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Effects of prescribed burning and seasonal and interannual climate variation on nitrogen mineralization in a typical steppe in Inner Mongolia

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ABSTRACT

Fires in grasslands significantly alter nutrient cycling processes. Seasonal climatic changes can interact with fire to further modify nutrient cycling processes. To investigate the effects of fire on soil nitrogen transformation processes and their seasonal change and interannual variability in a typical steppe in Inner Mongolia, we determined the rates of net nitrogen mineralization and nitrification over two growing seasons and a winter following a prescribed spring fire in May 2006. Fire significantly decreased rates of both net nitrogen mineralization and net nitrification during the first growing season and winter following burning. Cumulative net nitrogen mineralization in unburned and burned plots in the 2006 growing season was 133% and 183% higher, respectively, than in the drier 2007 growing season. Nitrogen mineralization apparently occurred in winter and the cumulative net nitrogen mineralization from October 2, 2006, to April 27, 2007 in unburned and burned plots amounted to 1.18 ± 0.25 g N m^{-2} and 0.51 ± 0.08 g N m^{-2}, respectively. Cumulative net nitrogen mineralization was higher in a wet 2006 than in a dry 2007 growing season, indicating that the net N mineralization rate was sensitive to soil moisture in a dry season. Our study demonstrated that a one-time prescribed fire decreased net N mineralization rates only for a short period of time after burning while interannual variation in climate had more significant effects on the process of nitrogen mineralization.

1. Introduction

N availability is an important factor influencing plant growth, and thus limits primary productivity and affects plant species competition (Vitousek and Howarth, 1991; Perakis and Kellogg, 2007; Cole et al., 2008) through altering plant nitrogen use efficiency (Aerts and Decaluwe, 1994; Yuan et al., 2005), changing the composition of soil microbial communities, and affecting the biomass of microbial organisms and roots (Zhang and Zak, 1998; Hu et al., 2001; Bradley et al., 2006). N availability can also regulate C storage and N trace gas emissions (Davidson et al., 1993; Luo et al., 2004). N availability, however, is mainly determined by mineralization of soil organics, i.e., the transformation of organic N to inorganic N. Previous studies indicate that N mineralization exhibits high spatial and temporal variability (Knoepp and Swank, 1998), and is regulated by several environmental factors, such as temperature, water and oxygen content in soils (Hatch et al., 1991; Vangestel et al., 1993; Sierra, 1997; Knoepp and Swank, 2002; Paul et al., 2003; Wang et al., 2006; Xu et al., 2007). However, different ecosystems might respond differently to those factors (Fisk and Schmidt, 1995; Yahdjian and Sala, 2008). Most studies on the seasonal patterns of net N mineralization have focused on the growing season (Blair, 1997; Knoepp and Swank, 1998; Xu et al., 2007). Winter processes and spring snowmelt were, however, also found important in N transformation processes (Schimel and Clein, 1996; Brooks et al., 1998; Brooks and Williams, 1999; Kielland et al., 2006). Thus, it is important to determine the winter contribution of N mineralization to N availability in areas with long duration of winter season and to fully understand the seasonal pattern of net N mineralization rates over an entire year.

Fire as a natural or anthropogenic disturbance can result in short- or long-term changes in ecosystem dynamics (Romanyà et al., 2001; MacKenzie and DeLuca, 2006). Fire can alter light penetration, energy balance and evapotranspiration by removing aboveground biomass and litter, and subsequently change soil temperature and moisture (Hulbert, 1969; Knapp and Seastedt, 1986; O'Lear et al., 1996; Knapp et al., 1998; Fynn et al., 2003; Zhang et al., 2008), thus affecting plant growth and soil microbial activities (Turner et al., 1997; Andersson et al., 2004; Xu and Wan, 2008). Studies, however, showed varied results regarding effects

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of fire on soil N availability in grasslands. Ojima et al. (1994) reported that burning induced short-term increases in inorganic N, while Blair (1997) and Turner et al. (1997) observed faster rates of net N mineralization in unburned sites. Similar results were reported in a South African grassland, where fire reduced potentially mineralizable N (Fynn et al., 2003). A meta-analysis, however, showed that soil N availability was generally increased by burning across various terrestrial ecosystems (Wan et al., 2001). Li and Herbert (2004) also found that prescribed burning only increased gross mineralization rates in relatively cold season such as April and May. As fire once was an important natural disturbance factor before 1980s in the semi-arid grassland area in Inner Mongolia, understanding how fire influences N mineralization process is critical for proper management of typical steppe ecosystems in this area.

In this study, we determined the rates of net N mineralization over two growing seasons and a winter season using an *in situ* incubation method after a prescribed burning. The purposes of this study were to investigate how burning affected inorganic N pools and N mineralization rates, and to examine the effects of seasonal and interannual climate variability on nitrogen transformation processes in a typical Inner Mongolia steppe. We hypothesized that fire would have significant effects on soil N dynamics, but fire effects might be influenced by other environmental factors such as precipitation because water can be a limiting factor in the semi-arid area of Inner Mongolia.

2. Materials and methods

2.1. Site description

This research was conducted between May 2006 and October 2007 in a typical steppe ecosystem in northern China, which is located near the Inner Mongolia Grassland Ecosystem Research Station (IMGERS, E116°42′, 43°38′N) of the Chinese Academy of Sciences. The experiment site was fenced to exclude large animal grazing since 1983. Average elevation of the site is approximately 1100 m. Mean annual precipitation is about 350 mm, mainly occurring from June to August. Average annual air temperature is −0.4 °C. Mean monthly air temperature ranges from −23.0 °C in January to 17.9 °C in July based on a long-term record of a nearby meteorological station. Mean growing season length is approximately 150 days (Bai et al., 2004). The soil is dark chestnut (sandy and silty loam in texture; Li, 1990). Vegetation at the site was dominated by *Leymus chinensis*, *Stipa grandis*, *Carex korshinskyi*, *Cleistogenes squarrosa*, and *Agropyron cristatum*. Fu et al. (2001) reported that fire in Xilingol League (E111°09′–119°58′, 41°35′–46°46′N) happened 24.5 times a year from 1986 to 1997, the burned area was about 312,450.44 h m^2, and about 60% of the fire happened in spring. The frequency of fire occurrence was about once every 3–5 years in this semi-arid grassland area before the 1980s. Almost no large-scale fire occurred since then. This is mainly due to fire prevention and dramatic decrease in aboveground biomass as stocking rates substantially increased since the early 1980s. The experiment site in this study had not been subjected to fire for at least 50 years.

2.2. Experimental design

The experimental site was established in 2005 and contained 9 blocks separated by a 2-m walkway between adjacent blocks. Each block was further divided into plots with 1-m buffer between adjacent 10 × 10 m plots. The burned plots and unburned plots were randomly arranged in 9 blocks. All plots were located at the same topographic position and on similar soils. Fire treatments were made in early May of 2006. The fire removed almost all the aboveground plant materials and soil surface litter.

2.3. Sampling and sample analysis

In situ net N mineralization was measured monthly from 3 May 2006 through 11 October 2007, using a PVC [polyvinyl chloride plastic] cores method (modified from Raison et al., 1987). Three sharpened PVC cores (5 cm diameter × 12 cm long) per plot were driven 10 cm into the ground, and covered with plastic film that prevented water penetration and allowed gas exchange. In unburned plots surface litter was moved to the side prior to inserting the cores, and put back after the PVC cores were installed. Cores were incubated in the field for about 30 days during growing season and unfrozen period in winter, and for whole frozen period in winter. At the time PVC cores were placed, three similar soil cores were taken in adjacent locations. Soil in the three cores was mixed as a composite sample and sieved through a 2-mm mesh. Subsamples were used to measure initial concentrations of inorganic N, total soil C and N, soil pH value, and soil water content (SWC). For inorganic N measurement, soil samples before and after incubation were extracted with 2 mol/L KCl. Concentrations of inorganic N (NH_4^+-N and NO_3^--N) in the filtered extracts (Whatman No. 1 filter paper) were determined using a flow injection autoanalyzer (FIAstar 5000 Analyzer, Foss Tecator, Denmark). SWC was determined with subsamples being dried at 105 °C for 24 h. The expression of soil inorganic N concentrations was based on dry soil.

The air-dried soil subsamples were used for measuring pH value, total organic C and N contents. The pH values were determined in water (water/soil = 2.5:1) suspension. Soil total organic C contents were analyzed using H_2SO_4–$K_2Cr_2O_7$ oxidation method (Nelson and Sommers, 1982). Soil total organic N contents were determined using the Kjeldahl acid-digestion method with an Alpkem autoanalyzer (Kjektec System 1026 Distilling Unit, Sweden). Daily rainfall and air temperature were recorded at a permanent meteorological station belonging to the IMGERS. The meteorological station was located at 6 km west of our study site. Soil temperature at 10 cm depth in each replicate plot was measured using digital thermometer in the field at the time of sampling. Soil bulk density was measured using a coring method. Aboveground plant biomass (in June–August) was determined by clipping all plants in nine randomly located 1 × 1 m quadrats in each plot, and oven-drying the plant materials at 70 °C for 48 h. Monthly net aboveground plant production (MNAPP) was determined by calculating the difference of aboveground biomass between two adjacent months.

2.4. Data analysis

Rates of net N mineralization (nitrification) during the incubation period were calculated from the difference of inorganic N (NO_3^--N) concentrations between the initial and after incubation samples. Cumulative net N mineralization was calculated by summing the rates of net N mineralization of each incubation period during the entire growing season or wintertime. Rates of net N nitrification and mineralization were calculated using the following equations:

For a time interval $\Delta t = t_{i+1} - t_i$,

$$A_{\mathrm{amm}} = \left[\mathrm{NH}_4^+ - \mathrm{N}\right]_{i+1} - \left[\mathrm{NH}_4^+ - \mathrm{N}\right]_i \qquad (1)$$