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Effects of snow absence on winter soil nitrogen dynamics in a subalpine spruce forest of southwestern China

Zhijie Li, Wanqin Yang, Kai Yue, Meta Francis Justine, Ruoyang He, Kaijun Yang, Liyan Zhuang, Fuzhong Wu, Bo Tan, Li Zhang, Zhenfeng Xu*

Key laboratory of Ecological Forestry Engineering, Institute of Ecology & Forest, Sichuan Agricultural University, Chengdu 611130, China

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ABSTRACT

The lack of snow cover due to winter climate change has great potential to impact winter soil nitrogen cycling in boreal forests. A snow manipulation was conducted in a Tibetan spruce forest to explore the effects of snow absence on winter soil nitrogen dynamics by shelter method. Snow absence on average reduced soil temperatures at the depths of 0 cm and 5 cm by 1.44 °C and 0.33 °C, respectively, throughout the winter. Moreover, snow absence increased soil frost and freeze-thaw cycles. Soil net nitrogen mineralization and labile nitrogen pools (ammonium, nitrate and dissolved organic nitrogen) were higher in the snow absence plots compared to control plots. Snow absence increased soil microbial biomass carbon but did not affect microbial biomass nitrogen. Nevertheless, soil enzyme activities involved in nitrogen cycles were often lowered by snow absence over the winter. The results noted in this study suggest that warming-induced absence in seasonal snowpack may stimulate winter soil nitrogen availabilities by changing soil microhabitats, which has important implications for soil biogeochemical cycles in the subalpine forest ecosystems on the eastern Tibetan Plateau.

1. Introduction

At high latitudes and altitudes, winter precipitation is more likely to occur in the form of rain rather than snow as a result of climate change (IPCC, 2013; Wang et al., 2016). A reduction in winter snowfall could result in decreased snow depth and thereby enhance freeze-thaw cycles and soil frost as a result of the lack of insulation (Kreyling et al., 2012; Bokhorst et al., 2013), which could, in turn, have significant impacts on soil biogeochemical processes in boreal forests.

In order to get better insights into mechanisms underlying soil biochemical responses, a number of snow manipulation experiments have been carried out in snowy region (e.g., Groffman et al., 2001; Shibata et al., 2013; Tan et al., 2014). However, no consistent conclusions have emerged from these studies (Li et al., 2016a, 2016b). The lack of insulating snowpack could decrease soil temperatures, resulting in lower microbial metabolism and enzymes activities, thereby decreasing organic matter mineralization rates. However, a decrease in snow depth may enhance soil frost and freeze-thaw cycles, inducing higher root and microbial mortality (Cleavitt et al., 2008; Tierney et al., 2001), which are important available N sources and play critical role in soil N cycling processes under snow cover (Schimel et al., 2004). Therefore, the increase in substrate availability due to the enhanced root and microbial mortality may, in part, counteract the temperature effect under snow-free conditions. In cold biomes, winter soil freezing might affect the potential for interaction between nutrients and microbes, which is a critical regulator of nutrient cycling and retention during snow-covered period (Brooks and Williams, 1999). Thus, the lack of snow cover associated with climate change may exert complicated and important effects on soil biogeochemical cycles in cold ecosystem. Soil biochemical responses to snowpack reduction may be dependent on ecosystem traits (e.g., substrate quality and quantity) and site conditions (e.g., snowfall, albedo).

As the earth's ‘third pole’, the Tibetan Plateau has experienced a pronounced warming and winter snowfall has been decreasing over last decades (Chen et al., 2013; Wang et al., 2016). Moreover, snow cover in this region has its unique characters, including shorter snow duration and thinner snow depth relative to high latitudes. Furthermore, winter soil temperature is close to physical melting point and belowground processes are very susceptible to slight temperature changes (Wang et al., 2007). Hence, soil biogeochemical processes could be more sensitive to the alteration of snowpack. Up to now, most of existing studies in climate change biology have only focused on the growing season (Xu et al., 2010; Yin et al., 2013), while climate change in this region is more significant and soil biological activities are high over the wintertime (Chen et al., 2013; Tan et al., 2012). Thus, in this study, a snow manipulation experiment was conducted in a Tibetan spruce

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* Corresponding author at: Institute of Ecology and Forestry, Sichuan Agricultural University, 211 Huimin Road, Wenjiang District, Chengdu 611130, Sichuan, PR China.
E-mail address: xuzf@sicau.edu.cn (Z. Xu).

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forest to assess the effects of snow absence on winter soil N dynamics. Specifically, we hypothesized that (1) snow absence would increase soil net N mineralization and N availability; (2) snow absence would increase soil microbial biomass and enzyme activities.

2. Materials and methods

2.1. Site description

The field experiment was conducted in a *Picea asperata* (Dragon spruce) stand at the Long-term Research Station of Alpine Forest Ecosystems, which is located on the eastern Tibetan Plateau, China (31°15′10″N,102°53′29″; 3021 m a.s.l). The annual mean precipitation and temperature are 850 mm and 3.0 °C, respectively. In general, snow cover begins to accumulate in late November and melts in late March of the following year. The understory is dominated by *Salix paraplesia*, *Rhododendron lapponicum*, *Cacalia spp*., *Carex spp*., and *Cyperus* spp. The soil is classified as Cambic Umbrisols (IUSS Working Group WRB, 2007). The basic physicochemical properties of soil (0–15 cm) are as follows: carbon 88.51 ± 10.52 $g\ kg^{-1}$, nitrogen 5.43 ± 0.51 $g\ kg^{-1}$, phosphorous 0.41 ± 0.01 $g\ kg^{-1}$, pH 6.41 ± 0.05 and bulk density 1.27 ± 0.03 $g\ cm^{-3}$, respectively.

2.2. Experimental design

In order to achieve a snow-free condition, six wooden roofs were set up in the spruce forest. One control plot was randomly established in the vicinity of each wooden roof. It was expected that all of the selected plots were identical in microhabitat characteristics. The wooden roof used in this study was 2 m height, with 3 m × 3 m in the ground area. A transparent plastic sheet on the top of roof was used to prevent snow accumulation on the ground. In late winter, the accumulated snow on the roof was added to the forest floor in order to ensure the similar water balance between the snow-free and control plots. The snow manipulation was started in late November 2015 and ended in late March 2016 when the seasonal snow in the control plots was melted.

2.3. Microclimate monitoring

Air temperature at 2 m height in the study site and soil temperatures 0 cm and 5 cm below the soil surface in the snow-free and control plots were measured by the Thermochron iButton DS1923–F5 Recorders (Maxim Dallas Semiconductor Corp., USA) every 1 h from mid November in 2015 to mid April in 2016. Soil moisture 5 cm below the soil surface was measured with a hand-held probe at about 2-week interval. Snow depth in the control plots and soil frost depth in each plot were measured approximately every 2 weeks. Soil frost depth was determined with soil tubes as described by Hardy et al. (2001). Briefly, the frost tubes consist of a permanently installed PVC tube and an inner tube. The inner tube was made of clear rubber and was filled with water and a dye. In winter, the inner dye-filled tubes were moved and the frost depth was measured. Freeze-thaw cycles were calculated as the number of occurrences when the soil temperature crosses the 0 °C isotherm and then returns to above-zero temperature more than 3 h (Konestabo et al., 2007).

2.4. Soil sampling and chemical analysis

Soil samples were collected from the top soil (0–15 cm) in the early snow cover (ESC), deep snow cover (DSC) and early snow melting (ESM) period, respectively. Three cores (5 cm in diameter, 0–15 cm deep) were randomly taken at each plot. The three soil cores from each plot were mixed to get one composite sample which was passed through a sieve (2 mm diameter), and any visible living plant material was manually removed from the sieved soil. The sieved soil was kept in the refrigerator at 4 °C (less than one week) for microbial properties, available nutrients and enzyme activities.

Inorganic soil N (ammonium and nitrate) was extracted with 2 M KCL extracting water solution and then measured by the Indophenol-blue and phenol disulphonic acid colorimetry, respectively (Xu et al., 2010). Soil microbial biomass carbon (MBC) and soil microbial biomass nitrogen (MBN) were measured by fumigation-extraction method. The released C and N were converted to MBC and MBN using *k*ec − 0.45 and *k*en − 0.54, respectively (Vance et al., 1987). Dissolved organic N (DON) was extracted by the method of Jones and Willett (2006). Total dissolved N (TDN) was measured using a total C & N analyzer (TOC-VcPH + TNM-1, Shimazu Inc., Japan). Dissolved organic N (DON) was calculated as DON = TDN − TIN (ammonium + nitrate). Soil nitrate and nitrite reductase activities were assayed as described by Xiong et al. (2014). For soil urease activity, we used the Kandeler and Gerber (1988) method.

Soil net N mineralization over the wintertime was determined from in situ incubations using the buried tube technique. The incubations were conducted using perforated PVC tubes (15 cm in height and 5 cm in diameter). Para film covered the top of each tube to avoid leaching of N. The wintertime net N mineralization (From mid November 2015 to early April 2016) was expressed as the difference in inorganic N (nitrate and ammonium) in the soil before and after incubation.

2.5. Statistical analysis

Repeated measures ANOVA was performed to test the effects of treatment, sampling date, and their interactions on measured parameters. For specific sampling dates, Student *t*-tests were used to compare the effect of the snow absence. Redundancy Analysis (RDA) was used to test the correlations between the measured N parameters and environmental factors. The statistical tests were considered significant at the $P < 0.05$ level. All statistical analyses are performed using 16.0 SPSS software package for Windows.

3. Results

3.1. Microclimates

The minimum air temperature was − 15.3 °C in late January 2016 (Fig. 1). Seasonal snow began to accumulate in late November 2015 and melted in late March 2016 with the maximum snow depth reaching approximately 40 cm in late February in the control plots (Fig. 2B). Compared to the control plots, snow absence lowered the average and minimal soil temperatures (Table 1). Snow absence on average reduced

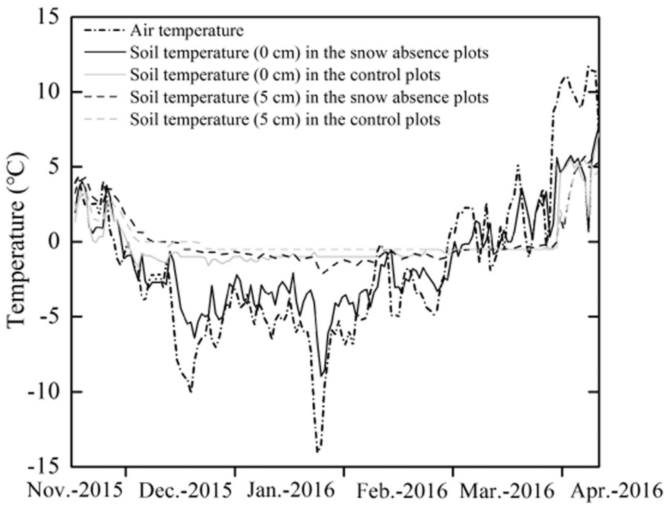

Fig. 1. Seasonal dynamics of air temperature (2 m high) and soil temperatures (0 cm and 5 cm) in the snow absence and the control plots in a subalpine forest of southwestern China.