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Topographic influences on shoot litter and root decomposition in semiarid hilly grasslands

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ABSTRACT

Topography has strong effects on microclimates; thus may influence the decomposition of organic matter, a key process determines soil nutrient availability and carbon fluxes in terrestrial ecosystems. Yet, little is known if and how topographic factors influence litter decomposition. We studied the effects of slope aspect (south- vs. north-facing slopes) and position (base and middle positions) on plant shoot litter and root decomposition. We analyzed dynamics of litter mass loss in a 442-day period, and soil and vegetation characteristics in a typical semiarid hilly grassland. Our results showed that the decomposition of roots was faster at south-facing than at north-facing sites, which can be explained by the 2 °C higher soil temperature at south-facing sites. Decomposition rate of shoot litter were not different between slope aspects. North-facing sites had 76% higher aboveground biomass and 80% higher belowground biomass than those at south-facing sites. Accordingly, plant N and C storages at north-facing sites were 67% and 76% higher than those at south-facing sites, respectively. The smaller plant carbon and nitrogen stocks and the faster root decomposition at south-facing slopes suggest higher proportions of plant C and N are lost from the ecosystem than that at north-facing slopes. This work highlights the necessity of taking slope aspect into account in carbon and nitrogen cycling studies in hilly grasslands.

1. Introduction

Decomposition of organic matter, particularly plant shoot litter and dead roots, is an important component of terrestrial carbon cycle. Together with primary production, it determines the soil carbon stocks and thus carbon balance in terrestrial ecosystems (Aerts, 1997; Austin and Vivanco, 2006; Prescott, 2010). Moreover, decomposition of organic matter is the major source of soil nutrients in most terrestrial ecosystems (Lambers et al., 1998). However, little is known if and how topography, e.g. slope aspect and position on the slope, influences decomposition process. Given the fact that large areas of terrestrial ecosystems are characterized by high relief dynamics, this knowledge is important for assessing and modelling carbon and nutrient cycling at ecosystem- or regional-scale.

Slope aspect influences microclimates, including near surface temperature, evaporative demand and soil moisture content (Bennie et al., 2008), which are mainly due to the difference in the amount of solar radiation intercepted. In the northern hemisphere, south-facing slopes are exposed to more direct sunlight, thus are dryer and warmer than north-facing slopes (Bennie et al., 2006; Gong et al., 2008). These topographic influences on microclimates likely affect decomposition rate, since climate (i.e. precipitation and temperature) and litter quality have been identified as the driving factors of litter decomposition (Aerts, 1997; Gholz et al., 2000; Zhang et al., 2008). Topographic microclimates are particularly relevant in semiarid/arid ecosystems, since the predicting power of litter quality was found to be low, and climatic factors are the major determinants of decomposition dynamics in those ecosystems (Giese et al., 2009; Parton et al., 2007). Moreover, it has been reported that slope aspect affected ecosystem properties including vegetation structures (Badano et al., 2005; Cantlon, 1953), primary production and plant species composition (Bennie et al., 2006; Gong et al., 2008), and soil properties (Casals et al., 1995; Kolbl et al., 2011). Knowledge on decomposition process may provide new insights for the topographical influences on ecosystem processes.

In Inner Mongolian steppes, hilly grassland represents an important landform which constitutes approximately 40% of the total area of the Xilin River Basin (Chen, 1988). In this semiarid ecosystem, primary production is constrained mainly by precipitation and secondarily by nitrogen availability (Bai et al., 2004; Chen et al., 2011; Gong et al., 2011).

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Grazing, as the dominant land-use practice, has led to net nitrogen losses in semiarid steppes (Giese et al., 2013). Thus, the decomposition process, as the main source of soil nitrogen (Giese et al., 2013), is particularly important for the maintenances of soil N availability and primary production in typical steppe ecosystems. Moreover, higher plant aboveground biomass (Gong et al., 2008) and thicker soil A-h layer at north-facing than at south-facing slopes are likely common features of semiarid hilly steppes (Gong et al., 2008; Wang and Cai, 1988). Although data of plant belowground biomass in hilly steppes have not been reported, these results indicate that net primary production and the properties of C and N cycling may differ between slope aspects. Thus decomposition, a key process related to plant production and soil C and N storage, should be studied at topographical sites.

In this study, the effects of slope aspect (south- and north-facing slopes) and position (base and middle positions) on plant shoot litter and root decomposition were studied by analysis of mass loss in litter bags during a period of 442 days in a semiarid hilly grassland. Time-courses of mass loss were fitted using exponential decay models, and the dynamic of decomposition at topographical sites were compared. Site-specific environmental parameters (i.e. soil water content and soil temperature) were monitored, and plant aboveground- and belowground biomass, and C and N storages were measured. We tested the hypotheses that, 1) the decomposition of shoot litter and roots are faster at south-facing than at north-facing slope, given that soil temperature was found to be higher at south-facing slope; and 2) plant carbon and nitrogen storages are higher at north-facing than at south-facing slope. The second hypothesis follows from the prediction that plant production is much higher at north-facing than at south-facing slope.

2. Material and methods

2.1. Study area and sites

The study area is located in Xilin River Basin (43°26′–44°29′N, 115°32′–117°12′E) of the Inner Mongolia grassland, which has a semiarid, continental climate. Long-term annual mean air temperature is 0.7 °C and annual mean precipitation is 343 mm (from 1983 to 2003) measured at Inner Mongolia Grassland Ecosystem Research Station (Table 1). More than 85% of the annual precipitation occurs between May to September, thus the climate conditions define a period of about 5 months as the annual growing season for plants. During winter time, snow cover is not a common landscape feature in the study area. According to the observations in 2005 and 2006, soil was frozen during the period of November to April; snow cover was shallow (<7 cm) and lasted only 1.5 months (Zhao et al., 2013). The dominant soil types are Calcic Chernozems derived from aeolian sediments above volcanic rock (Steffens et al., 2008). This study was carried out in 2004 and 2005, which included a year with a medium amount of precipitation (325 mm in 2004) and a dry year (166 mm in 2005) (Table 1).

Experimental sites located at 4 topographic positions of a hill (Fig. 1), including the base position of the south-facing (BS) and north-facing (BN) slopes, and the middle position of the south-facing (MS) and north-facing (MN) slopes, with five plots (about 3 × 3 m per plot) at each site as replicates. This hill is representative of the hilly steppes under long-term local grazing management (stocking rate of about 4.3 sheep ha^{-1}). During the growing season of 2004 and 2005, all sites were uniformly and continuously grazed with the same stocking rate, thus plant biomass presented in this paper is standing biomass. The dominant species were *Stipa grandis* P. Smirn., *Cleistogenes squarrosa* (Trin.) Keng, *Artemisia frigida* Willd., *Carex korshinskyi* Kom., *Potentilla acaulis* Linnaeus, and *Leymus chinensis* (Trin.) Tzvel..

Topographic and soil attributes of the sites are given in Table 2. The altitude of experimental sites ranged from 1200 m (base position) to 1230 m (middle position) (Fig. 1), and the slope angle of topographic sites are shown in Table 2. All topographic sites had similar soil texture of sandy loam or loamy sand (Table 2) and similar soil pH (ranged between 6.0 and 6.5). MS had a soil type of Haplic Regosol with a A-horizon depth of 28 cm; while the other sites had a soil type of Haplic Kastanozem with A-horizon depths >80 cm (BS, 89 cm; MN, 80 cm, BN, 90 cm), according to FAO's world reference base for soil resources (FAO, 2006). North-facing sites (BN and MN) had higher total N and C content in soil, and plant available P and K compared to south-facing sites (BS and MS).

Table 1
Annual precipitation and growing season precipitation, mean annual air temperature and mean growing season air temperature in 2004 and 2005, and long-term means (1983–2003) in the study area.

	Precipitation (mm)			Air temperature (°C)		
	2004	2005	1983–2003	2004	2005	1983–2003
Annual	325	166	343	1.9	0.9	0.7
May–Sep.	288	126	294	15.1	16.7	15.0

2.2. Plant and soil sampling

The standing biomass of plants was measured at the end of the growing season, when it reached maximum amount in years with moderate precipitation. Plant aboveground green biomass (AGB) was sampled on 7 Sep. 2004 and 3 Sep. 2005. AGB was determined by clipping all plants of 1 m^2 at the soil surface in each plot (5 replicates per topographic position) and separating green parts from standing dead biomass and litter, then measuring the dry mass after drying at 80 °C for 48 h.

Root samples were taken on 11 Sep. 2004 and 6 Sep. 2005. A soil core of 0–20 cm depth was sampled at each plot using a metal auger with a diameter of 25 cm. Soil samples were put into mesh bags (mesh width 0.2 mm) and washed to remove the soil. Samples were then transferred onto a 0.2 mm sieve to separate roots from litter material, debris and stones. A sub-sample of roots was taken to determine the root length density of living roots (RLD) by the line intersect method (Tennant, 1975). Finally, root samples were oven-dried at 80 °C for 48 h to determine belowground biomass (BGB), which includes living and dead roots.

Plant aboveground and belowground dry matters were milled in a micro hammer mill (Culatti, Zürich, Switzerland) and afterwards in a ball mixer mill (MM200, Retsch, Germany). The nitrogen and carbon contents were analyzed by an elemental analyzer (EA1108, Carlo Erba, Italy). Plant above- and below-ground carbon- and nitrogen stocks were quantified by multiplying AGB and BGB with their C and N concentrations.

In order to survey physical and chemical soil characteristics, soil samples were taken from the surface down to 20 cm depth on 25 May 2005. At each topographic position 10 soil cores were collected (2 cores per plot) with a soil auger of 3 cm diameter and pooled for the determination of total N and C, and plant available P ($NaHCO_3$ extraction, Olsen) and K (NH_4OAc extraction) (Table 2). Soil particle size was analyzed by a laser grain-size analyzer (MasterSizer 2000, Malvern Instruments Co, Ltd., Worcestershire, United Kingdom). Soil particle size was classified into sand (0.02–2 mm), silt (0.002–0.02 mm), and clay (<0.002 mm) according to the classification of the International Soil Society (ISSS).

Soil samples (0–20 cm) were collected monthly in 2005, and were analyzed for soil mineral nitrogen concentration (N_{min}). Fresh soil samples were extracted with 0.01 M $CaCl_2$ and the extract was analyzed for nitrate and ammonium concentrations by an auto-analyzer (TRAACS 2000, Bran Luebbe, Nordstadt, Germany). N_{min} was calculated as the sum of nitrate and ammonium concentrations.

Soil water content in 0–7 cm depth was measured weekly using an ML2× soil moisture sensor (Thetaprobe, UK). Soil temperature was continuously logged every 3 h at 15 cm depth at each sampling site with temperature loggers (Kooltrak, Sweden).