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Small and transient response of winter soil respiration and microbial communities to altered snow depth in a mid-temperate forest

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ABSTRACT

Global climate change is altering snow depth in winter, which could significantly affect soil respiration and microbial communities. However, belowground responses are still uncertain as they depend on the thermal effects on soils, the acclimation of soil microbial communities and ecosystem type. Here, we conducted a snow manipulation experiment including 50% removal of snowpack (mean snow depth after treatment was 3.1 ± 0.7 cm), ambient snow (mean snow depth was 6.3 ± 0.7 cm), and 50% increase of snowpack (mean snow depth after treatment was 9.6 ± 1.5 cm) to explore the effects of altered snow depth on winter soil respiration and microbial communities in a mid-latitude plantation forest with continental climate with dry winters. Winter soil CO_2 effluxes varied from 0.09 to 0.84 $\mu mol\, m^{-2} s^{-1}$ with a mean of 0.32 ± 0.07 $\mu mol\, m^{-2} s^{-1}$. The cumulative soil CO_2 effluxes from 11 December 2014 to 21 March 2015 were 27.3 ± 1.1, 26.5 ± 2.1, and 29.5 ± 1.3 $g\, C\, m^{-2}$ under reduced, ambient and added snowpack, which corresponded to 5.7 ± 0.2%, 5.5 ± 0.3%, and 5.8 ± 0.1% of the annual soil CO_2 effluxes, respectively. Our one-year observation results suggested that although snow reduction decreased soil temperature, microbial biomass carbon (MBC) and soil respiration did not change, suggesting microbial adaptation to cold conditions between −4 °C and −1 °C. In contrast, snow addition increased soil temperature, MBC, and soil respiration. Microbial community structure (F/B, ratio of fungi to bacteria) was also changed and soil enzymatic (β-glucosidase) activities increased under snow addition. However, these effects were short-lived and disappeared when soil temperature did not differ between the addition and control plots at the 14th day after treatment. These results indicated that the responses of soil microbial communities and respiratory activities to changing soil temperature were rapid and the response of soil respiration to snow addition was transient. Consequently, altered snow depth did not affect cumulative soil CO_2 effluxes. Our study suggests that wintertime soil respiration rates are generally low and snow manipulation has minor effects on soil CO_2 efflux, soil temperature (the determinant driver of wintertime soil CO_2 efflux) and soil microbial biomass at our site.

1. Introduction

Climate projections indicate that global mean annual air temperature will increase 2–5 °C by year 2100 compared with preindustrial values (Rogelj et al., 2012; IPCC, 2013). Global warming is predicted to significantly change the depth of snow cover (Qin et al., 2006; IPCC, 2007; Peng et al., 2010), especially in mid-latitude (N 30–60° and S 30–60°, non-alpine) terrestrial ecosystems (Henry, 2008; Kreyling and Henry, 2011). Changes in snowpack depth associated with climate change have been shown to profoundly impact the soil carbon cycle, especially soil respiration (Monson et al., 2006b; Nobrega and Grogan, 2007; Du et al., 2013; Durán et al., 2014). Because winter soil respiration makes an important contribution to annual carbon budgets by accounting for 3–50% of annual carbon emissions (Hubbard et al.,

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Abbreviations: CO_2, Carbon dioxide; F/B, Ratio of fungi to bacteria; C, Carbon; N, Nitrogen; TDR, Time domain reflectometry; PVC, Polyvinyl chloride; SR, Soil respiration; Q_{10}, increased soil respiration rate per 10 °C increase in soil temperature; EOC, Extractable organic carbon; TDN, Total dissolved nitrogen; TOC, Total organic carbon; TN, Total nitrogen; MBC, Microbial biomass carbon; MBN, Microbial biomass nitrogen; PLFA, Phospholipid fatty acid; G^+, Gram-positive bacteria; G^-, Gram-negative bacteria; AM, Arbuscular mycorrhizal; EAAs, Extracellular enzymatic activities; PCA, Principal component analysis; RDA, Redundancy analysis

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2005; Mo et al., 2005; Monson et al., 2006a; Elberling, 2007; Schindlbacher et al., 2007; Liptzin et al., 2009; Wang et al., 2010; Shi et al., 2012; Schindlbacher et al., 2014; Shi et al., 2014), it is important to understand how winter soil respiration responds to altered snow depth.

The impacts of snow depth on soil respiration in winter mainly results from its regulation of soil temperature. Snow serves as an insulation layer, preventing soil freezing at cold winter temperatures (Brooks et al., 2011). A thicker snowpack could thus effectively decouple soil and air temperatures, generally resulting in higher soil respiration rates (Elberling, 2007; Nobrega and Grogan, 2007; Sullivan et al., 2008; Liptzin et al., 2009). A thinner snowpack could inhibit soil microbial activities by reducing soil temperature, which could lead to lower soil respiration rates (Brooks et al., 1997; Monson et al., 2006b; Blankinship and Hart, 2012; Liu et al., 2016). In addition, the reduction of snow pack may also increase the release of dissolved organic carbon and nitrogen from soil aggregates and fresh litter due to more pronounced daily variations in soil temperature (Joseph and Henry, 2008; Freppaz et al., 2012), which could enhance the substrate supply of soil microbial communities and thus potentially lead to higher soil respiration rates. In addition to soil temperature, snowpack could also affect soil water content, especially during snowmelt (Merbold et al., 2011; Shibata et al., 2013). Higher soil water content may stimulate soil microbial activities (Monson et al., 2006a; Aanderud et al., 2013), but it may also limit oxygen diffusion in the soil and thus, reduce respiratory activity in the soil (Yohannes et al., 2011). Therefore, although changes in snow cover depth have been frequently observed to affect soil C cycling, the underlying mechanism are still poorly understood and the magnitude is highly uncertain as it depends upon prevailing soil and snow conditions.

Soil microorganisms play a vital role in understanding the underlying mechanisms of the responses of winter soil respiration to altered snow depth (Lipson et al., 2002; Puissant et al., 2015). Soil microbial biomass might be higher in winter than in summer (Edwards et al., 2007; Puissant et al., 2015) and soil microbial community may be distinct during winter (Lipson et al., 2000). For example, Monson et al. (2006b) found that soil respiration was very sensitive to changes in snow depth because a unique soil microbial community exhibited exponential growth during winter beneath the snow. Increased snowpack depth could enhance microbial biomass (Buckeridge and Grogan, 2008), stimulate microbial activities (Schimel and Weintraub, 2003) and increase the ratio of fungi to bacteria (Robroek et al., 2013). On the contrary, decreased snowpack depth was found to diminish microbial biomass (Durán et al., 2013), constrain microbial activities (Tan et al., 2014), and alter microbial community composition (Zinger et al., 2009; Aanderud et al., 2013; Robroek et al., 2013). Examination of these changes of microbial characteristics could help better understand why soil respiration responded to altered snow depth.

A number of studies documented the effects of altered snowpack depth on the carbon cycle under climate change in the past decades (Li et al., 2016). Almost all studies were conducted in high latitude (N 60–90° and S 60–90°) and altitude regions (Grogan and Jonasson, 2006; Schimel et al., 2006; Elberling, 2007; Schindlbacher et al., 2007; Merbold et al., 2013; Semenchuk et al., 2016), while only few studies have been done in temperate regions (Groffman et al., 2006; Aanderud et al., 2013; Sanders-DeMott and Templer, 2017). Although temperate ecosystems are characterized by relatively short winters, they have a stronger variation in the amount of snow cover compared to arctic, boreal and alpine ecosystems (Peng et al., 2010; Aanderud et al., 2013; Yu et al., 2013). In China, snow depth showed a dynamic variation with an increasing trend during the period 1982–1998 and a decreasing trend during the period 1998–2005 across the entire temperate region (Yu et al., 2013). Due to the dry winter climate, the annual snow depth is normally low ranging from 0 cm to 10 cm in Northeast China (Peng et al., 2010; Yu et al., 2013). Here, we conducted a snow cover manipulation experiment to study the effects of altered snow depth on winter soil respiration in a mid-temperate forest plantation ecosystem in Northeast China. The objectives of our study were: (i) to assess how altered snow cover depth affected winter soil respiration rates; and (ii) to explore the underlying mechanisms from environmental, nutrient and microbiological perspectives.

2. Material and methods

2.1. Site description

The research site was located nearby Shenyang, Liaoning, northeast China (41°54′22″N, 123°35′48″E, elevation of 122 m). The research forest is a 20-year-old plantation forest, dominated by Larch (*Larix gmelinii (Rupr.) Kuzen.*). The mean annual temperature is 8.3 °C with a maximum monthly temperature of 24.8 °C in July and minimal monthly temperature of −10.5 °C in January, respectively. The mean annual precipitation is 726 mm and winter precipitation is 30 mm. The mean annual snow depth is approximately 6 cm from 1978 to 2006 (Chen et al., 2008). The annual snow depth was 63 ± 7 mm in the winter of 2015. The number of days with snow was 102 days from 11 December 2014 to 21 March 2015. Snowmelt started on 12 March 2015 and all snow had disappeared in all plots at on 21 March 2015. The minimum winter air temperature and minimum annual soil temperature were −21 °C and −2.9 °C, respectively. The site is on a south facing slope of 5°. The soil is sandy loam with a mull-type organic surface layer having a ~1 cm thick litter layer. The soil is classified as aquic Brown soil by Chinese Soil Classification (equivalent to Typic Haplaqualf by USDA Soil Taxonomy). The basic characteristics of the studied soils (0–5 cm) are as follows: soil texture: 45.0 ± 1.0% sand, 24.9 ± 0.4% silt, 30.1 ± 0.5% clay, pH: 4.7 ± 0.0, bulk density: 1.2 ± 0.0 g cm^{-3}, total C: 20.4 ± 0.8 g kg^{-1}, total N: 1.8 ± 0.1 g kg^{-1}, C:N: 12.0 ± 0.1.

2.2. Experimental design and snow manipulation

The experimental snow manipulation was laid out as a completely randomized design with a one-way treatment structure and the following three treatments: snow reduction (50% removal of snowpack, Reduction); control (ambient snow, Control) and snow addition (50% increase of snowpack, Addition). Each treatment had five replicates on 2.5 × 2.5 m plots with each containing one larch tree. The experimental plots were approximately 5 m apart from each other. A 0.5 m buffer was used around the edge of each plot to avoid disturbance and interactions among plots. In order to facilitate shoveling in the plots, the understory vegetation (30 herbs per square meter) was clipped in all plots. The snow manipulation was conducted immediately once each snowfall event exceeded 5 cm, namely on 18 December 2014, 28 January 2015 and 19 February 2015, respectively. On the snow-reduction plots, we left at least a 2.5 cm snow layer to avoid a disturbance of the forest floor and to keep the surface albedo. The treatment was done by gently shoveling the snow from the reduction treatment plot to the addition treatment plot using a shovel.

2.3. Microclimate monitoring

The forest air temperature (2 m above the ground) and soil temperature (5 cm depth) were recorded by buried Thermochron iButton (iButton DS1923-F5, Maxim Com.USA) in each plot. It recorded temperature every 2 h from 1 November 2014 to 1 April 2015. Snow depth was measured using a graduated stainless steel rod once a week. Soil volumetric water content (0–5 cm) was measured using TDR300 soil moisture probe (Spectrum Technologies Inc., Plainfield; IL, USA) (2 soil moisture probes in each plot).