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Effects of land use on soil respiration in the temperate steppe of Inner Mongolia, China

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ABSTRACT

Land use change has greatly affected ecosystem C processes and C exchanges in grassland ecosystems. The aim of this study was to determine the effects of land use (mowing, grazing exclusion, and grazing) on soil respiration (R_s) of a semi-arid temperate grassland during two growing seasons in Inner Mongolia, northern China, and to identify the main factors that affected R_s. During the growing season, R_s for the mowing, grazing exclusion, and grazing land-use types averaged 129, 150, and 194 g C m^{-2} yr^{-1}, respectively, in 2011 (a dry year), versus 309, 272, and 262 g C m^{-2} yr^{-1}, respectively, in 2012 (a wet year). Root respiration (R_r) accounted for 13–55% of R_s in 2011, versus 10–62% in 2012. R_s was strongly positively correlated with soil moisture for all three land uses, but weakly correlated with soil temperature ($R^2 < 0.4$ in all cases). R_s was significantly positively correlated with aboveground biomass ($R^2 = 0.834$), soil organic matter ($R^2 = 0.765$), root biomass ($R^2 = 0.704$), lignin mass loss rate ($R^2 = 0.422$), and the cellulose mass loss rate ($R^2 = 0.849$) and significantly negatively correlated with the litter C/N ($R^2 = 0.609$). The temperature sensitivity (Q_{10}) exhibited large monthly changes, and ranged from 0.52 to 2.12. Rainfall plays a dominant role in soil respiration: precipitation increased soil respiration, but the response differed among the land-use types. Thus, soil water availability is a primary constraint on plant growth and ecosystem C processes. Soil temperature plays a secondary role. Litter decomposition rates and litter quality also appear to be important.

1. Introduction

Soil respiration is one of the main terrestrial contributors to CO_2 fluxes in the global carbon cycle. This process returns about 80 Pg C back to the atmosphere every year (Raich et al., 2002). This released carbon (C) plays an important role in global C cycling and therefore affects climate change (Valentini et al., 2000). Because of this large mass, even small proportional changes in soil respiration may greatly affect soil carbon sequestration and atmospheric carbon exchange (Raich and Schlesinger, 1992). Grassland ecosystems, which account for more than 40% of the global landscape and store large amounts of soil C, are influenced strongly by both anthropogenic activities such as grazing management and cultivation and by global changes in climatic factors such as precipitation and temperature (Flanagan et al., 2002; Fay et al., 2008; Casasovas et al., 2012). Changes in these ecosystems that affect C sequestration can therefore have significant global effects.

Grasslands in China cover nearly 4×10^6 km^2, more than 40% of its total land area. The temperate arid and semi-arid grasslands of Inner Mongolia comprise the main body of temperate grassland in northern China, and play an important role in livestock farming and environmental conservation (Akiyama and Kawamura, 2007). However, the expanding human population and changing lifestyles (e.g., increased consumption of both vegetables and meat) in this region have contributed to widespread conversion of grassland into cropland or grazing land, and unsustainable use of grasslands for these purposes has led to ecosystem degradation (Zhou et al., 2007). These changes have undoubtedly greatly affected ecosystem C processes, and particularly the exchanges of C between the atmosphere and the terrestrial C pools in aboveground and belowground biomass and soils (soil organic matter, including surface litter); they have also affected leaf- and canopy-scale photosynthesis, vegetation cover, community species composition, ecosystem productivity, and nitrogen utilization, all of which have

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consequences for soil C and biogeochemical cycles (Houghton et al., 1999; Zeller et al., 2000; Wohlfahrt et al., 2003; Ingram et al., 2008; Ciais et al., 2011).

Grazing and mowing are two of the most important land-use types that affect ecosystem C processes and alter C exchange in grassland ecosystems (Han et al., 2012; Zhang et al., 2012). They also have considerable effects on soil CO_2 efflux and its components (Aatonsen and Olsson, 2005; Zhou et al., 2007). The mechanisms for how a given land use affects soil respiration are complex and will vary among vegetation and soil types; they will also be affected by climatic changes. The potential changes in soil CO_2 efflux associated with changing land use and climatic factors such as precipitation depend on the relative contributions of the autotrophic and heterotrophic components of soil respiration. Changes in land use and climatic factors can affect soil respiration by changing the soil microclimate, canopy photosynthesis, the loss or gain of aboveground litter, and the soil's temperature sensitivity, and all of these changes can affect root and microbial respiration (Bremer et al., 1998; Wan and Luo, 2003; Zhou et al., 2007; Han et al., 2012).

Precipitation is one of the most important factors that affect the structure and functioning of grassland soils (Knapp et al., 2008; Fay et al., 2008). Because the amounts and patterns of precipitation vary from year to year, this variation affects soil moisture and plant biomass, and further influences the soil's characteristics and microbial activity (Liu et al., 2002; Chimner and Welker, 2011). The soil's characteristics and microbial activity are important factors that control soil respiration and C cycling in grasslands (Ingram et al., 2008). Precipitation affects the soil's carbon cycle by affecting soil moisture, which in turn affects plant and microbial activity. The soil's water storage capacity depends on the vegetation type, vegetation cover, and soil properties, so the response of soil moisture to precipitation varies among the different types of grassland use. However, few studies have focused on the direct or indirect effects of land use and precipitation on soil respiration. To provide more information, we performed a field study in northern China during two years with very different annual precipitation levels: 188 mm in a drought year and 465 mm in a wet year. This allowed us to investigate the effects of precipitation variation on soil respiration.

Soil respiration comprises both the heterotrophic respiration by microorganisms, which decompose organic residues and mineralize humus substances, and autotrophic respiration, which represents the production of CO_2 associated with root growth and metabolism (Hanson et al., 2000; Wang et al., 2006b). The contribution of root respiration to the total soil respiration ranges from 10 to 90%, depending on the vegetation type and season (Hanson et al., 2000; Frey et al., 2006). These processes are controlled by a range of abiotic and biotic factors such as water availability, photosynthetic activity, soil temperature, the supply of metabolic substrates, soil moisture, vegetation, soil texture, litter biomass, microbial biomass, carbon content, and management practices (Lloyd and Taylor, 1994; Buchmann, 2000; Stoyan et al., 2000; Li et al., 2008). The decomposition of dead organic matter by soil organisms and the litter's chemical composition are important factors that determine the decomposition rate (Teklay et al., 2007). Tewary et al. (1982) reported that litter quality affected soil respiration rates, but this has not been demonstrated (Raich and Tufekcioglu, 2000). In addition, soil respiration and its components usually exhibit intra-annual (seasonal) and interannual variability (Wang et al., 2006a). Understanding the seasonal and interannual variability and their responses to simultaneous changes in climate will improve predictions of ecosystem C cycling. Therefore, estimates of the components of soil CO_2 efflux and their responses to climate change are required for us to understand the influences of land use on soil respiration. This improved understanding of the carbon budget of grasslands will let us identify the most favorable land uses and management strategies to balance forage production with environmental conservation objectives.

In the present study, we investigated soil respiration in a temperate grassland of northern China under different land uses to determine the effects of these land uses on soil respiration. The overall objective was to explore the effects of land use, precipitation, and soil temperature on soil and root respiration of temperate grasslands in Inner Mongolia. Our specific objectives were (i) to clarify the seasonal and interannual responses of soil respiration under different land uses, (ii) to clarify the responses of soil respiration to precipitation changes for a given land use, (iii) to distinguish the contributions of roots and microbes to soil respiration, and (iv) to clarify the relationship between litter quality and soil respiration.

2. Materials and methods

2.1. Study site

Our study was conducted during the 2011 and 2012 growing seasons at a long-term experimental site managed by the Grassland Ecosystem Research Station of Inner Mongolia University (116°02′E–116°30′E, 44°48′N–44°49′N). The study site is located in relatively flat land in the middle reaches of the Xilin River at an average elevation of 1505 m. The region has a semi-arid continental temperate steppe climate with a dry spring and a moist summer. The mean annual precipitation is 300 mm, with more than 70% falling during the growing season from June to August. The mean annual air temperature was 1.7 °C, with an extreme minimum temperature of −42.4 °C in January and an extreme maximum temperature of 38.3 °C in July.

Three adjacent measurement sites were established in the study area: a grazing-exclusion site, a mowing site (in which the grass is mowed to provide fodder), and a grazing site. The study site was divided into three blocks. The 15-ha grazing-exclusion site has been fenced since 2008. The 14-ha mowing site was protected from grazing, and was mowed in August of each year. The 15-ha grazing site was grazed by 11 sheep (light grazing) throughout the year. The area is dominated by *Stipa grandis*, *Leymus chinensis*, and *Artemisia frigida* (Table 1). The sandy loam soil was classified as a chestnut soil (USDA), with an average depth of 80 ± 6 cm. The water table at our study site typically lies at a depth of 20–30 m; therefore, the water table was well below the rooting zone throughout our measurements. The soil organic matter (SOM) content is 2–3%. The soil characteristics that we measured at each site are described later in the Methods. We measured these and other parameters during the growing season, from May to September, in 2011 (a drought year, with 188 mm of total annual precipitation) and 2012 (a moist year, with 465 mm of total annual precipitation).

2.2. Soil respiration

We randomly selected eight sample plots at each site, but with the constraint that the plots were located at least 5 m from the

Table 1
Importance value (see Eq. (1)) for the dominant species at the three study sites (values are mean ± SE, $n = 5$). Values for a species followed by different letters differ significantly between the three treatments (LSD test, $p < 0.05$).

Dominant species	Grazing-exclusion	Mowing	Grazing
Artemisia frigida	0.11 ± 0.08b	0.16 ± 0.07a	0.06 ± 0.01c
Leymus chinensis	0.08 ± 0.12c	0.14 ± 0.04b	0.22 ± 0.05b
Stipa grandis	0.07 ± 0.08c	0.10 ± 0.02b	0.15 ± 0.08a