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Soil organic matter in a ponderosa pine forest with varying seasons and intervals of prescribed burn

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Abstract

Prescribed burning is used to reduce fuel loads and return ponderosa pine forests of the Western U.S. to their historical structure and function. The impact of prescribed burning on soil is dependent on fire severity which is largely managed by burning in the fall or the spring; frequency of fire will also regulate long-term fire impacts. The objective of this study was to determine if soils and soil organic matter (SOM) were affected by prescribed burning in the fall or the spring using singular or multiple prescribed burns. Prescribed burning was initiated in the spring of 1997 and fall of 1997 at 5-year intervals and once during a 15-year period on a study site located within the Malheur National Forest of the southern Blue Mountains of eastern Oregon. Soils were sampled by major genetic horizon in 2004. The 5-year interval plots had burned twice with 1–2 years of recovery while the 15-year interval plots had burned only once with 6–7 years of recovery. Samples were analyzed for pH, carbon (C), nitrogen (N), C/N ratio, cation exchange capacity, base saturation, water repellency, and humic substance composition by alkali extraction. Fall burning decreased C and N capital of the soil (O horizon +30 cm depth mineral soil) by 22–25%. Prescribed burning did not have an effect on fulvic or humic acid C concentration (FA and HA, respectively) of the mineral soil and only a minor effect on FA and HA concentration of the O horizon. One or two fall burns decreased humin and the alkali non-soluble C (NS) content of O horizon by 15 and 30%, respectively. Initiating fall burning in fire-suppressed stands may not preserve soil C, N, humin, and NS content, but may replicate the natural fire regime. Spring burning using a return interval of 5 or more years reduces the fuel load while having little impact on soil C, N, and SOM composition and may be used to prepare a site for subsequent fall burns.

Keywords: Forest soil; *Pinus ponderosa*; Prescribed burning; Carbon; Nitrogen; Humic acid; Fulvic acid; Humin; Blue Mountains

1. Introduction

Ponderosa pine (*Pinus ponderosa* Dougl. Ex Laws) forests in the inland Northwestern U.S. are fire adapted with fire-return intervals ranging from 7 to 38 years (Agee, 1994). Recent climate trends with fire exclusion and timber harvesting practices over the last 100 years have caused fuel loads to increase. This has resulted in frequent catastrophic wildfire, and shifts in the vegetative community (Tiedemann et al., 2000; Wright and Agee, 2004). Managers use prescribed burning to reduce fuel loads and return ecosystem structure and function to a historical set point. The impact to the ecosystem caused by this restoration process is dependent on the severity of the prescribed fire, which is primarily managed by burning in either the fall or spring.

Historically, fires burned through these forests during the summer when fuels were dry, but frequent burning limited fuels resulting in low-severity fires (Agee, 1993). Prescribed burning is rarely conducted during the summer due to dry fuel conditions which causes fires to burn at a high severity; combined with the low likelihood of summer precipitation results in a difficult situation for fire control. For these reasons prescribed fires in ponderosa pine forests are frequently ignited during the spring or during the fall when fuel moisture is high and the probability of fire extinguishing precipitation is higher. Fall burning can be of moderate to high severity since the fuels have dried during the summer months and may represent the natural fire severity better than the low-severity spring burning. Fall burning may have a larger impact on accumulated fuels, but the current high fuel load may result in higher fire severity,

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which may be detrimental to management goals of preserving and restoring vegetation or soil processes. Very few studies have characterized the difference between spring and fall burning on ecosystem components, especially soils.

Multiple treatments of prescribed fire may be necessary to obtain the desired forest conditions especially if the burn applications are low severity. The frequency with which fires are applied will determine if fire-induced changes accumulate or if the forest is able to recover between burn applications. The interaction of frequency and intensity may achieve some desired outcomes such as fuel reduction, but may cause cumulative impacts on soil nutrients and soil organic matter (SOM), potentially impacting forest productivity.

Soil organic matter includes both humic and non-humic organic substances associated with organic and mineral soil. Non-humic substances are generally any materials that can be identified and classified. Humic substances are refractory, dark colored, heterogeneous, organic compounds, produced as byproducts of microbial metabolism (Stevenson, 1994).

Classes of SOM have been operationally defined by an alkaline extraction and subsequent solubility under acidic conditions. Humin is composed of the largest molecules that have the greatest degree of aromaticity and the lowest concentration of oxygen (Stevenson, 1994). Humin is often associated with mineral surfaces, is very stable in the soil, and is not alkaline extractable. Non-soluble (NS) materials in O horizons, analogous to humin in the mineral soil, are usually made up of recognizable cellulose and lignin. Humic acid (HA) is soluble in alkaline conditions but precipitates in subsequent acidic solution and is relatively immobile in soils. Fulvic acid (FA) is soluble in both alkaline extract and in a subsequent acidic solution.

Black carbon (BC) is another component of SOM that is often included in the insoluble humin fraction of both O and mineral soil horizons. Black carbon is the heterogeneous, aromatic, and carbon-rich residue of biomass burning and fossil-fuel combustion; it includes charcoal, soot, and graphite (Goldberg, 1985). Charcoal is often part of the ash and residue remaining after biomass burning. Soot particles form in the gaseous phase and are easily transported from a fire site in the smoke plume. Graphite is usually geologically formed and inherited by soil. Black carbon decomposes at a much slower rate than uncharred material and has been suggested as a form of C useful for sequestering C in soil (Shneour, 1966; Kuhlbusch and Crutzen, 1995).

The effect of fire on soils is largely through the alteration and combustion of SOM, which can provide much of a soil's cation exchange capacity (CEC) and contains the majority of soil N capital (Stevenson, 1994). Combustion and volatilization may result in losses of SOM and may also mineralize organically bound elements such as N, P, and base cations, which are then available for uptake by plants or leaching from the soil (DeBano et al., 1998). Residual unburned SOM altered by heating is left with disproportionate losses of hydrogen and oxygen relative to C and increased aromaticity (Almendros et al., 1990; Baldock and Smernik, 2002; Almendros et al., 2003; Gonzalez-Vila and Almendros, 2003; Gonzalez-Perez et al., 2004; Knicker et al., 2005). Increasing heating severity on SOM has been shown to decrease the oxygen content, thereby reducing FA and HA fractions while increasing aromaticity and humin content (Almendros et al., 1990; Fernandez et al., 1997, 2001, 2004). The shift of SOM to these recalcitrant materials has been shown to limit nutrients to organisms (Guinto et al., 1999). Few studies have examined the effect of varying fire severity in a natural setting on soils and SOM, especially in terms of season of prescribed burning.

A season of burn and burn interval study was begun in the southern Blue Mountains of eastern Oregon in 1997. This study provided an opportunity to examine the season of prescribed burn and repeated burn effects on soil and SOM. The objectives of this study were to: (1) determine the changes in soil chemical characteristics including SOM pools that result from difference types and number of prescribed burns and (2) quantify changes to total soil C and N capitals. This research is important to clarify processes that are controlling SOM quantity and quality and develop management recommendations for prescribed fire that protect soil quality.

2. Materials and methods

2.1. Site characteristics

The study site was located within the Malheur National Forest of the southern Blue Mountains of eastern Oregon (43°52′41″N/118°46′19″W). Elevation ranged from 1585 to 1815 m. Ponderosa pine is the dominant tree with some western juniper (*Juniperus occidentalis* Hook.) and curl-leaf mountain mahogany (*Cercocarpus ledifolius* Nutt.) in areas that have shallow soils. The ponderosa pine trees are predominantly between 80 and 100 years old; the sites were thinned in either 1994 or 1995. Kerns et al. (2006) found that grasses and sedges that dominate the understory include Idaho fescue (*Festuca idahoensis* Elmer), bluebunch wheatgrass (*Pseudoroegneria spicata* (Pursh) A. Löve), sedges (*Carex* spp.), bottlebrush squirreltail (*Elymus elymoides* (Raf.) Swezey), basin wild rye (*Leymus cinereus* (Scribn. & Merr.) A. Löve), California Brome (*Bromus carinatus* Hook. & Arn), and western needlegrass (*Achnatherum occidentale* (Thurb.) Barkworth). Herbaceous cover consists of parsnipflower buckwheat (*Eriogonum heracleoides* Nuttall.), and large flowered collimia (*Collomia grandiflora* Douglas Ex Lindl.). Shrub cover is dominated by sage brush (*Artemisia tridentata* Nutt.), Oregon grape (*Mahonia repens* (Lindl.) G. Don), and rabbitbrush (*Chrysothamnus* Nutt. Spp.).

Parent materials of the study sites consist of basalt, andesite, rhyolite, tuffaceous interflow, altered tuffs, and breccia (Carlson, 1974). In addition, the soil has received ash from pre-historic eruptions of ancient Mount Mazama and other volcanos in the Cascade Mountains to the west (Powers and Wilcox, 1964). Carlson (1974) found Lithic Argixerolls, Lithic Haploxerolls, and Vertic Argixerolls within the research sites, which were confirmed during this study. Mollic Haploxeralfs, Humic Haploxerepts, and Typic Haploxerepts were also found during the soil sampling phase of the study.