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Responses of ecosystem respiration to nitrogen enrichment and clipping mediated by soil acidification in an alpine meadow

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ABSTRACT

Clipping is one of the most important land-use practices in grassland ecosystems, yet the extent of clipping effect on ecosystem carbon (C) cycles depends on its interaction with nitrogen (N) deposition in future global climate change scenario, especially in the N-limited alpine meadow ecosystem. We conducted a field N addition (40 kg N ha^{-1} yr^{-1}) and clipping experiment in an alpine meadow on the northern Tibet Plateau to investigate the effects of exogenous N input and clipping on ecosystem (Re) and soil respiration (Rs). Generally, N enrichment enhanced Re, Rs and aboveground biomass (AGB) in the second year of the experiment, but the extent of the enhancements decreased from the third year of the experiment. Clipping didn't affect Re, Rs and AGB relative to the control, while clipping and N addition significantly increased belowground biomass. Soil inorganic N increased, while soil pH decreased with the year of N additions. Significant positive correlations of aboveground biomass with Re and Rs suggest the increase of plant photosynthetic C fixation under N addition is a key force in driving thus ecosystem CO_2 efflux. However, the positive correlation between soil pH and aboveground biomass indicated soil acidification could be one of important factors decelerating the positive responses of plant growth to soil N availability increase. All the results suggest soil acidification due to N addition influenced the effects of N enrichment and clipping on ecosystem CO_2 efflux through modulating plant growth and photosynthetic C allocation.

1. Introduction

Nitrogen (N) is a limiting resource for plant growth and productivity in many terrestrial ecosystems (Frink et al., 1999; Vitousek and Howarth, 1991). However, soil N availability is increasing due to the increasing atmospheric N deposition. For example, atmospheric N deposition is very dramatic on the eastern Qinghai-Tibetan Plateau region, ranging from 8.7 to 13.8 kg N ha^{-1} yr^{-1} (Lü and Tian, 2007). Meanwhile, N fertilization has been widely used to restore the productivity and improve the forage quality of degraded grasslands (Conant et al., 2001; Schellberg et al., 1999). Generally, appropriate rate of N application can enhance plant production and provide more forage production (LeBauer and Treseder, 2008; Xia and Wan, 2008). Previous studies demonstrated that N addition can initially increase ecosystem and soil CO_2 efflux (Contosta et al., 2011; Peng et al., 2011; Graham et al., 2014), which causes decline of soil carbon (C) sequestration. However, studies on long-term responses of plant production and ecosystem CO_2 efflux to N addition in alpine meadow ecosystems are still lacking.

Generally, chronic external N input may affect the stability and diversity of ecosystem (Blake et al., 1994; Stevens et al., 2010), due to the alteration of soil physico-chemical environment (Guo et al., 2010a, 2010b; Phoenix et al., 2012). A meta-analysis in forest ecosystems reported that N-induced soil acidification can lead to leaching of calcium (Ca^{2+}) and magnesium (Mg^{2+}), and activation mineral-associated aluminum (Al^{3+}), which influence forest production and soil microbial activities due to the limitation of mineral cations and/or Al^{3+} toxicity (Aber et al., 1998; Lucas et al., 2011). More recently, large-scale comparisons using historical data

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indicated that anthropogenic N deposition have led to 0.61 unit decline of soil pH (also called soil acidification) in alpine meadow on the Tibetan Plateau during the last two decades (Yang et al., 2012). However, comparison studies on initial and short-term effects of N addition are still lacking, especially for in-situ N addition studies coupled with other land use practices.

Mowing, also known as clipping, is one of the most prevalent land-use practice in grasslands, and has the potential to substantially alter C cycling (Niu et al., 2013). Clipping frequently remove plant aboveground tissue, which could decrease temporarily soil CO_2 efflux (Bahn et al., 2008). However, at annual time scale Rs was found to be higher at mowed sites compared to grazed sites, and higher soil respiration under mowing than under grazing explained by biomass differences (Bahn et al., 2008). Therefore, effects of N addition together with clipping on plant productivity and ecosystem CO_2 efflux should be accurately assessed in grasslands. Plant photosynthate, such as root exudates is a major driver of the short-term dynamics of soil communities (Bardgett and van der Putten, 2014). Resource pulses from root exudates can drive short-term temporal dynamics of soil biota, with consequences for nutrient cycling and plant nutrient supply (Bardgett and van der Putten, 2014). Previous studies showed, for example, that the time between photosynthesis and the transfer of photosynthate from plant leaves to soil organisms is extremely rapid, only taking hours in grassland (Bahn et al., 2009) or days in forests (Högberg et al., 2010). In addition, as much as half of the photosynthate can be released from soil by respiration within several hours or days (Högberg et al., 2010; Pollierer et al., 2007). Root exudation is also stimulated by biotic interactions with foliar foraging (such as grazing or clipping) (Hamilton and Frank, 2001), which trigger short-term pulses of soil microbial activity and C cycling in the rhizosphere (Guitian and Bardgett, 2000; Bahn et al., 2006; Mikola et al., 2009). N enrichment generally increases plant photosynthetic C fixation which may enhance allocation of photosynthetic C to root exudates, and thus raise soil CO_2 efflux. However, it is still unknown how changes in plant photosynthetic C and its allocation due to N addition and clipping affect ecosystem CO_2 efflux.

The Tibetan Plateau covers about 2.5 million km^2 with average altitude more than 4000 m, 35% of which is occupied by alpine meadow (Zheng, 2000). Slow decomposition rate of soil organic matter in alpine ecosystem is mainly constrained by low temperature, which leads to the shortage of available nutrient to alpine plant growth (Cao and Zhang, 2001; Jiang et al., 2013). Due to climate change and overgrazing during the last decades, some alpine meadow pastures on the Tibetan Plateau have been severely degraded (Cao et al., 2011; Wu et al., 2014, 2010). In addition, land-use change is another important factor which could fundamentally alter ecosystem C cycling and its response to climate change (Chapin et al., 2008). Clipping is one of the most prevalent land uses in grasslands, and has the potential to substantially change ecosystem C cycling (Bai et al., 2010; Niu et al., 2013). The extent of clipping effect on ecosystem C cycles depends on its interaction with N deposition in future global climate change scenario. However, knowledge on the interactive effects of N addition and clipping on ecosystem C cycles is still lacking.

We conducted a N addition and clipping experiment in an alpine meadow ecosystem on the Tibetan Plateau from 2010. We measured Re and Rs in three consecutive years from 2011 to 2013. We also measured plant above- and belowground biomass and soil pH. We aimed to (1) test the initial (1–2 years) and short-term (3 years) effects of N addition and clipping on ecosystem respiration (Re) and soil respiration (Rs) as well as soil properties; (2) explore the drivers underlying the response of Re and Rs to long-term N addition and clipping. We hypothesized that the effects of N addition on ecosystem CO_2 efflux are different in the initial (1–2 years) and short term (3 years), which regulated the effects of clipping on ecosystem C cycling.

2. Materials and methods

2.1. Site description and experiment design

Studies were conducted in the grassland station of Damxung County (91°05′ E, 30°51′ N, 4333 m a. s. l.) in the south-facing slope of Nyaiqentanglha Mountains, mid-south of the Tibetan Plateau. Detailed information of study site can be found in Shi et al. (2006) and Jiang et al. (2013). Briefly, the climate in this site is characterized as semi-arid alpine continental type. Mean annual temperature is 1.3 °C with a minimum of −10.4 °C in January and a maximum of 10.7 °C in July. Annual precipitation is 477 mm, 85% of which is concentrated from June to August. The soil is classified as Mat-Gryic Cambisol, corresponding to Gelic Cambisol, with a depth of about 0.3–0.5 m. Soil particle composition is 67.02% of sand, 18.24% of silt, and 14.74% of clay (Fu et al., 2012). Detailed soil properties can be found in Zong et al. (2014).

An area of 50 m × 50 m alpine meadow, with vegetation cover about 30–50%, was selected for N fertilization and clipping experiment in early July 2010. Dominant species are *Kobresia pygmaea* C. B. Clarke var. *pygmaea*, *Stipa capillacea* Keng and *Carexmontis everestii* Kükenth. Complete randomized block design was used for N addition and clipping manipulation. We established four blocks, and four 3 m × 3 m split plots were set up in each block. Two-meter aisles were left as buffering zones between the adjacent plots. The four plots in each block were assigned randomly for the following N addition and clipping treatments: control (CK), N addition (40 kg N ha^{-1} yr^{-1}, N), clipping (C), N addition (40 kg N ha^{-1} yr^{-1}) combined with clipping (N + C). N application rate is roughly equal to 4 times of the current levels of N deposition (Lü and Tian, 2007; 8.7–13.8 kg N ha^{-1} yr^{-1}) and designed to approximate projected atmospheric deposition in this region by the year of 2050 (Galloway et al., 2004). Our previous study indicated that N saturation thresholds for alpine meadow, in terms of plant cover and biomass change at the community level, were 50 kg N ha^{-1} $year^{-1}$ (including the ambient N deposition rate 10 kg N ha^{-1} $year^{-1}$) (Zong et al., 2016). It means that plant production reaches maximum when N addition rate is 40 kg N ha^{-1} yr^{-1}, and at this dose of N grassland can provide maximum forage for livestocks.

N fertilization and clipping were started in early July 2010. N was applied as NH_4NO_3 in aqueous solution using sprayers (18 L in each plot), twice during each growing season with each half added in early June and early August. The addition of water to each plot represented a 6-mm increase in precipitation, or approximate 1.2% of annual precipitation, well within the magnitude of inter-annual variations (Zong et al., 2014). The same amount of water was also sprayed to the control and clipping plots.

We clipped the plots twice in early June and early August, at the same day before each N addition treatment. Plants were manually clipped to about 0.5–1.0 cm height above the ground with scissors, which is similar to the plant height grazed by animals (yak) outside the fence. In addition, only species with palatable edibility for livestock were clipped, such as grasses and sedges. Totally, we removed about 15–20% of the live peak aboveground biomass from each clipping plot.

2.2. Measurement of ecosystem CO_2 efflux, plant production and cover

Ecosystem respiration (Re) and soil respiration (Rs) data were measured in each collar by a LI-COR 8100 Automated Soil CO_2 Flux System (LI-COR Inc., Lincoln NE, USA) in the field. The system was