutrients have denitrified into inert nitrogen.

2. Phosphate increased by 68% probably due to the lack of plants that utilize it and its ability to be stored in the soil for long periods of time.
3. Potassium remained the same.

Statistics Summary: (review table on following page)

Significant results were found between unburned forest soils and burned forest soils. The results that were significant included ammonia, nitrate, phosphorus, soil dept, litter depth, rhizome depth, moisture and temperature.

Insignificant results were found between burned forest soils and burned with salvage forest soils. The only significant difference was temperature. All other results showed no statistical difference between burned and burned and salvaged soils.

Future Implications

The best time to enter a burn for salvage or restoration purposes is immediately after the burn before plants have established themselves. Plants such as legumes that house nitrogen-fixing microbes right in their roots should be established. By favoring populations of nitrogen-fixing soil micro-biota, fire can enhance long-term nitrogen availability in forest ecosystems ("During")". Invasive plants that utilize nitrates over ammonia (most noxious weeds) could also be discouraged by spraying areas with a rhizobial tea extract made from old growth litter to ensure that ammonia is present in high concentrations which favor late seral plants (Ingham).

Summary

Three years after catastrophic fires soil conditions continue to be degraded at significant levels compared to control plots due to the absence of soil biota that enhance nitrogen levels, specifically ammonia from litter. Without proper nutrients, noxious weeds and annuals are encouraged which farther degrade the soils reducing soil depth, duff depth, rhizome depth and percent moisture, while increasing compaction and soil temperatures. Wildfires have a dramatic and negative effect on forest soils that require native myccorhizae to remedy.

Salvage following a burn does not significantly impact forest soils, except by increasing temperatures significantly. This could help microbes cycle nutrients and re-establish soil biota more quickly in conditions when moisture remains high, but at the expense of soil moisture. However, in this study, soil moisture dropped, though not significantly.

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