An Overview of Fire Effects on Soils

D. G. Neary, Ph.D. – Rocky Mountain Research Station, Flagstaff, Arizona

Fires in forests and rangelands produce some of the most profound impacts on ecosystems of the Southwest. Wildfires and prescribed fires affect the vegetation, soils, wildlife, and water resources of watersheds. They impose a wide range of effects depending on the mosaic of fire severities and post-fire hydrologic events.

Changes in soils after fires produce varying responses in the water, floral, and faunal components of ecosystems because of their complex interdependencies. The effects of fire on soils are a function of the amount of heat released from combusting biomass – the fire intensity – and the duration of combustion. The impact of these factors on the physical, chemical, and biological properties of the soil is measured as severity.

Fire severity is defined in terms of: 1) the length of time fuel accumulates between fires and the amount of the accumulated fuels; 2) properties of the fuels (such as size, flammability, and moisture or mineral content); 3) how the fuels impact fire location and behavior (causing crown, surface, or ground fires); and 4) heat transfer in the soil during the combustion of above-ground fuels and surface organic layers (DeBano et al., 1998). High intensity fires – those that reach 1,200 degrees Celsius or more – do not always result in high severity impacts in the soil if their duration is short, but low intensity fires of just 300 degrees Celsius that smolder for a long time in roots or organic matter can produce large changes in the nearby soil.

Physical impacts of fire on soil include breakdown in soil structure, reduced moisture retention and capacity, and development of water repellency, all of which increase susceptibility to erosion. Chemically, fire-impacted soils experience changes in nutrient pools cycling rates, loss of elements to the atmosphere, and loss of organic matter.

Increased runoff on soils damaged by the Rodeo-Chediski Fire of 2002.

Biological properties are altered by changes or loss of microbial species and population dynamics, reduction or loss of invertebrates, and partial elimination (through decomposition) of plant roots. Although the most severe impacts on soils occur in stand-replacing wildfires, prescribed fires can produce local effects.

The effects of fire on soils are a function of the amount of heat released from combusting biomass…and the duration of combustion.

Physical Effects

When fire consumes vegetation and underlying litter layers, hydrophobic or water-repellant soil conditions can form. The hydrophobic zone appears as a discreet layer in the soil, at or parallel to the surface, where hydrophobic organic compounds coat soil aggregates or minerals. This phenomenon occurs at soil temperatures of 176 to 288 degrees Celsius (DeBano, 1981). Hydrophobic soils prevent water from wetting aggregates (see photo above right), essentially sealing off the soil during rainfall, greatly increasing surface runoff (see photo above) and erosion. The net effect is a reduction in soil moisture content, erosion of nutrient-rich ash and upper soil horizon sediments, and ultimately watershed drying. Drier soils also diminish the viability of microbes that are involved in biogeochemical cycling and can inhibit re-colonization by plants that stabilize soils.

One of the most important impacts on soils results from the combustion of organic matter. Consumption of organics can range from scorching (producing black ash) to complete ashing (producing white ash) (DeBano et al., 1998), depending on fire severity, moisture content, and thickness of the organic layer. Campbell et al. (1977) found that moderately burned areas maintained 38 percent of the vegetative and litter cover, while severely burned areas had none to 23 percent retention. Observations by the author following catastrophic stand-replacing fires in pinyon-juniper woodlands and ponderosa pine forests of Arizona also indicated a 75 to 100 percent loss of organic material. This loss of organics causes changes in soil structure and porosity. Soil structure degradation can persist for a year to decades after a fire and is often responsible for reduced infiltration and increased runoff.

Chemical Changes

Biogeochemical changes in the mineral soil are most pronounced when burning is of high severity, with carbon and nitrogen strongly affected. The significance of these changes is directly tied to the pre-fire productivity of a given ecosystem. Nutrient-limited forests, such as ponderosa pine, tend to be impacted more than nutrient-rich ones.

Water drops bead on a soil surface with fire-induced repellency.

Recovery of soil nutrient levels after fires can be fairly slow in some ecosystems, particularly those with limited nitrogen, and in semi-arid regions where decomposition rates are slow. Klopatek (1987) determined that 35 years after a wildfire, nitrogen concentrations beneath pinyon-juniper canopies had not recovered to levels found in stands that had not burned in 300 years. In addition, soils beneath burned stands showed a twofold increase over unburned stands in the percent of total nitrogen that was changed from organic forms such as litter and humus to more mobile nitrates and ammonium. While these mobile forms of nitrogen are more accessible for plant uptake, they are also more prone to off-site movement in surface runoff and leaching (Neary et al., 1999).

Biological Impacts

The short- and long-term effects of fire on soil microorganisms, and the resulting effects on ecosystem sustainability, are uncertain and often debated. The effects of fire on soil microorganism populations and species composition depend on the severity of the fire, as well as the site conditions and pre- and post-fire weather. Low-severity, rapidly moving fires do not have a major effect on microbial populations, whereas high-severity fires with long durations have the greatest impact. Field studies by Klopatek et al. (1988) showed that ten years after burning, mycorrhizae numbers, soil nutrients, and vegetation with severely burned canopies had not recovered to pre-burn levels.

Invertebrates play an important role in litter decomposition, carbon and nutrient mineralization, soil turnover, and soil structure formation. However, the effects of fire on invertebrates and subsequently on belowground sustainability are difficult to assess because of variability in fire severity, invertebrate species present, and species response to fire (DeBano et al., 1998).

Wildfires definitely produce the largest soil impacts of any disturbance to ecosystems of the Southwest because they tend to be more severe and cover larger areas. Although much information exists about the effects of fires on soils and other watershed resources, efforts need to be made to put this information into a systematic context so that it can be useful to wildland fire managers.

Contact Dan Neary at dneary@fs.fed.us.

References . . . .

Campbell, R.E., M.B. Baker, Jr., and P.F. Ffolliott, 1977. Wildfire effects on a ponderosa pine ecosystem: An Arizona case study. USDA Forest Service Research Paper RM-191, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO, 12 p.

DeBano, L.F., 1981. Water repellent soils: a state-of-the art. USDA Forest Service, General Technical Report PSW-46, Berkeley, CA.

DeBano, L.F., D.G. Neary, and P.F. Ffolliott, 1998. Fire's Effects on Ecosystems. New York: John Wiley & Sons, Inc. 333 p.

Klopatek, J.M., 1987. Nitrogen mineralization and nitrification in mineral soils of pinyon juniper ecosystems. Soil Science Society of America Journal 51: 453-457.

Klopatek, C.C., L.F. DeBano, and J.M. Klopatek, 1988. Effects of simulated fire on vesicular arbuscular mycorrhizae in pinon juniper woodland soil. Plant and Soil 109: 245-249.

Neary, D.G., C.C. Klopatek, L.F. DeBano, and P.F. Ffolliott, 1999. Fire effects on belowground sustainability: a review and synthesis. Forest Ecology and Management 122: 51-71.