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Stellera chamaejasme L. increases soil N availability, turnover rates and microbial biomass in an alpine meadow ecosystem on the eastern Tibetan Plateau of China

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ABSTRACT

Plant species have been shown to have significant effects on soil nutrient pools and dynamics. *Stellera chamaejasme* L., a toxic perennial weed, has established and is now abundant in the alpine meadow on the eastern Tibetan Plateau of China since the 1960s. We quantified the effects of *Stellera* on carbon and nitrogen cycling in two topographic habitats, a flat valley and a south-facing slope, where *Stellera* was favored to spread within the study area. Aboveground litter biomass and tissue chemistry of aboveground litter and root were measured to explain the likely effects of *Stellera* on soil carbon and nutrient cycling. The sizes of various soil pools, e.g. nitrate, ammonium, inorganic phosphorus, microbial biomass, soil respiration and turnover rates including net mineralization, gross nitrification and denitrification were determined. The results showed that *Stellera* produced more aboveground litter than each of the co-occurring species. Aboveground litter of *Stellera* had higher tissue N and lower lignin:N than the other species. *Stellera* significantly increased surface soil (0–15 cm) organic matter, whereas no significant differences were found for organic C and total P in subsoil (15–30 cm) within and between patches of *Stellera*. Soil extractable nitrate concentrations in *Stellera* surface soil were 113% and 90% higher on the flat valley and on the south-facing slope, respectively. Both microbial biomass C and N were significantly higher in *Stellera* surface soil. Gross nitrification and microbial respiration were significantly higher in *Stellera* surface soil both on the flat valley and on the south-facing slope, whereas significant differences of denitrification were found only on the flat valley. The differences in the quantity and quality of aboveground litter are a likely mechanism responsible for the changes of soil properties.

1. Introduction

Plant species have been shown to have significant effects on nutrient dynamics (Hobbie, 1992; Vinton and Burke, 1995; Berendse, 1998; Evans et al., 2001; Ehrenfeld, 2003). Plant species affect carbon (C) and nitrogen (N) cycling and their net balances in ecosystems through several mechanisms, including the quantity of resources produced (i.e. net primary productivity, NPP), quality of resources produced, competitiveness against microorganisms for nutrients, formation and modification of habitats, and different plant characteristics, such as life-history, physiological traits and tissue chemistry (Scott et al., 2001; Ehrenfeld, 2003; Eviner, 2004). Aboveground and belowground litter quantity and quality play an important role in regulating soil C and N pool sizes and turnover rates through microbial biomass, composition and activity (Beare et al., 1990; Groffman et al., 1996; Grayston et al., 1998; Bardgett et al., 1999; Allisona et al., 2006). High NPP, commonly associated with high quantity of litter, often stimulates populations of microorganisms (Seastedt, 1988). Plant litter which has a high C:N ratio, high lignin and high phenolics tends to support low levels of microbial biomass and activity (Beare et al., 1990), low decomposition (Palm and Sanchez, 1991), low N mineralization and nitrification (Wedin and Tilman, 1990; Steltzer and Bowman, 1998) and low CO_2 and CH_4 flux (Verville et al., 1998; Wardle, 1999).

In grazed ecosystems, unpalatable plant species can increase in abundance and potentially alter soil nutrient dynamics, if their traits differ from the species they replace. *Stellera chamaejasme* L., a toxic perennial weed, is a dominant or common weed with an estimated area of 1.33×10^6 ha in western China. It has become one of the most serious weeds threatening a wide range of grasslands, which were grazed heavily (Liu et al., 2004). In particular, alpine meadows on the eastern Tibetan Plateau have been overgrazed during the last several decades and are suffering serious invasion of *Stellera*. One outcome of *Stellera* spread in this area is displacement of the dominant palatable *Kobresia* and *Poa* species, while its toxicity prevents it from being eaten by yaks (Liu et al., 2004). For these reasons, *Stellera* spread threatens productivity, conservation and ecological sustainability in wide range of meadows and

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grasslands on the Tibetan Plateau of China (Xing and Song, 2002; Liu et al., 2004).

Past research on *Stellera* has been focused on population distribution and dynamics (Xing and Song, 2002; Xing et al., 2002) and its allelopathic effects on forages (Zhou et al., 1998). However, the species' effect on soil properties is not known and could be one mechanism leading to its increased abundance.

Our primary objective in this study was to determine the pattern of changes of soil C and N pool sizes and turnover rates caused by the spread of *Stellera* under two topographic habitats in an alpine meadow ecosystem on the Tibetan Plateau of China. We were also interested in determining effects of productivity and tissue chemistry of *Stellera* on soil nutrient pools and processes such as microbial biomass, net N mineralization and availability and gross nitrification. We expected that nutrient availability and turnover rates would differ under *Stellera* and reflect plant litter quality, such as litter N, C:N and lignin:N and litter production. Such data provide valuable insights into likely changes in nutrient cycling and pools under different ecological conditions and also insights into how plant species drive the changes.

2. Materials and methods

2.1. Study area

Studies were conducted at the alpine rangeland of Anbei Village (N32°53′, E103°40′, 3170 m a.s.l.), about 35 km north of Songpan County on the eastern Tibetan Plateau. According to the records from the meteorological station (3300 m a.s.l.) near the study area, the annual mean temperature is 2.8 °C with a mean temperature of −7.6 °C in January and 9.7 °C in July. There is no absolute frost-free season and the annual mean time of solar radiation is 1827.5 h. The annual average accumulative temperature above 10 °C is 428.6 °C (degree–days). The annual precipitation is 717.7 mm, 72% of which falls in summer from June to August. The whole area consists of low hills and wide flat valleys. Vegetation is typical of alpine meadow and dominated by *Kobresia* and *Poa* species in the study area. Other common species include perennial grasses, *Clinelymus nutans* L., *Potentilla anserina* L. var. anserina; the shrubs, *Spiraea mongolica* Maxim. var. mongolica, *Cotoneaster horizontalis* L.; the forbs, *Polygonum sphaerostachyum* L., *Gentiana squarrosa* Ledeb., *Gentianopsis paluosa* (Munro) ma., *Delphinium tongolense* Franch., *Scutellaris hypericifolia* L. and *G. macrophylla* Pall. var. fetissowii (Sichuan Vegetation Research Group, 1980). The soil is a Mat Crygelic Cambisols (Chinese Soil Taxonomy Research Group, 1995), which consists of 19% clay, 66% silt and 15% sand.

The local people used the alpine meadow as winter rangeland (from yearly November to May) with very heavy grazing intensity in the last several decades. The presence of *Stellera* was not noted before the 1960s. However, since that time, *Stellera* has established and is now abundant on the flat valleys and on the south-facing slopes. *Stellera* has a stout, woody rhizome and clustered stems and tends to form well-defined patches. When sampling, the size of *Stellera* patches in the study area ranged from 15 cm to 25 cm. The distances between patches ranged from 20 cm to 50 cm. The cover of *Stellera* was 23% and total plant cover was about 100% on the flat valley, where the vegetation was still dominated by *Kobresia* and *Poa* species. On the south-facing slope, *Stellera* cover was 65% and total plant cover was 85%, so *Stellera* is the dominant species. *Stellera* is not present on north-facing slopes. For the protection and restoration, grazing has been prohibited in the study area by local government since the end of 2004. For assessing effects of *Stellera* on soil carbon and nutrient cycling in different topographic habitats, two study sites within the area were established in 2006. One was on the flat valley and another on the south-facing slope.

2.2. Sampling and analyses

2.2.1. Soil sampling and analyses

In August peak season of 2006, we randomly took 15 surface soil (0–15 cm) samples within *Stellera* patches and 15 samples between patches of *Stellera* both on the flat valley and on the south-facing slope. Meanwhile, we also randomly took nine subsoil (15–30 cm) samples within *Stellera* patches and nine samples between patches of *Stellera* on the flat valley and on the south-facing slope, respectively. When sampling, one *Stellera* patch was chosen randomly and then one patch which located 20–30 cm (considering distances between *Stellera* patches) away from the *Stellera* patch was chosen in random direction. Soil samples were kept at 4 °C in cool boxes to the laboratory. Sub-samples for water content, pH, organic carbon, total nitrogen, total phosphorus, ammonium, nitrate and inorganic phosphorus were processed on the next day of arrival. Sub-samples for microbial biomass carbon, nitrogen and phosphorus were frozen and processed within 30 days of sampling but frequently sooner. Each of 60 surface soil samples and 36 subsoil samples was analyzed.

Rates of *in situ* net N mineralization and net nitrification in August were determined in the field using the buried-bag technique (Eno, 1960). We chose 15 patches within and between *Stellera* randomly in each of two topographic habitats. In each sampling patch, aliquots of surface soil sample were sealed in a polyethylene bag and buried at a depth of 10 cm, aliquots were kept in cool box to the laboratory and analyzed for ammonium–N (NH_4^+–N) and nitrate–N (NO_3^-–N) as the initial sample for measurement of net mineralization and net nitrification. The soil samples in the buried bags were retrieved after 28 days of incubation and analyzed as the final sample. The difference between the initial and final inorganic N concentrations was used to calculate net N mineralization rates. The difference between the initial and final NO_3^-–N concentrations was used to calculate net nitrification rates.

We measured gross rates of nitrification, denitrification and microbial respiration using the Barometric Process Separation (BaPS) instrument (UMS GmbH Inc., Germany) through laboratory incubations. BaPS is based on the consideration that within an isothermal, gas-tight, closed system containing an intact soil core of an oxic soil, major changes in air pressure are due to the microbial processes of nitrification and denitrification and the nonbiological (physico chemical) process of CO_2 dissolving into soil solution. The oxidation of NH_4^+ to NO_3^- consuming molecular O_2 and, therefore, nitrification is a net gas-consuming process. Denitrification is a net gas-producing process, because denitrification produces CO_2 as well as gaseous N (N_2, N_2O, NO). Soil respiration is neither a net-producing nor a net gas-consuming process, because the amounts of O_2 consumed and CO_2 produced are identical. Thus, soil respiration itself will not lead to pressure changes within the system. However, CO_2 is produced in the soil and is not quantitatively emitted to the atmosphere. CO_2 will partly dissolve into soil solution and the pressure decrease due to this physicochemical process is also considered in the BaPS. Therefore, data of gross nitrification rates, denitrification and microbial respiration can be derived from measurements of changes (i) in air pressure within the closed system, which are primarily the result of the activities of nitrification (pressure decrease), denitrification (pressure increase), and respiration (pressure neutral), and (ii) of O_2 and CO_2 concentrations in the system (Ingwersen et al., 1999). We randomly chose nine patches within and between *Stellera* in each of two topographic habitats. In each patch, three intact soil cores were taken by soil containers with a diameter of 5.6 cm and a height of 4.1 cm. The soil containers were transported at coolers to the laboratory and processed immediately.

Soil texture was determined using the hydrometer method (Gee and Bauder, 1986). Fresh soil samples were sieved to separate plant