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Forest wildfire and grassland prescribed fire effects on soil biogeochemical processes and microbial communities: Two case studies in the semi-arid Southwest

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ABSTRACT

Fire is a natural disturbance that shapes many ecosystems. In semi-arid regions, where high temperatures and low soil moisture limit nutrient cycling and plant growth, fire is critical to supply nutrients and drive vegetation composition. We examined soil chemical and biological properties to assess the short-term impacts of wildfire and prescribed fires on soil functioning in semi-arid regions of Texas. Better understanding of soil organic matter transformation and nutrient cycling processes will aid land managers in predicting ecosystem recovery response post-fire. Soil samples were collected following both prescribed grassland fires in June of 2009 in Lubbock, TX and the April 2012 Livermore Ranch Complex Fire located in the Davis Mountains, TX. Prescribed fire samples (0–2.5 cm) were collected within six h prior to burning and again at 0.5, 24, 48, and 168 h post-fire to experimentally examine short-term influences of fire and fire frequency (1× vs. 2×) on soil carbon dynamics, inorganic nitrogen, and microbial community composition. Wildfire samples (0–5 cm) were collected two and six months following the wildfire. We evaluated the effects of three burn severity levels and sampled under three tree species (*Juniperus deppeana*,*Pinus cembroides*, and *Quercus grisea*). Within 0.5 h of the prescribed fire, CO_2 flux, NH_4^+-N concentration and total microbial biomass (as estimated by total fatty acid methyl esters) increased. A shift in the microbial community from a predominance of fungi to Gram positive bacteria occurred immediately following the fire. Chemical shifts were short lived (decreased within 24 h), but the biotic shift to a dominance of Gram negative bacteria and actinomycetes was measured in samples collected after 168 h. Soil pH and NH_4^+-N concentration increased at two and six months following the wildfire. In contrast, soil organic matter content decreased at two months post wildfire which, in combination of abiotic conditions such as low moisture content (<3.3%), resulted in reduced soil microbial biomass and enzyme activity. Increased soil moisture six months post fire created more favorable conditions for nitrification resulting in increased NO_3^--N concentration (0.8 to 36.1 mg NO_3^--N kg^{-1} soil), particularly following high severity fire. Prescribed fire did not have lasting impacts on soil nutrients, but both prescribed and wildfire resulted in increased NH_4^+-N, shifts in microbial community structure and decreased in microbial biomass. While the increase in nitrogen maybe be beneficial to the plant growth and revegetation, the loss of microbial biomass may have far reaching implications to the overall sustainability of the soils in these systems.

Abbreviations: SOC, soil organic carbon; SOM, soil organic matter; MBC, microbial biomass carbon; MBN, microbial biomass nitrogen.

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1. Introduction

Fire has been a recurrent natural disturbance that shapes terrestrial ecosystem structure (Omi, 2005) and functioning (Johnson et al., 1998; Sampson et al., 1995). Fire patterns, frequency, and behavior are closely related to the interactions between topography, soils, environmental conditions and vegetation composition (Hood and Miller, 2007). A typical fire creates a mosaic pattern leaving areas unburned or burned across a range from low to high severity. In the USA, fire has been used deliberately in grassland ecosystems since the inhabitation of native people on the Great Plains. In these ecosystems, fire aids in the removal of dead litter, stimulates the growth of prairie grasses and suppresses woody species. Fire also is a valuable component of forest regeneration and management. Regardless of the ecosystem, fires typically result in impacts to vegetation structure, composition, dynamics, and biodiversity. The severity of the effect and the rate of recovery depend upon interactions among fire regime (e.g., fire frequency and intensity) and organismal fire response traits (Janzen and Tobin-Janzen, 2008; Keeley 2008).

The combustion of organic material can reduce soil organic matter (SOM) and leave portions of the soil surface bare or covered in ash (Chandler et al., 1983; DeBano et al., 1998). Exposed ground and gaps in the forest canopy alter soil radiative forcing (shifts in both temperature and light), evapotranspiration, and the preferential regrowth of vegetation adapted to respond quickly to these conditions (Cerdá and Robichaud, 2009; Chandler et al., 1983; DeBano et al., 1998; Glenn and Finley, 2009). Incomplete combustion of soil organic matter near the surface and ash inputs influences the soil chemistry by increasing soil pH (Pyne, 2001; Raison, 1979; Viro, 1974) and providing a source of inorganic nutrients (Rau et al., 2008; Rodriguez et al., 2009; Schafer and Mack, 2010) that feed the microbial organisms and stimulate plant regeneration. Soil microorganisms are driving agents which facilitate this regeneration and ecosystem recovery following fire via critical ecosystem processes such as SOM decomposition and nutrient mineralization through the activities of extracellular enzymes. Due to the natural variability within an ecosystem, studies from different fire-prone systems report varying findings of fire effects on different soil properties and also on the time scale required for their restoration (Dangi et al., 2010; Doerr and Cerda, 2005; O'Bryan et al., 2009). In general, soil microbial populations tend to be reduced immediately (90 days) following fire (Andersson et al., 2004; D'Ascoli et al., 2005; Grady and Hart, 2006; Yeager et al., 2005) but quickly recover (Neary et al., 1999). Consequently, combustion, cell death, and denaturation due to increased soil temperatures can also contribute to decreased soil enzymatic activity (Boerner et al., 2005; Fortúrbel et al., 2012; Gutknecht et al., 2010). However, the majority of research has focused on long-term impacts of fires on soil, however it was our intent to examine the immediate, short-term impacts the potential recovery rate in semi-arid systems.

The overall objective of this study was to determine the short-term impacts of fire on soil microbial and biogeochemical processes in semi-arid soils. Soil samples were collected from two independent case studies: (1) a prescribed fire in a native rangeland in Lubbock, TX and (2) the Livermore Ranch Complex Fire in Jeff Davis, TX. These studies allow us to investigate (1) short term fire effects in a relatively homogenous environment and (2) longer term effects across a wider range of soil habitats and microbial communities.

Specific objectives for the prescribed grassland fire were to evaluate short-term (within 7 days) effects and fire frequency (single year vs. two-year summer fires) on soil responses following single-year fires (June 2009) and following two summer fires (June 2008 and 2009) at 0.5, 24, 48, and 168 h after the June 2009 fires. Specific objectives for the forest wildfire were to evaluate the impact of different fire severities on soil chemical and biological properties across a range of fire severities and across three replicated soil environments under three tree species at two and six months post fire. Three different tree species found in all fire regimes and therefore allowing us to conduct appropriate comparisons were targeted in order to examine their potential to influence on microbial community structures stemming from differences in mycorrhizal associations, rooting depths, and effects on soil moisture and pH. In general, we hypothesized that fire would: (1) increase soil moisture, and inorganic N through the deposition of a nutrient-rich ash layer; and (2) reduce SOM, soil microbial biomass, and soil enzyme activity. More specifically, we expected the higher frequency prescribed fires to have fewer impacts on soil properties than the single prescribed fires because of lower fuel loads and because these systems would have adapted to frequent disturbances caused by fire. In the wildfire study, we hypothesized that soil response would be most pronounced in the high burn intensity sites and would differ under the different tree species. These differences may stem from differences in local fire intensities, pre-fire and post-fire soil moisture (evergreen vs. deciduous), rooting depths, and the diversity of microbial communities in relation to different tree species.

2. Materials and methods

2.1. Prescribed fire sites and sample collection

Prescribed fire sites were located on the Natural Resource Management (NRM) Erskine Native Rangeland Research Station, in northwest Lubbock, Texas (33°36′17.52″N, 101°54′07.55″W) at 992 m elevation. The native range site is on approximately 65 hectares and has never been plowed but has been grazed historically (last grazed by cattle in 2002). Dominant soils are Acuff (Fine-loamy, mixed, superactive, thermic Aridic Paleustolls) and Amarillo (Fine-loamy, mixed, superactive, thermic Aridic Paleustalfs). Mean annual precipitation was 475 mm with peak precipitation occurring between May and September. Average daily temperatures ranged from 7.9 °C to 22.9 °C with the coldest temperatures occurring in January (−4.4 °C) and warmest temperatures in July (33.3 °C). Vegetation is typical of short-grass plains common to the Southern Great Plains and include mesquite (*Prosopis glandulosa* Torr. var. *glandulosa*), blue grama (*Bouteloua gracilis* [H.B.K.] Griffiths), buffalograss (*Buchloe dactyloides* (Nutt.) Engelm.), purple threeawn (*Aristida purpurea*), silver bluestem (*Bothriochloa saccharoides* (Sw.) Rydb.), Arizona cottontop (*Digitaria californica* (Benth.) Henr.), sand dropseed (*Sporobolus cryptandrus* (Torr.) A. Gray), and various forbs (Sorenson et al., 2012).

As part of a larger study designed to examine the effects of prescribed fire frequency of a summer burn on the invasive species purple threeawn, a total of 42 plots (4 m × 4 m) were randomly positioned on level terrain within the NRM research station (Sorenson, 2010). Plots were placed in areas of similar soil type, vegetation composition, and vegetative cover. Using a completely randomized design, plots were assigned to one of seven treatments with six reps assigned to each treatment. For the purpose of our study, we examined the short-term effects of prescribed fire in three treatments: control (never burned), June 2009 (burned 1×; S'09) and June 2008 and 2009 (burned 2×, S'08S'09). Samples were collected following the June 2009 fires in four out of the six replicates for each prescribed fire treatment. Eight soil samples to a depth of 2.5 cm were collected within each plot using a hand trowel within 6 h prior to burning (time 0) and then at 0.5, 24, 48, and 168 h after the fire. Because measured soil chemical properties were not expected to change over the short (7 day) sampling