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Snow removal alters soil microbial biomass and enzyme activity in a Tibetan alpine forest

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ABSTRACT

Projected future decreases in snow cover associated with global warming in alpine ecosystems could affect soil biochemical cycling. To address the objectives how an altered snow removal could affect soil microbial biomass and enzyme activity related to soil carbon and nitrogen cycling and pools, plastic film coverage and returning of melt snow water were applied to simulate the absence of snow cover in a Tibetan alpine forest of western China. Soil temperature and moisture, nutrient availability, microbial biomass and enzyme activity were measured at different periods (before snow cover, early snow cover, deep snow cover, snow cover melting and early growing season) over the entire 2009/2010 winter. Snow removal increased the daily variation of soil temperature, frequency of freeze–thaw cycle, soil frost depth, and advanced the dates of soil freezing and melting, and the peak release of inorganic N. Snow removal significantly decreased soil gravimetric water, ammonium and inorganic N, and activity of soil invertase and urease, but increased soil nitrate, dissolve organic C (DOC) and N (DON), and soil microbial biomass C (MBC) and N (MBN). Our results suggest that a decreased snow cover associated with global warming may advance the timing of soil freezing and thawing as well as the peak of releases of nutrients, leading to an enhanced nutrient leaching before plant become active. These results demonstrate that an absence of snow cover under global warming scenarios will alter soil microbial activities and hence element biogeochemical cycling in alpine forest ecosystems.

1. Introduction

Soils in high-latitude or high-altitude ecosystems during winter experience extensive snow cover, freezing, thawing, and freeze-thaw cycle with the air temperature fluctuates above and below 0 °C (Edwards et al., 2007; Groffman et al., 2011). The global air temperature may increase 1.0–3.0 °C over this century (Lewis, 2013), with more pronounced warming at the high-latitude and high-altitude regions (IPCC, 2007). Warmer temperatures are predicted to decrease the depth and duration of snow cover and increase the frequency, severity, and spatial extent of soil freezing events (Freppaz et al., 2008; Groffman et al., 2011). Such changes could have profound repercussions for soil nutrient cycling and biological activity in high-latitude and high-altitude ecosystems during winter (Koch et al., 2007; Matzner and Borken, 2008; Steinweg et al., 2008; Groffman et al., 2011).

Soil temperature, moisture and soil freezing are closely related to the depth and duration of seasonal snow cover (Hardy et al., 2001; Groffman et al., 2011). In general, a 30–40 cm depth of snow cover could decouple soil temperature from air temperature, preventing the physical changes associated with soil freezing and thawing (Cline, 1997; Steinweg et al., 2008). Removing snow in the early winter could induce soils to remain frozen for most of the winter even after snow re-accumulation (Groffman et al., 2001b; Steinweg et al., 2008). Moreover, a later developed and earlier melt snow cover also could result in greater daily soil temperature variations, more frequent soil freezing and thawing events, deeper soil frost depth and lower soil moisture during winter (Hardy et al., 2001; Groffman et al., 2011). Therefore, decreases in snow cover may potentially affect soil nutrient availability and microbial properties by altering the environmental factors (i.e., soil temperature and freeze-thaw cycle) in cold ecosystems.

In general, soil nutrient availability, microbial biomass and enzyme activity are regulated by environmental factors (i.e., soil temperature, moisture). As mentioned above, snow removal could cause significant effects on soil temperature, moisture and

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freeze-thaw cycles, which in turn affect soil biochemical processes (Freppaz et al., 2008; Buckeridge et al., 2010; Groffman et al., 2011). Microbes play a critical role in carbon and nutrient transformation in forest soils (Lipson et al., 2002). Any changes in the microbial biomass or community structure may affect the cycling of C and N, and N availability to plants (Saffigna et al., 1989; Clein and Schimel, 1995). Soil enzyme activities are also used as sensors to study the influence of global changes on microbial functionality (Sardans et al., 2008; Allison and Treseder, 2008) and are greatly affected by changes in soil freeze-thaw (Groffman et al., 2009, 2011). In order to understand the overall effects of warming on soils, it is essential to investigate the effects of warming-induced seasonal snow decreases on soil enzymes involved in C and N mineralization (i.e., invertase promotes the hydrolysis of organic C and urease promotes the hydrolysis of organic N) in alpine ecosystems.

The depth and duration of snow cover are often substantially lower in temperate alpine regions than in the subarctic and boreal regions (Edwards et al., 2007). Under moderate snow cover soil organic carbon and nitrogen are significantly greater than either under deep or shallow snow (Freppaz et al., 2012). Inorganic nitrogen stored in snow may range between 0.2 and 0.8 kg N ha^{-1} corresponding to about five of the over-winter-N mineralization (Filippa et al., 2010). The predicted changes in soil frost and snow cover in the subarctic and boreal regions have showed variable effects on above- and below-ground processes in different ecosystems (i.e., Steinweg et al., 2008; Wipf et al., 2009; Bombonato and Gerdol, 2012). As compared to the arctic tundra and boreal forest, the duration of seasonal snow cover on the eastern Tibetan Plateau is shorter and the snow depth is relatively thinner (Qin et al., 2006). Moreover, snow on the forest floor in these forests was often close to its melting point and might thus rapidly respond to minor changes in temperature (Wang et al., 2007). Therefore, responses of soil biochemical process in alpine forests on the Tibetan Plateau might be more sensitive to a decreased snow cover compared to other cold ecosystems. However, information is limited on how soil microbial activities and nutrient biogeochemical cycling could be affected under a projected snow cover decrease on the Tibetan Plateau.

The alpine forests of western China between the Tibetan Plateau and the Sichuan Basin are typical alpine forests at low latitude, with important consequences for regional C and N balances (Taylor et al., 1996; Shi et al., 2006). The dynamics surrounding freezing and snowpack development and subsequent thawing often last about half a year (Wu et al., 2010). Moreover, the magnitude of global warming on the Tibetan Plateau is projected to be larger relative to other temperate regions at the same latitude (IPCC, 2007). Thus, the depth and duration of snow cover in alpine forests of western China could be greatly decreased by future climate change. To test these hypotheses, we conducted an experiment to manipulate the depth and duration of snow cover throughout a whole winter season (October 2009 to May 2010) in a fir-spruce dominated alpine forest by an artificial snow removal manipulation with transparency plastic film coverage and returning of melt snow water, our objectives were thus to address how an altered snow cover depth and duration could affect (1) soil microbial properties related to C and N cycling and (2) soil C and N pools under a Tibetan alpine forest.

2. Materials and methods

2.1. Study site

The study site locates in a 120 years old natural alpine forest in the Bipenggou Nature Reserve of Lixian County, Sichuan, China (31°15′28.10″N, 102°53′29.34″E, 3580 m *a.s.l.* in the Eastern Tibetan Plateau). Canopy vegetation is dominated by fir (*Abies faxoniana*) and dragon spruce (*Picea asperata*) with some understory shrubs (i.e., *Salix paraplesia*, *Rhododendron* spp.) and grasses (i.e., *Cacalia auriculata*, *Cystopteris montana*, *Carex capilliformis*) (Tan et al., 2010). Annual mean precipitation is 850 mm. Annual mean temperature is 3.0 ± 0.5 °C with maximum of 23.1 ± 1.1 °C (July) and minimum of–18.0 ± 1.3 °C (January), respectively. Soil temperature goes down below 0 °C and remains frozen during the whole cold snow season from late-November to mid-April (Wu et al., 2010). Soil is classified as Cambic Umbrisols (IUSS Working Group WRB, 2007) with a ~15 cm deep organic matter layer. The basic chemical properties of soils (0–15 cm) are as follows: pH 6.1 ± 0.5, 150.3 ± 15.9 g total organic C kg^{-1}, 9.7 ± 0.9 g total N kg^{-1}, 1.2 ± 0.2 g total P kg^{-1} and 13.4 ± 1.0 g total K kg^{-1}.

The experiment had two treatments: with and without the snow removal from the forest floor. Each treatment had five plots or replicates (5 m × 5 m each) with ≥50 m distance away from each other. Based on Sulkava and Huhta (2003), five roofs (0.8 m above the soil surface at the eaves and 1.5 m at the top) with plastic film coverage were used to prevent snow accumulation on the forest floor. The film is made of low density polyethylene that transmits ~80% photosynthetically active radiation. With minimal vegetation damage and soil disturbance, this method differs from the snow removal manipulation by shovel at the Hubbard Brook Experimental Forest (Groffman et al., 2001a, b). The snow removal was started in early November 2009 and ended in late April 2010 when the snow cover in the snow treatment was completely melted. Meanwhile, the forest floor under the plastic film cover was watered three times (21 December 2009, 21 January and 22 March 2010) to simulate rain showers and melting of snow during thaw periods in winter and the melted snow water from the plastic film cover was returned to the forest floor under the plastic film cover, and the irrigation was performed when the air temperature was above 0 °C in winter. On the other hand, five polyethylene roofs with 1.2 m cuts every 1.3 m range within the 5 m × 5 m plot plastic coverage were also supplied to the no-snow removal treatment for the drop-off of snow into the forest floor.

2.2. Microclimate monitoring

Temperature of both forest floor air and soil (5 cm depth) were recorded by buried Thermochron iButton DS1923–F5 Recorders (Maxim Dallas Semiconductor Corp., USA) every 1 h in all plots between October 2009 and May 2010. The start of soil freezing or thawing is defined as the soil temperature is continually dropped below 0 or above 0 °C for more than 3 days (Jones, 2001). Meanwhile, a freeze–thaw cycle is defined as whenever the soil temperature is dropped below 0 °C for at least 3 h and followed by a rise above 0 °C for at least 3 h, and vice versa (Konestabo et al., 2007). Soil gravimetrical water, snow depth (no-snow removal plots) and soil frost depth in all plots were routinely measured.

2.3. Soil sampling

The winter season in the study site had been divided into five periods: (1) early snow, (2) early cold, (3) deep cold, (4) late cold and (5) thaw (Wu et al., 2010). However, during this study no obvious transition was observed between the early snow and early cold or between the late cold and thaw. As a result, in this study only three coverage periods for the winter was divided: (1) early snow, (2) deep snow and (3) snow melting. Meanwhile, two other periods as the before snow cover and the early growing were included for a total five periods in this study.

A total of seven samplings were performed on (1) 19 October for the before snow cover (BSC, 19 October to 9 November 2009), (2) 21 December for the early snow cover (ESC, 9 November to 31