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Effects of temperature and root additions on soil carbon and nitrogen mineralization in a predominantly permafrost peatland

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ABSTRACT

Approximately one-third of northern peatlands are within permafrost regions. Soil organic matter (SOM) and plant root biomass in permafrost peatlands are vulnerable to future global warming. However, previous studies have primarily focused on the response of SOM mineralization to increases in temperature without analysing the potential interaction effects of increased plant root biomass. This study investigated the influence of temperature and root additions on soil carbon and nitrogen mineralization as well as the mechanisms driving mineralization in a high latitude permafrost peatland in the Da Xing'an Mountains, Northeast China. We investigated changes in shallow soil (0–15 cm) and deep soil (15–30 cm) carbon mineralization, available N contents, microbial biomass carbon (MBC), dissolved organic carbon (DOC), and enzyme activities in response to increasing temperature and *Eriophorum vaginatum* root additions by using an incubation experiment. Our results indicate that elevated temperature significantly increased soil carbon mineralization. The Q_{10} values of the carbon mineralization rates in the shallow soil and deep soil were 3.95 and 2.91, respectively. In contrast, the soil MBC and DOC decreased significantly, confirming that labile carbon is the main driving force of microbial mineralization activities under warming conditions. Elevated temperature significantly increased the shallow soil net N mineralization rates and increased the net nitrification rates in both soil layers. At high temperatures, ammonification rates increased in the shallow soil but decreased in the deep soil. The increase in the incubation temperature resulted in significantly increased shallow soil β-glucosidase activity and decreased invertase activity. This suggests the increased production of complex substrate enzymes, and decreased production of simple substrate-acquiring enzymes. The root additions significantly increased the soil C mineralization and stimulated the secretion of invertase by soil microorganisms. These findings indicate that future climate warming in the northern high latitude will significantly stimulate soil carbon and nitrogen mineralization in permafrost peatlands. Furthermore, increases in plant roots will enhance C accumulation and may even enhance the response of soil C mineralization to temperature, significantly impact the soil C balance in high latitude permafrost peatlands.

1. Introduction

Peatland soils play an important role in the global carbon (C) cycle because of their long-term accumulation of soil organic matter (SOM) (Weedon et al., 2013). Peatland biogeochemistry and hydrology are also closely related to climate (Wu and Roulet, 2014). Global warming has the potential to alter the C balance of peatland systems, which consequently induces positive feedback (Kim et al., 2012; Weedon et al., 2013). Climate warming is generally assumed to favour primary production in peatlands (Belyea and Malmer, 2004). In addition, high temperatures are associated with greater increases in peat decay than net primary production. Thus, an increasing number of peatlands will become C sources rather than C sinks, which will have a positive effect on climate warming (Bu et al., 2011; Charman et al., 2013). Approximately one-third of northern peatlands are within permafrost regions (Smith et al., 2007), and they are more vulnerable to global warming than non-permafrost peatlands. Increased permafrost temperatures and the thickening of active layers by global warming may expose a large

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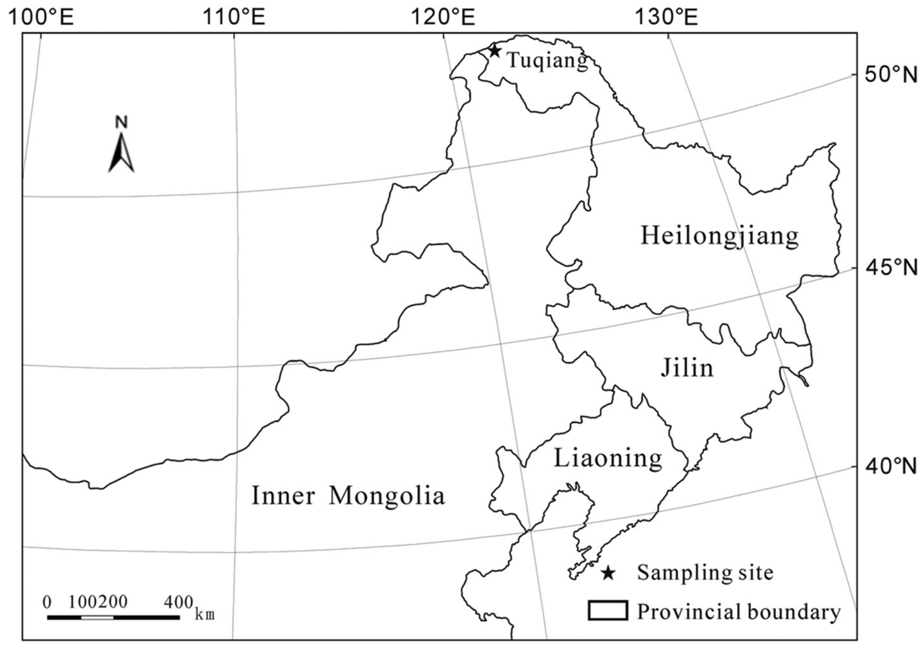

Fig. 1. Map of the sampling site on the Da Xing'an Mountains, Northeast China.

pool of stable C stored in permafrost to microbial decomposition (Schuur et al., 2008; Lee et al., 2011). On the other hand, the increase in permafrost melt water could potentially increase the total area of peatlands and influence soil organic C (SOC) flux rates by promoting peat formation in water-logged soil conditions (Rodgers, 2015). Understanding the variation and control of SOC in permafrost regions is critical for studying the C cycle and its potential feedbacks to climate change. Hence, the influence of temperature increases on SOM decomposition in permafrost peatlands should be investigated.

Temperature is a key factor that regulates almost all biochemical processes in terrestrial ecosystems, such as C mineralization, N mineralization, and soil enzyme activity. Recently, the temperature sensitivity of organic matter decomposition in peatlands has received considerable attention. Some experimental and observational studies have shown increases in C and N mineralization with increased temperature in peatlands (Rustad et al., 2001; Weedon et al., 2012). There is a clear need to clarify the driving mechanisms of soil mineralization in peatlands under warming conditions. Substrate availability is known to influence the temperature sensitivity of SOM mineralization (Weedon et al., 2013; Schütt et al., 2014). Labile C decomposes is depleted first, whereas the more complex and stable C dominates the decomposition occurring during later stages of the process (Thiessen et al., 2013). Soil enzymes are involved in rate-limiting steps of decomposition, and their catalysis, production, and degradation rates are regulated by temperature (Jing et al., 2014). Soil enzymes are being actively studied to determine microbial biomass dynamics and analyse the potential responses of soil C dynamics to climate change (Henry, 2012).

Furthermore, temperature is one of the most important factors controlling the root biomass of plants. The rates of plant root growth and mortality increase with temperature if other factors do not limit photosynthesis and respiration (Pregitzer et al., 2000). The root-derived C input is a key component of the soil C cycle because roots supply soil microbes with highly assimilable C-rich substrates that drive microbial decomposition processes (Kong and Six, 2010). Increased root input might result in an increase of soil C losses via heterotrophic respiration (Hu et al., 2016a). However, Hu et al. (2016b) found that increased root input helped increase C sequestration even as soil microbial respiration rates were stimulated. Moreover, the indirect effects of temperature-driven root inputs can potentially be more important controls on C cycle responses to warming than the direct temperature effects (Weedon et al., 2013). However, few data are available about these processes, and the response mechanisms remain unclear. Further studies are needed to understand the mechanisms underlying the effects of root-derived C input on soil C cycling in the context of temperature changes. Such studies would help us determine how warming will interact with the soil C that is provided via plants.

This study aimed to investigate the influence of temperature changes and root additions on soil C and N mineralization and the mechanisms driving mineralization in the peatland of the Da Xing'an Mountains, Northeast China. This peatland is located at the southern margin of the permafrost region of the Eurasian continent. Low temperature and frequent inundation considerably reduces the decomposition of litter and SOM, thereby accelerating peat deposition in this area. However, in recent decades, the permafrost boundary in this area has moved northward with the deepening of the active layer, and the total permafrost area has shrunk considerably since the 1970s (Jin et al., 2007). Such changes may influence the C and N turnover of the local permafrost peatlands. We hypothesized that (1) the stability of the soil C stocks would be proportional to the changes in the soil labile C fractions and enzyme activities induced by the increased temperature, and (2) adding root litter would not only increase soil C mineralization but also increase C accumulation due to the additional inputs of slowly decomposing C. In the current study, the soil C mineralization (as CO_2 evolution rates), N mineralization, ammonification, nitrification, microbial biomass C (MBC), dissolved organic C (DOC), and soil enzyme activity were measured at different temperatures and different soil layers. The effects of root additions on these parameters were also determined.

2. Materials and methods

2.1. Soil and plant root collection

In July 2013, the materials used for this study were sampled from a peatland at the northwest slope of the Da Xing'an Mountains of Northeast China (52°44′N, 122°39′E) (Fig. 1). The elevation of the site is 467 m. Based on long-term records from area weather stations, the annual average temperature from 1980 to 2009 was −3.9 °C. The annual average precipitation was 452 mm (Miao et al., 2012). The minimum monthly mean temperature at the site is −28.7 °C in January,