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Soils Under Fire: Soils Research and the Joint Fire Science Program

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Cover photo:

In 2003, the B&B Fire burned over 36 400 ha (90,000 acres) in the Deschutes and Willamette National Forests, Mount Jefferson Wilderness, and the Warm Springs Reservation in central Oregon. The photo shows an area where an entire log has been consumed by the fire. The intense heat generated by the burning of large woody material causes soil oxidation, conspicuously changing the soil color from black to various shades of red. High-severity fires that consume entire logs or stumps affect relatively small areas but can have profound soil impacts. After a severe fire, soils may be void of almost all biological activity, and the length of time for recovery is unknown. Photo by Jane E. Smith, U.S. Forest Service.



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ABSTRACT

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Soils are fundamental to a healthy and functioning ecosystem. Therefore, forest land managers can greatly benefit from a more thorough understanding of the ecological impacts of fire and fuel management activities on the vital services soils provide. We present a summary of new research on fire effects and soils made possible through the Joint Fire Science Program and highlight management implications where applicable. Some responses were consistent across sites, whereas others were unique and may not easily be extrapolated to other sites. Selected findings include (1) postfire soil water repellency is most likely to occur in areas of high burn severity and is closely related to surface vegetation; (2) although wildfire has the potential to decrease the amount of carbon stored in soils, major changes in land use, such as conversion from forest to grasslands, present a much greater threat to carbon storage; (3) prescribed fires, which tend to burn less severely than wildfires and oftentimes have minor effects on soils, may nonetheless decrease species richness of certain types of fungi; and (4) early season prescribed burns tend to have less impact than late season burns on soil organisms, soil carbon, and other soil properties.

Keywords: Soils, fire effects, prescribed fire, wildfire, soil carbon, soil organisms, water repellency, nutrients, forest restoration.

INTRODUCTION

Soils are the foundation of an ecosystem in many ways. They are the medium for plant growth, and they release, recycle, and filter nutrients and toxins. By providing habitat and supplying water and energy for soil organisms, soils support biodiversity. Soils are also sources and sinks of globally important greenhouse gases, and they store carbon, nutrients, and water within watersheds. Obviously, soils are fundamental to a healthy and functioning ecosystem. Individuals and agencies charged with managing the land can benefit from a solid understanding of how their activities may affect the many vital services soil provides.

SOILS AND FIRE

Both wildfire and prescribed fire can drastically alter soils and the services they provide. Wildfires have burned increasingly large areas of land, especially in the West, and that trend is expected to continue. The area of land subjected to prescribed fire may also be increasing as fire is being returned to historically fire-dependent forests as a means of restoration.

How soils are affected by fire and how much impact a fire has on an ecosystem are largely determined by how severely a fire burns. Fire severity reflects the duration and amount of energy that is released and available to alter various components of an ecosystem, whereas soil burn severity reflects the impact of fire on soils owing to heat at the soil surface.

Prescribed fires, by design, tend to be much less severe than wildfires, resulting in less impact on soil. Soil burn severity from both wild and prescribed fires is rarely uniform across a burned area. Even the most severe fires have areas where the surface organic layer has not been destroyed;

conversely, low-severity fires often have hot spots where the organic layer has been completely consumed.

Fires can be both beneficial and detrimental to soils; which designation may depend on perspective. Probably the greatest benefit of fire to soil ecosystems, and the most well known, is an increase in soil fertility, which facilitates greater crop production and favors some plant species over others. If the favored plant species is a nonnative invasive, the increase in fertility may be considered negative. Other likely negative impacts of severe fire on soil include destruction of the protective vegetation canopy and forest floor, a significant loss of soil carbon and nitrogen, and reduced infiltration capacity, which can lead to landslides, dry ravel (downslope movement of loose, dry particles), and erosion by wind and water causing increased runoff and sediment input into streams.

Scientists have studied the relationships between fire and soil for many decades. Details of the principles and processes governing these



Elaine Kennedy Sutherland, Fire and Fire Surrogate Program, Ohio Hill Country Site

Prescribed fire moving through an oak forest in southern Ohio. Prescribed fires, by design, burn less intense than wildfires, and, depending on fire behavior, may only impact soils for a relatively short amount of time.

complex relationships have recently been compiled by Neary et al. (2005). Much of what we present as background information has been taken from that review; we recommend this and the additional readings at the end of each section for more information.

THE JOINT FIRE SCIENCE PROGRAM AND SOILS RESEARCH

The Joint Fire Science Program (JFSP)¹ has funded over 300 projects examining wildfire, prescribed fire, and fuel management activities. Many of these projects, or portions of them, are examining or have examined fire effects on soils. The topics considered by these studies are as varied as the services provided by soils. All share the common goal of increased understanding of both short- and long-term responses of soil to fire by building on previous knowledge and providing specific information from forests and other ecosystems where detailed information is lacking.

For this synopsis, we have gathered information from JFSP studies that address the following five key questions related to soils and fire:

1. How does fire affect soil hydrology?
2. How do soil organisms respond to fire?
3. How does fire influence carbon storage and loss?
4. How does fire impact soil nutrient availability?
5. How does the season of prescribed fire burning influence soils?

¹ Joint Fire Science Program [JFSP]. Joint Fire Science Program: research supporting sound decisions. <http://www.firescience.gov>. (December 2007). Information on all JFSP projects, including many final reports, can be obtained by searching on Title or Principal Investigator on the JFSP Web page.

Soils are a product of climate, vegetation and other life, parent material or originating substrate, local topography, and time (Jenny 1980); many of the responses of soils to fire are as unique as the interactions among the factors that form them. One of the challenges of soils research is to identify whether unifying principles apply across sites. We hope this synopsis is a step toward that goal.

REFERENCES

Neary, D.G.; Ryan, K.C.; DeBano, L.F. 2005.

Wildland fire in ecosystems: effects of fire on soils and water. Gen. Tech. Rep. RMRS-GTR-42. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 250 p. Vol. 4.

Jenny, H. 1980. The soil resource. Ecological Studies 37. New York: Springer-Verlag. 377 p.

Question 1:

How Does Fire Affect Soil Hydrology?

When fire removes the forest canopy and the forest floor that protect the underlying mineral soil, modifications to several hydrologic properties of soil may result. One of these is an enhancement of soil water repellency that may lead to increased runoff and erosion. Soil water repellency (hydrophobicity) can be found in both fire- and non-fire affected soils and is often the result of mineral soil particles being coated with a fine layer of organic matter. Water repellency can occur at the soil surface or in a deeper layer (Neary et al. 2005).

Fire can change the distribution and intensity of water repellency in naturally water-repellent soils such as the ashcap soils found in the northern Rockies. In the Bitterroot National Forest in western Montana, Peter Robichaud and colleagues^{1,2} found that wildfire destroyed surface soil water repellency and created a strong water repellent layer 1 to 2 cm below the surface (Brady et al. 2001). During subsequent rain events, the non-water-repellent surface layer became quickly saturated down to the more water-repellent layer. The soil in the saturated layer is easily detached and carried downhill with storm runoff, causing increased erosion and sedimentation. Managers can use this information to assess the risk of damaging runoff and erosion events occurring after a fire and to decide where, when, and how to apply the most effective postfire erosion mitigation treatments.

¹ JFSP project title: Risk assessment of fuel management practices on hillslope erosion processes. Principal investigators: Robichaud, P.; Pierson, F.; Elliot, W.; Wohlgemuth, P.

² Risk assessment of fuel management practices on hillslope erosion processes. Robichaud, P.; Pierson, F.; Elliot, W.; Wohlgemuth, P. Joint Fire Science Program final report. http://www.firescience.gov/projects/98-1-4-12/98-1-4-12_final_report.pdf. (December 2007).

In addition, the Robichaud team (see footnote 1) has incorporated new information on variability in soil properties and burn severity into the Erosion Risk Management Tool (ERMiT), a postfire soil erosion prediction tool. ERMiT is a Web-based model that combines the probability of rain events occurring with the variability of postfire soil properties and soil burn severity to predict potential erosion rates and their probability of occurrence (Robichaud et al. 2006, 2007a, 2007b).

Joint Fire Science Program research has built on our understanding that vegetation may influence whether soils become water repellent after fire. After the 1999 Denio Fire in Nevada, Robichaud and his team (see footnote 1) found that soil water repellency was higher and infiltration rates were lower under burned shrubs than under unburned shrubs. This fire-induced change contributed to a fourfold increase in erosion under burned shrubs. Erosion rates were still elevated 1 year after this fire owing to the slow recovery of vegetation (Pierson 2001). Peter Wohlgemuth and colleagues³ found that after the 2002 Williams Fire in southern California, soil water repellency was lower in areas of native chaparral than in areas converted to grassland, suggesting that landscape conversion may contribute to erosion.⁴

³ JFSP project title: The effects of soil properties, fuel characteristics, and vegetation recovery on postfire watershed hydrology and sediment yield in chaparral steepplands. Principal investigators: Wohlgemuth, P.; Narog, M.; Beyers, J.; Hubbert, K.

⁴ The effects of soil properties, fuel characteristics, and vegetation recovery on postfire watershed hydrology and sediment yield in chaparral steepplands. Wohlgemuth, P.; Narog, M.; Beyers, J.; Hubbert, K. Joint Fire Science Program final report. http://www.firescience.gov/projects/03-2-3-13/03-2-3-13_final_report.pdf. (December 2007).

Vegetation also interacts with soil texture to influence infiltration rates after fire. In pinyon-juniper woodlands in the Great Basin, Jeanne Chambers, Benjamin Rau, and their colleagues⁵ found that infiltration rates after prescribed burning decreased more under pinyon canopies compared to under shrubs or areas without vegetation.⁶ The interspace areas without vegetation always had low infiltration rates, and after fire, the infiltration rates under pinyon were nearly as low as in the interspaces. Soil texture also differed under the different plant canopies. Under pinyon, coarse-textured, skeletal (with many rock fragments) soil is often found and is more prone to fire-induced water repellency than the finer-textured non-skeletal soil with few rock fragments located elsewhere. However, the effect of increased soil water repellency on surface hydrology depends on rainfall. In this area, because the chance of getting enough rain to exceed these reduced infiltration rates is so low (about 0.1 percent in a given year), the researchers concluded that prescribed fire would not likely have a negative impact on surface hydrology (Rau et al. 2005).

Steve Wondzell and Katy Clifton⁷ also found that in the absence of major storms within the first few years after prescribed fire in northeastern Oregon, erosion rates were very low, and there were no

⁵ JFSP project title: A demonstration area on ecosystem response to watershed-scale burns in Great Basin pinyon-juniper woodlands. Principal investigators: Chambers, J.; Tausch, R.; Amacher, M.; Germanoski, D.; Fleishman, E.; Zamudio, E.

⁶ A demonstration area on ecosystem response to watershed-scale burns in Great Basin pinyon-juniper woodlands. Chambers, J.; Tausch, R.; Amacher, M.; Germanoski, D.; Fleishman, E.; Zamudio, E. Joint Fire Science Program final report. http://www.firescience.gov/projects/00-2-15/00-2-15_final_report.pdf. (December 2007).

⁷ JFSP project title: Evaluating the effects of prescribed fire and fuels treatment on water quality and aquatic habitat. Principal investigators: Wondzell, S.; Clifton, C.

significant differences in surface erosion between burned and unburned plots. Although erosion rates were low, the researchers did find that erosion was related to the amount of area with bare ground, in particular where elk (*Cervus elaphus*) and small mammals disturbed the soil.⁸

Soil erosion, when present following severe wildfire, makes a dramatic impact on the soil-forest ecosystem. Bernard Bormann and his colleagues⁹ studied the 2002 Biscuit Fire in southern Oregon and found that after landscapes are denuded by severe fires, substantial losses of soil through runoff and wind erosion can occur.¹⁰ They found major losses of fine soil near the surface, and in some locations, not only was the forest floor burned, but several centimeters of mineral soil were also missing. Given the large nutrient stores in these upper soil layers, it is possible the fire will have caused major losses of nutrient capital in the forest. The researchers also found that wind erosion associated with the fire was as significant as water-driven erosion. However, most water-eroded soil appeared to remain behind needle dams, logs, or in windrow pits, suggesting little movement overall into streams (Bormann and Darbyshire 2005).

⁸ Evaluating the effects of prescribed fire and fuels treatment on water quality and aquatic habitat. Wondzell, S.; Clifton, C. Joint Fire Science Program final report. <http://www.fs.fed.us/r6/uma/nr/hydro/jfsp/>. (December 2007).

⁹ JFSP project title: Ecosystem effects and propagation of the Biscuit Fire across the large-scale plots of the long-term ecosystem productivity experiment. Principal investigators: Bormann, B.; Homann, P.; Cromack, K., Jr.; Darbyshire, R.; Grant, G.; Molina, R.

¹⁰ JFSP project title: Ecosystem effects and propagation of the Biscuit Fire across the large-scale plots of the long-term ecosystem productivity experiment. Bormann, B.; Homann, P.; Cromack, K., Jr.; Darbyshire, R.; Grant, G.; Molina, R. Joint Fire Science Program final report. http://www.firescience.gov/documents/Final_Report_Bormann_Example1.pdf. (December 2007).

A common way to assess changes in soil properties in the field is to collect a soil sample down to a constant depth, say 10 or 15 cm. However, because of the large loss of surface soil after the Biscuit Fire, the Bormann team caution that sampling soil to a constant depth could be misleading, not only here, but in other areas where surface soil is lost. Instead, the Bormann team used a “comparable layers approach” where layers with similar rock contents are equated and then sampled; this works because rocks are least likely to change during fire (Bormann 2007).

Where Is Water Repellency More Likely to Occur After Fire?

- In coarse-textured soils (more easily coated with organics than fine-textured soils)
- Under some types of vegetation (especially important in chaparral and rangelands)
- In areas of high burn severity. (Note that the effect of water repellency on soil erosion by runoff is strongly influenced by the amount and duration of rainfall following a fire.)

REFERENCES

Bormann, B. 2007. Personal communication. Plant physiologist, Pacific Northwest Research Station, Forestry Sciences Laboratory, 3200 SW Jefferson Way, Corvallis, OR 97331.

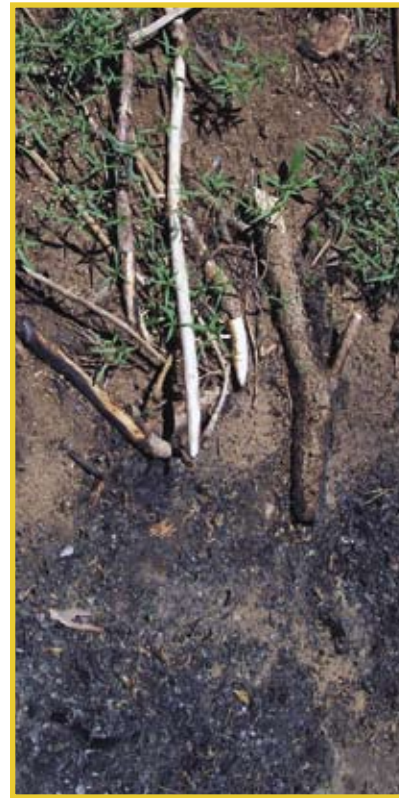
Bormann, B.T.; Darbyshire, R. 2005. Ecosystem effects of the Biscuit Fire. In: Mixed severity fire regimes: ecology and management symposium. Spokane, WA: Washington State University: 10. <http://www.emmps.wsu.edu/fire/Papers/Bormann%20and%20Darbyshire.pdf?access-key=spakbrbdr546kk6h>. (March 2008).

Brady, J.A.; Robichaud, P.R.; Pierson, F.B. 2001. Infiltration rates after wildfire in the Bitterroot Valley. American Society of Agricultural Engineers annual meeting. Paper No. 01-8003. St. Joseph, MI: American Society of Agricultural Engineers [ASAE]. 11 p.

Neary, D.G.; Ryan, K.C.; DeBano, L.F. 2005. Wildland fire in ecosystems: effects of fire on soils and water. Gen. Tech. Rep. RMRS-GTR-42. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 250 p. Vol. 4.

Pierson, F.B.; Robichaud, P.R.; Spaeth, K.E. 2001. Spatial and temporal effects of wildlife on the hydrology of a steep rangeland watershed. *Hydrological Processes*. 15: 2905–2916.

Rau, B.M.; Chambers, J.C.; Blank, R.R.; Miller, W.W. 2005. Hydrologic response of a central Nevada pinyon-juniper woodland to prescribed fire. *Rangeland Ecology and Management*. 58: 614–622.



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Small patches of unburned forest floor, lie adjacent to patches where a fire burned relatively hot, as indicated by the surface charcoal.

Robichaud, P.R.; Elliot, W.J.; Pierson, F.B.; Hall, D.E.; Moffet, C.A. 2006. Erosion Risk Management Tool (ERMiT). Version 2006.01.18. <http://forest.moscowfsl.wsu.edu/fswapp/>. (December 2007).

Robichaud, P.R.; Elliot, W.J.; Pierson, F.B.; Hall, D.E.; Moffet, C.A. 2007a. Erosion Risk Management Tool (ERMiT) user manual (version 2006.01.18). Gen. Tech. Rep. RMRS-GTR-188. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 24 p.

Robichaud, P.R.; Elliot, W.J.; Pierson, F.B.; Hall, D.E.; Moffet, C.A. 2007b. Predicting postfire erosion and mitigation effectiveness with a Web-based probabilistic erosion model. *Catena*. 71: 229–241.

Question 2: How Do Soil Organisms Respond to Fire?

Soil organisms are incredibly diverse and include such groups as algae, bacteria, fungi, springtails, nematodes, millipedes, and earthworms. They are key components of soil food webs and, through their activities, make an important contribution to soil fertility. However, how they respond to fire is not well understood, in part because of the challenges in studying these small organisms.

One way to study soil microflora (bacteria and fungi) after a fire is to culture the organisms on different substrates and look for changes in substrate utilization. After a 2002 wildfire in the Santa Fe National Forest, Stephen Hart and Gregory Newman¹ discovered that surviving fungi in the soil became functionally more diverse, whereas bacteria became functionally less diverse. This is interesting because fungi typically show greater sensitivity than bacteria to heat. They also found that certain nitrifying bacteria increased 10 times over levels in unburned forests 1 month after the fire (Hart et al. 2005), which could explain in part why nitrate levels in soils often increase after fire (see question 4). Additional research at the site by Overby et al. (2006) confirmed the decrease in bacterial diversity following fire.² A decrease in microbial functional diversity likely has consequences for the entire ecosystem, but exactly how is not known.

¹ JFSP project title: Ecosystem responses to a high-severity wildfire: a serendipitous opportunity to enhance the fire/fire surrogate study. Principal investigators: Overby, S.; Hart, S.; Bailey, J.

² Ecosystem responses to a high-severity wildfire: a serendipitous opportunity to enhance the fire/fire surrogate study. Overby, S.; Hart, S.; Bailey, J. Joint Fire Science Program final report. <http://www.firescience.gov>. (December 2007).

In two mixed-oak forests in southern Ohio, C. Gai and Ralph Boerner³ found that after experimental restoration treatments of prescribed burning, burning with forest thinning, and thinning alone, bacterial activity increased with burning and thinning after 4 years, whereas fungal activity showed no change in activity (Gai and Boerner 2007). The bacterial and fungal communities appeared to shift their substrate preferences after burning in unique ways, yet overall, there was no change in the diversity of substrates used by either bacteria or fungi with the restoration treatments. Taken together, the New Mexico and Ohio studies indicate that microbial responses to fire may be as diverse and complex as the microbial communities in soil.

Soil ecosystems also include mycorrhizae, a symbiotic association between plant roots and certain fungi. Mycorrhizae facilitate nutrient and water uptake for plants, protect against root pathogens, and contribute to soil structure. Jane E. Smith and her team⁴ found that in mixed stands of ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) and Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) in eastern Oregon, the species richness (number of types) of mycorrhizae was significantly lower in areas experimentally burned compared to unburned areas. In addition, live root biomass and duff thickness were decreased by both thinning and burning fuel reduction treatments. They suggested that the high mortality of the mycorrhizae, combined with the loss of organic material, may affect tree seedling survival

³ Fire and Fire Surrogate Study: Ohio Hill Country Site. <http://www.fs.fed.us/ffs/>. (December 2007).

⁴ Fire and Fire Surrogate Study: Hungry Bob Site. <http://www.fs.fed.us/ffs/>. (December 2007).



Matt Trappe, Oregon State University, Department of Environmental Science

This colorful mat of fungal hyphae was formed by the truffle species *Rhizopogon truncatus* at Crater Lake National Park, and found during a JFSP study examining prescribed fire/fungal interactions. The occurrence of many of these mat-forming fungi is correlated with litter and woody debris mass. Consequently, they may be vulnerable to severe fires.

in the future—something the researchers will be watching for (Smith et al. 2005).

Beetles and other arthropods naturally occur on fallen leaves and needles in forests and may be significantly affected by fuel management. At a mixed-conifer forest in the Sierra Nevadas,⁵ Kyle Apigian and his associates found that the overall impacts of fuel reduction treatments involving

burning, overstory thinning, and combined burning and thinning were moderate and that some groups of arthropods increased in response to treatment, whereas others decreased (Apigian et al. 2006). In general, beetle community structure changed more with fire than with thinning. The researchers point out that because habitat heterogeneity increased with treatments, there might be greater opportunities in the future for rare species to coexist in landscapes where fuel treatments occur.

⁵ Fire and Fire Surrogate Study: Blodget Forest Site. <http://www.fs.fed.us/ffs/>. (December 2007).

Ralph Boerner and his team (see footnote 3) examined soil enzymes 2 years after prescribed burning treatments were conducted in an oak forest in Ohio. Soil enzymes integrate the activities of fungi, bacteria, and other soil organisms, and can present a holistic view of microbial response to change. Several enzymes increased late in the growing season and were related to increases in organic carbon, especially in the burned plots (Boerner et al. 2005). This shows that fire enhanced the activity of soil biological processes at these sites and highlights the need to understand the seasonality of the organisms.

In another study at the Clemson Experimental Forest in South Carolina,⁶ Boerner and colleagues found that prescribed burning alone in loblolly pine (*Pinus taeda* L.) forests had little effect on enzyme activity. However, mechanical thinning, alone or combined with burning, increased enzyme activity, with the response lasting for the duration of the study (4 years). The authors concluded that thinning may be a means to stimulate nutrient turnover in loblolly pine forests (Boerner et al. 2006).

REFERENCES

- Apigian, K.O.; Dahlsten, D.L.; Stephens, S.L. 2006.** Fire and fire surrogate treatment effects on leaf litter arthropods in a western Sierra Nevada mixed-conifer forest. *Forest Ecology and Management*. 221: 110–122.
- Boerner, R.E.J.; Brinkman, J.A.; Smith, A. 2005.** Seasonal variations in enzyme activity and organic carbon in soil of a burned and unburned hardwood forest. *Soil Biology and Biochemistry*. 37: 1419–1426.
- Boerner, R.E.J.; Waldrop, T.A.; Shelburne, V.B. 2006.** Wildfire mitigation strategies affect soil enzyme activity and soil organic carbon in loblolly pine (*Pinus taeda*) forests. *Canadian Journal of Forest Research*. 36: 3148–3154.
- Giai, C.; Boerner, R.E.J. 2007.** Effects of ecological restoration on microbial activity, microbial functional diversity, and soil organic matter in mixed-oak forests of southern Ohio, USA. *Applied Soil Ecology*. 35: 281–290.
- Hart, S. C.; DeLuca, T.H.; Newman, G.S.; Mackenzie, M.D.; Boyle, S.I. 2005.** Post-fire vegetative dynamics as drivers of microbial community structure and function in forest soils. *Forest Ecology and Management*. 220: 166–184.
- Overby, S.T.; Hart, S.C.; Newman, G.S.; Erickson, D. 2006.** Microbial response to high severity wildfire in the southwestern United States: a case study. In: Viegas, D.X., ed. V. International conference on forest fire research. [Place of publication unknown]: [Publisher unknown], 1–11.
- Smith, J.E.; McKay, D.; Brenner, G.; McIver, J.; Spatafora, J.W. 2005.** Early impacts of forest restoration treatments on the ectomycorrhizal fungal community and fine root biomass in a mixed conifer forest. *Journal of Applied Ecology*. 42: 526–535.

⁶ Fire and Fire Surrogate Study: Southeastern Piedmont Study Site. <http://www.fs.fed.us/ffs/>. (December 2007).

Question 3—How Does Fire Influence Carbon Storage and Loss?

Soils store a lot of carbon, nearly twice the amount found in the atmosphere. When soil organisms (including plants) use organic carbon to produce energy in a process called respiration, carbon dioxide (CO₂) is also produced and released into the atmosphere. Because CO₂ is a greenhouse gas, there is a need to know how various fuel reduction techniques might impact this process.

In a southern pine forest,¹ Mac Callaham and his team found that soil respiration decreased on study plots that were burned (Callaham et al. 2001). In contrast, Leda Kobziar and Scott Stephens,^{2,3} found that burning a ponderosa pine plantation in California actually stimulated soil respiration, although when burning was combined with thinning and mastication, soil respiration decreased (Kobziar et al. 2004). These two studies show that soil responses to prescribed fire are often site specific.

Wildfire has the potential to decrease the amount of carbon stored in soils and in vegetation. A recent modeling study⁴ looked at how changes in climate and fire frequency affect carbon storage at Yellowstone National Park. The researchers

found that only major changes in land use, such as conversion from forests to shrublands, would cause a significant reduction in carbon storage. Moreover, even with the increases in fire frequency predicted to occur with climate change, changes in carbon storage are not likely to occur (Kashian et al. 2006).

By using detailed data collected in 1992 for a long-term productivity experiment, Bernard Bormann, Peter Homann, and colleagues⁵ were able to remeasure plots burned in the 2002 Biscuit Fire to determine that over 22 percent (16 Mg/ha) of soil carbon was lost from the soil in areas severely burned by the fire. Associated with this loss of carbon were dramatic losses of soil aggregation (aggregation is crucial for beneficial water movement and storage of water, nutrients, soil organisms, and carbon) and nutrients likely needed to achieve prefire rates of growth, perhaps slowing the rate that the ecosystem can restore soil carbon to prefire levels.⁶

Ralph Boerner and colleagues also examined the effect of burning, mechanical thinning, and thinning combined with burning on soil organic carbon at the studies in Ohio⁷ and South Carolina.⁸ In Ohio, they found no change in soil carbon after 4 years with any of the treatments (Giai and Boerner 2007). In South Carolina, however, soil

¹ Fire and Fire Surrogate Study: Southeastern Piedmont Study Site. <http://www.fs.fed.us/ffs/>. (December 2007).

² JFSP project title: Fire hazard reduction in ponderosa pine plantations. Principal investigators: Swanson, J.; Stephens, S.; O'Hara, K.; Blonski, K.; Shelly, J.; Kobziar, L.

³ Fire hazard reduction in ponderosa pine plantations. Swanson, J.; Stephens, S.; O'Hara, K.; Blonski, K.; Shelly, J.; Kobziar, L. Joint Fire Science Program final report. http://www.firescience.gov/projects/00-2-30/00-2-30_final_report.pdf. (December 2007)

⁴ JFSP project title: Carbon cycling at the landscape scale: the effect of changes in climate and fire frequency on age distribution, stand structure, and net ecosystem production. Principal investigators: Ryan, M.; Romme, W.; Tinker, D.; Turner, M.

⁵ JFSP project title: Ecosystem effects and propagation of the Biscuit Fire across the large-scale plots of the long-term ecosystem productivity experiment. Principal investigators: Bormann, B.; Homann, P.; Cromack, K., Jr.; Darbyshire, R.; Grant, G.; Molina, R.

⁶ Ecosystem effects and propagation of the Biscuit Fire across the large-scale plots of the long-term ecosystem productivity experiment. Bormann, B.; Homann, P.; Cromack, K., Jr.; Darbyshire, R.; Grant, G.; Molina, R. Joint Fire Science Program final report. http://www.firescience.gov/documents/Final_Report_Bormann_Example1.pdf. (December 2007).

⁷ Fire and Fire Surrogate Study: Ohio Hill Country Site. <http://www.fs.fed.us/ffs/>. (December 2007).

⁸ Fire and Fire Surrogate Study: Southeastern Piedmont Study Site. <http://www.fs.fed.us/ffs/>. (December 2007).

carbon was reduced with thinning and thinning combined with burning relative to controls, but there was no change on burned plots. They suggest management for long-term storage of soil carbon may be best achieved by using prescribed fire (Boerner et al. 2006).

REFERENCES

- Boerner, R.E.J.; Waldrop, T.A.; Shelburne, V.B. 2006.** Wildfire mitigation strategies affect soil enzyme activity and soil organic carbon in loblolly pine (*Pinus taeda*) forests. *Canadian Journal of Forest Research*. 36: 3148–3154.
- Callahan, M.A., Jr.; Anderson, P.H.; Waldrop, T.A.; Lione, D.J.; Shelburne, V.B. 2004.** Litter decomposition and soil respiration responses to fuel-reduction treatments in Piedmont loblolly pine forests. In: 12th biennial southern silvicultural research conference. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 25–29.
- Giai, C.; Boerner, R.E.J. 2007.** Effects of ecological restoration on microbial activity, microbial functional diversity, and soil organic matter in mixed-oak forests of southern Ohio, USA. *Applied Soil Ecology*. 35: 281–290.
- Kashian, D.M.; Romme, W.H.; Tinker, D.B.; Turner, M.G.; Ryan, M.G. 2006.** Carbon storage on landscapes with stand-replacing fires. *BioScience*. 56: 598–606.
- Kobziar, L.N.; Stephens, S.L. 2006.** The effects of fuels treatments on soil carbon respiration in a Sierra Nevada pine plantation. *Agricultural and Forest Meteorology*. 141: 161–178.



Trygve Steen, Fire and Fire Surrogate Program, Hungry Bob Site

Areas at the base of trees, particularly large-diameter pines, often burn much hotter than surrounding areas, as indicated by the white ash on the soil surface. The heat is generated by the burning of accumulated bark and needle litter and may cause mortality of fine roots and even the tree itself.

Question 4—How Does Fire Impact Soil Nutrient Availability?

Soil chemical properties commonly affected by fire include organic matter; nutrient elements such as nitrogen, sulfur, and phosphorus; cations such as calcium, potassium, and magnesium; pH (soil acidity); and buffering capacity. Many of these components interact to influence nutrient availability, which is critical because nutrients often play a key role in vegetation composition and productivity after fire.

In Douglas-fir and ponderosa pine forests on the east side of the Cascade mountains in Washington, fire suppression, similar to elsewhere in the Western United States, has disrupted the former pattern and frequency of wildfire. Jeff Hatten, Darlene Zabowski, and their team¹ wondered if low-intensity lightning-caused fires affected

¹ Fire and Fire Surrogate Study: Mission Creek Site. <http://www.fs.fed.us/ffs/>. (December 2007).

soil chemistry in these forests. They found that despite decades of fire suppression, soil chemistry (including pH, total carbon and nitrogen, and extractable phosphorus—a measure of plant-available phosphorus) appeared unchanged by single, low-intensity lightning fires. In addition, the chemistry of these soils can be highly variable, which the authors speculate may have been caused by historical fires that burned with a range of intensities (Hatten et al. 2005).

Still, fire is known to increase levels of certain nutrients in soil. Ammonium (NH_4^+) and nitrate (NO_3^-), the main sources of nitrogen for plants, often increase after fire. This is because NH_4^+ is released from organic matter with heating, and nitrification, which converts NH_4^+ to NO_3^- , is often stimulated (Wan et al. 2001). Jeanne Chambers and colleagues² monitored soil chemistry changes at a pinyon-juniper woodland in the Great Basin after prescribed burning.³ Immediately after the burn, increases in NH_4^+ were observed. Nitrate increased within a few months and remained elevated for 3 years (Rau et al. 2007). They also found that the micronutrients manganese and zinc increased after fire; this appears to be one of the few times this has been noted. The increase in NH_4^+ followed by NO_3^- is consistent with findings in other forest ecosystems, including in ponderosa pine in western Montana, where Michael Gundale and

associates⁴ found that net nitrification remained stimulated 3 years after a low-severity prescribed burn (Gundale et al. 2005). This suggests relatively long-lasting responses in these forests even after low-severity prescribed burning. Although the burn in western Montana was not very severe overall, there was a direct relationship between net nitrification and the amount of fine fuels consumed, indicating a strong link between fire severity and microbial processes (Gundale et al. 2005).

In central Idaho, Katy Kavanagh and her students⁵ found only short-term effects on soil NO_3^- concentrations in soils after low-severity spring burns. Soil NO_3^- concentrations were increased solely for the growing season immediately following the prescribed burns, whereas the magnitude of increased soil NO_3^- concentrations in concurrently studied wildfire sites was much higher and effects lasted for about 3 years. Interestingly, a severe spring prescribed burn carried out under warmer and drier conditions had a response similar to that of wildfires. Nitrate loss from the soil into headwater streams occurred in wildfire sites but not in prescribed burn sites. Spring prescribed burn effects were only localized and short-lived, whereas wildfire effects have watershed-wide and long-term effects. This research highlights the connections between season of burn (see question 5), fire severity, and the effects on nitrogen cycling (Kavanagh 2007).

² JFSP project title: A demonstration area on ecosystem response to watershed-scale burns in Great Basin Pinyon-Juniper woodlands. Principal investigators: Chambers, J.; Tausch, R.; Amacher, M.; Germanoski, D.; Fleishman, E.; Zamudio, E.

³ A demonstration area on ecosystem response to watershed-scale burns in Great Basin pinyon-juniper woodlands. Chambers, J.; Tausch, R.; Amacher, M.; Germanoski, D.; Fleishman, E.; Zamudio, E. Joint Fire Science Program final report. http://www.firescience.gov/projects/00-2-15/00-2-15_final_report.pdf. (December 2007).

⁴ Fire and Fire Surrogate Study: Lubrecht Study Site. <http://www.fs.fed.us/ffs/>. (December 2007).

⁵ JFSP project title: The effect of spring prescribed fires on nitrogen dynamics within riparian and stream ecosystems. Principal investigator: Kavanagh, K.

Prolonged elevated NO_3^- contents in soils after wildfires have often been reported, including in some JFSP studies. In addition to enhanced nitrification after fire, reduced uptake of NO_3^- by microbes and plants can also contribute to this effect. Kavanagh (2007) found no difference in NO_3^- production rates (nitrification) between burned soils and controls. However, they found that microbial uptake rates of NO_3^- were significantly lower in burned soils than controls. They concluded that the decoupled nitrate production-consumption rates in burned soils were causing the elevated NO_3^- contents in soils they observed. They measured several important factors that could influence microbial uptake rates of NO_3^- and found that the available carbon was the most important predictor for microbial NO_3^- uptake (Kavanagh 2007).

Recently, there has been renewed interest in understanding how charcoal influences soil fertility. In western Montana, Michael Gundale and Tom DeLuca (see footnote 4) found that net nitrification was enhanced with added charcoal and this was independent of the temperature used to produce the charcoal (Gundale and DeLuca 2006). However, the temperature at which wood burns and charcoal forms can make a difference in soil chemistry. Charcoals produced at high temperatures were better able to absorb an allelochemical (a chemical produced by one organism that is toxic to another) than charcoals produced at lower temperatures (Gundale and DeLuca 2006). This could explain why a few allelochemical-producing plants appear to be influenced by fire severity.

REFERENCES

- Gundale, M.J.; DeLuca, T.H. 2006.** Temperature and source material influence ecological attributes of ponderosa pine and Douglas-fir charcoal. *Forest Ecology and Management*. 231: 86–93.
- Gundale, M.J.; DeLuca, T.H.; Fiedler, C.E.; Ramsey, P.W.; Harrington, M.G.; Gannon, J.E. 2005.** Restoration treatments in a Montana ponderosa pine forest: effects on soil physical, chemical and biological properties. *Forest Ecology and Management*. 213: 25–38.
- Hatten, J.; Zabowski, D.; Scherer, G.; Dolan, E. 2005.** A comparison of soil properties after contemporary wildfire and fire suppression. *Forest Ecology and Management*. 220: 227–241.
- Kavanagh, K. 2007.** Personal communication. Professor, University of Idaho, Forest Resources, P.O. Box 441133, Moscow, ID 83844-1133.
- Rau, B.M.; Blank, R.R.; Chambers, J.C.; Johnson, D.W. 2007.** Prescribed fire and time: soil extractable nitrogen and phosphorus dynamics in a Great Basin sagebrush ecosystem. *Journal of Arid Environments*. 71: 362–375.
- Wan, S.; Hui, D.; Luo, Y. 2001.** Fire effects on nitrogen pools and dynamics in terrestrial ecosystems: a meta-analysis. *Ecological Applications*. 11: 1349–1365.

Why Is Plant Growth Sometimes Stimulated After Fire?

- Ash from fire increases soil pH (higher pH benefits plants by increasing the availability of many nutrients).
- Burning releases organically-bound nutrients into the soil, making them available for plant growth.
- Burning removes dense litter layers, which can often impede germination of seedlings.
- Exposed and burned soils are warmer than soils covered with litter (the higher temperatures contribute to faster plant growth).
- Soils are moister postfire if overstory vegetation is killed, thereby reducing transpirational water loss.

Question 5—How Does the Season of Prescribed Fire Burning Influence Soils?

Prescribed burns are often conducted during cooler seasons such as spring or fall, but not much is known about how soils respond to burning in different seasons.

Early season burns studied by Eric Knapp and colleagues in Sequoia National Park¹ consumed less organic matter than later season burns because fuels were drier in the fall (Knapp et al. 2005).

¹ Fire and Fire Surrogate Study: Sequoia National Park Site. <http://www.fs.fed.us/ffs/>. (December 2007).

The early season burns were also patchy and may have mimicked the patchiness that occurred when fires were more frequent and fuel loadings lower. Because of the greater patchiness, erosion and loss of wildlife may be reduced in early season burns. Similarly, the percentage of ground area burned was less with prescribed burns conducted in the spring versus in the fall. During spring, fuel moisture was greater, and higher fuel moisture levels are related to increased burn heterogeneity (Knapp and Keeley 2006). Early season burns also had less dramatic short-term impacts on soil pH, moisture, temperature, carbon stocks, and microbial activity than late season burns, reflecting the lower severity of early season burns (Hamman et al., in press).

In another study,² Matt Busse and colleagues found that fire-related soil temperatures were strongly affected by soil moisture, with dry soils (less than 20 percent volumetric moisture) burning much hotter than wet soils (above 20 percent moisture). Given that soils are often more moist in the spring compared to the summer or fall in many parts of the Western United States, burning in the spring should limit damaging temperatures to the upper 5 cm of mineral soil (Busse et al. 2006).

The season of burn also affected the fruiting patterns of mycorrhizal fungi in old-growth ponderosa pine at Crater Lake National Park. In a study comparing early spring, late spring, and fall burns,³ the fall burns were more detrimental to mushroom production and diversity than spring burns, which showed seasonal patterns

² JFSP project title: Masticated fuel beds: custom fuel models, fire behavior, and fire effects. Principal investigators: Knapp, E.; Busse, M.; Skinner, C.

³ JFSP project title: Effects of prescribed burning on mycorrhizal fungi in Crater Lake National Park. Principal investigators: Cromack, K.; Smith, J.E.; Molina, R.; Trappe, J.; Cázares-Gonzalez, E.; Rasmussen, M.; Trappe, M.

of mushroom production similar to those in unburned control plots (Trappe 2006).

Prescribed burning is also used to restore northeastern oak-pine sandplain forests, where oaks have been replacing pines in the absence of burning. William Patterson, Chris Neill, and colleagues investigated how soils responded to the timing and frequency of prescribed burning at the Cape Cod National Seashore.⁴ They found that burning less frequently than annually did not significantly alter soil carbon or nitrogen pools

⁴ JFSP project title: Managing fuels in Northeastern Barrens. Principal investigators: Patterson, W.; Crary, D.

and that summer burning decreased organic horizon thickness more than spring burning. This is important, as some of the desirable species may germinate more successfully with a reduced organic horizon (Neill et al. 2007).

REFERENCES

Busse, M.; Shestak, C.; Knapp, E.; Fiddler, G.; Hubbert, K. 2006. Lethal soil heating during burning of masticated fuels: effects of soil moisture and texture. In: Proceedings of the third international fire ecology and management congress. San Diego, CA. <http://www.emmps.wsu.edu/2006firecongressproceedings>. (March 2008) 4 p.



Mike Battaglia, U.S. Forest Service

Researchers at the Rocky Mountain Research Station are manipulating the depth of chipped or masticated trees on 2-by-2-m plots in pinyon-juniper and lodgepole pine ecosystems to study the effects of chipping on soils and soil processes.

- Hamman, S.T.; Burke, I.C.; Knapp, E.E. [In press].** Soil nutrients and microbial activity after early and late season prescribed burns in a Sierra Nevada mixed conifer forest. *Forest Ecology and Management*.
- Knapp, E.E.; Keeley, J.E. 2006.** Heterogeneity in fire severity within early season and late season prescribed burns in a mixed-conifer forest. *International Journal of Wildland Fire*. 15: 37–45.
- Knapp, E.E.; Keeley, J.E.; Ballenger, E.A.; Brennan, T.J. 2005.** Fuel reduction and coarse woody debris dynamics with early season and late season prescribed fire in a Sierra Nevada mixed conifer forest. *Forest Ecology and Management*. 208: 383–397.
- Neill, C.; Patterson, W.A., III; Crary, D.W., Jr. 2007.** Responses of soil carbon, nitrogen and cations to the frequency and seasonality of prescribed burning in a Cape Cod oak-pine forest. *Forest Ecology and Management*. 250: 234–243.
- Trappe, M. 2006.** Personal communication. Doctoral student (graduating in 2008). Environmental Sciences, 2046 Cordley Hall, Corvallis, OR 97331-2904.

Key Findings:

- Postfire water repellency is closely related to the type of surface vegetation.
- The net effect of increased water repellency on soil erosion after fire is influenced by the amount of rainfall after fire and the infiltration rate of the soil.
- Soil organisms are complex in their responses to fire—sometimes contradicting previously held notions about how they respond. Low-severity fires appear to impact them the least.
- Small, low-severity fires, such as those caused by lightning, appear to have minimal impacts on soil chemistry and nutrient availability.
- Prescribed burning may increase soil fertility by both direct (releasing ammonium, (NH_4^+) and later nitrate (NO_3^-)) and indirect (input of charcoal, reduced microbial uptake of inorganic nitrogen) effects.
- Prescribed burning has variable effects on many soil attributes including soil nutrient and carbon pools, soil respiration, and microbial functional diversity.
- Early season prescribed burns tend to have less impacts than late season burns on soil organisms, soil carbon, and additional soil properties.
- Soil organisms may respond positively to less intense spring burns (compared to fall burns) and other fuel reduction treatments that cause an increase in habitat patchiness.
- Given the site-specific responses of many soil properties to prescribed fire, extrapolation to other sites needs to be done with caution.

WHAT TO WATCH FOR:

- An assessment of how soil productivity responds to salvage logging. This will be accomplished by measuring a suite of soil properties coupled with tree growth responses after salvage logging and different burn intensities on the 2003 B&B Fire in central Oregon. JFSP project title: *Impacts of post-fire salvage logging and wildfire burn intensity on soil productivity and forest recovery*. Jane E. Smith and Elizabeth Sulzman (E.S., deceased June 10, 2007).
- Salvage logging effects on erosion. JFSP project title: *Evaluating postfire salvage logging effects on erosion*. Pete Robichaud, Lee MacDonald, and Bill Elliot.
- Remote sensing for improved soil burn severity mapping. JFSP project title: *Causes and consequences and spatial variability of burn severity: a rapid response proposal*. Penny Morgan, Andrew Hudak, Pete Robichaud, and colleagues.
- A test of the effectiveness of seeding and fertilization treatments for promoting high plant biomass and litter cover. An experiment will examine how well these treatments, as part of the burned area emergency response (BAER) protocol, work to stabilize slopes after fire. JFSP project title: *Evaluating the efficacy and ecological impacts of BAER slope stabilization treatments on the Pot Peak/Deep Harbor wildfire complex*. David W. Peterson and Richy Harrod.
- A better understanding of the mechanisms responsible for changes in nitrogen availability in stream ecosystems after fire. Results from this study will help managers make informed decisions on the consequences of burning in riparian areas. JFSP project title: *The effect of wildfire on nitrogen dynamics within headwater streams*. Kathleen Kavanagh, Wayne Minshall and colleagues.
- An assessment of the long-term effects of thinning ponderosa pine forests on soil microbial populations. JFSP project title: *Effects of thinning ponderosa pine on microbial communities*. Steven Overby, Dan Neary, and colleagues.
- The ecological impacts of chipping and mastication fuel treatments on soils in lodgepole pine and pinyon-juniper ecosystems. JFSP project title: *A regional assessment of the ecological effects of chipping and mastication fuels reduction and forest restoration treatments*. Mike Ryan, Sigrid Resh, Mike Battaglia, and colleagues.
- Three upcoming (2008) special issues in the journals *Ecological Applications*, *Forest Ecology and Management*, and *Forest Science* will cover findings from the Fire and Fire Surrogates Study.

ENGLISH EQUIVALENTS

| When you know: | Multiply by: | To get: |
|-------------------------------|--------------|---------------|
| Centimeters (cm) | 0.394 | Inches |
| Meters (m) | 3.28 | Feet |
| Hectares (ha) | 2.47 | Acres |
| Megagrams per hectare (Mg/ha) | .446 | Tons per acre |

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Visit the Joint Fire Science Program
Web site for upcoming findings from
these and other interesting studies.

<http://www.firescience.gov/>

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A black and white photograph showing three workers in a field. They are wearing hard hats and work clothes, and are carrying shovels. They appear to be walking along a path or a cleared area in a field with some trees in the background. The image is slightly faded and has a grainy texture.

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