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Fire severity effects on soil organic matter in northern Minnesota, USA

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Abstract

Wildfire may cause major losses of forest soil organic matter and consequently limit soil nutrient availability and forest regeneration, although the characteristics of post-fire organic matter are also likely to influence these processes. The 2011 Pagami Creek wildfire in northern Minnesota was a historical fire event and resulted in a range of fire severity levels determined via remote sensing and field measurements. To evaluate the effects of fire severity on forest soil organic matter, we sampled soils immediately following fire in areas and quantified total soil carbon (C) and nitrogen (N) content using elemental analysis, and black (pyrogenic) C using nuclear magnetic resonance (NMR) spectroscopy. Forest floor C content decreased with fire severity, and there were no differences in forest floor N content among severity classes. Similarly, there were no differences in total C or N contents for mineral soil at 0-10 cm or 10-20 cm depths. All fire severity levels decreased C:N ratio relative to unburned reference areas for the forest floor and 0-10 cm mineral soil; however, there were no differences in C:N among severity levels. Results on pyrogenic C content will be presented. Our results indicate that fire effects on soil C and N contents are limited primarily to the organic soil layers, and that effects on mineral soil are minimal. Understanding the environmental effects of forest fire as a function of fire severity is critical for developing appropriate policies and practices for minimizing detrimental effects and managing fire-prone forests for long-term resilience.

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1 Introduction

Fires can both stimulate and depress forest recovery by affecting soil processes. In moisture-limited systems, such as dry coniferous forests, fire can accelerate soil organic matter (SOM) breakdown and nutrient release (Neary et al., 2008). Severe fires, however, may contribute to decreases in nutrient availability by consuming SOM, volatilizing nitrogen, and decreasing microbial processes associated with nutrient cycling, thereby potentially limiting post-fire forest recovery.

Incomplete combustion of biomass during fires produces black carbon (C), a highly concentrated form of C characterized by an aromatic chemical structure, which contributes to resistance to decomposition and its potential to sequester C over the long term (Preston & Schmidt, 2006; Schmidt & Noack, 2000). However, black C quantity and characteristics depend on the fire conditions in which the black C was produced (Bergeron et al., 2013), and knowledge of the role of wildfire-produced black C in forest soils is limited. The 2011 Pagami Creek wildfire in northern Minnesota provided a unique opportunity to evaluate the effects of a range of fire severity levels on forest soil carbon (C) and nitrogen (N), including the black C component of forest soil.

2 Methods

The 2011 Pagami Creek wildfire was initiated by a mid-

August lightning strike in the Boundary Waters Canoe Area in northern Minnesota, USA. Although fire is a key ecological process in this region (Frelich, 2002; Heinselman, 1996), the 38,000 ha fire was the largest to occur in this region since 1894. The fire burned through diverse forest types including *Pinus*-dominated stands and *Populus-Betula* stands with *Picea-Abies* understory and exhibited a full range of behavior ranging from light surface fire to rapidly spreading crown fire. The fire resulted in range of fire severity levels based on both field estimates (Jain & Graham, 2007) and remotely sensed measures using a RdNBR approach (Miller et al., 2009).

Soils were sampled from the burned area in October-November 2011. Fire severity was assessed in each sample plot, using severity estimates for soil and for the forest canopy. Unburned reference sites were sampled in the spring of 2012. To evaluate the effects of fire severity on forest soil organic matter, we quantified total soil carbon (C) and nitrogen (N) using elemental analysis, and black (pyrogenic) C using nuclear magnetic resonance (NMR) spectroscopy in areas classified as low to high fire severity.

3 Results and Discussion

Forest floor C content decreased with fire severity, and there were no differences in forest floor N content among severity classes. Similarly, there were no differences in total C or N contents for mineral soil at 0-10 cm or 10-20 cm depths. All fire severity levels decreased C:N ratio relative to unburned reference areas for the forest floor and 0-10 cm mineral soil; however, there were no differences in C:N among severity levels. Results on pyrogenic C content will be presented.

Up to 40% of soil C may exist as black C in fire-disturbed forests (Preston & Schmidt, 2006). Black C has been positively correlated with soil pH, total C and N, P availability, and conifer seedling regeneration (MacKenzie et al., 2008; Makoto et al., 2011), indicating that black C influences post-fire forest recovery. Our study provides information on the black C component of total soil C, and evaluates relationships among fire severity, black C, and total soil C and N in forest soil. The western Great Lakes region has experienced recent patterns of prolonged drought (Potter & Conkling, 2012), which increases wildfire risk and severity. Understanding the role of black C in post-fire forest soils as a function of fire severity is important for anticipating how continued changes in regional climate will affect nutrient pools in forest soil.

4 Conclusions

Our results indicate that fire effects on total soil C and N are limited primarily to the organic soil layers, and that effects on mineral soil are minimal. These results represent immediate (<1 year) effects of fire on soil. Evaluating changes in black C and total soil C and N through time since fire will provide additional information on how the persistence of fire effects differs among fire severity levels.

Our study provides information on the environmental effects of forest fire as a function of fire severity, and is relevant for anticipating changes in wildfire disturbance regimes likely to occur under predicted future climate scenarios (Turner, 2010). This information is critical for developing appropriate policies and practices for minimizing detrimental effects of ecosystem disturbance and managing fire-prone forests for long-term resilience.

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