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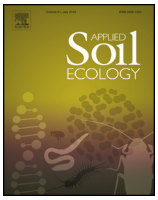

Effects of land use and precipitation on above- and below-ground litter decomposition in a semi-arid temperate steppe in Inner Mongolia, China

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ABSTRACT

Land use greatly affects litter production, quality, and decomposition rates, and therefore alters the soil carbon stocks and influences ecosystem carbon cycling. In this study, our aims were to investigate the effects of land use (grazing, mowing, and grazing exclusion), litter types, and precipitation on litter production, decomposition processes, and soil carbon stocks. Litter inputs, quality, and decomposition rates were significantly influenced by land use and differed greatly between 2011 (a dry year) and 2012 (a moist year). Above-ground litter production in 2012 ranged from 165 to 180 g m^{-2}, versus from 50 to 73 g m^{-2} in 2011; below-ground litter production in 2012 was 1.9 to 6.0 times that in 2011. Decomposition rates of above-ground litter (k_a) were greater than those of below-ground litter (k_b). The k_a in 2012 was 1.9 to 2.8 times those in 2011 and k_b in 2012 was 6.5 to 10.8 times those in 2011. The k_a was strongly positively correlated with the N content ($R^2 = 0.713$) and strongly negatively correlated with the C/N ratio ($R^2 = 0.585$), whereas k_b was explained best by the C/N ratio. Precipitation was a main factor that controlled ecosystem C cycling processes, and increased litter decomposition increased soil carbon stocks. Land use therefore played an important role in litter input and decomposition processes and in carbon sequestration, but these processes responded to the initial litter quality and precipitation.

1. Introduction

Grassland ecosystems, which cover 40% of the global land surface and store large amounts of soil carbon (C), are important components of terrestrial nutrient cycling and are influenced strongly by anthropogenic activities and climate change (Bontti et al., 2009). Litter decomposition is a critical ecological process for nutrient cycling in terrestrial ecosystems, as it regulates the turnover and fate of C, soil formation, and the availability of nutrient needed by plants and soil microorganisms (Mincheva et al., 2014). Decomposition processes are governed by a range of biological and environmental factors, including the complex nature of the decomposer community, litter quality, and the physical and chemical characteristics of the environment (Smith et al., 2014). However, the relative importance of those factors varies with the scale at which they are examined (Cleveland et al., 2014). Thus, identifying the key factors that control decomposition rates is fundamental to quantitative analysis of C and nutrient cycling in terrestrial ecosystems (Peh et al., 2012).

Grazing and mowing to produce fodder are two of the most important land uses in grasslands. Long-term grazing and mowing activities can affect litter decomposition directly, by altering the plant species composition and soil decomposer community, or indirectly, through changes in soil properties such as soil temperature and water availability (Solly et al., 2014). Several studies have shown that less-productive areas that are lightly grazed by herbivores tend to be dominated by tougher, lower-quality plant species, resulting in slower decomposition rates (Haynes et al., 2014). In contrast, more frequent cutting can promote decomposition by increasing the N concentrations in leaves (Walter et al., 2013). However, no clear consensus exists regarding the relationship between land use and litter decomposition rates (Zhang et al., 2013).

Environmental changes, and especially climate change, could exert strong and rapid effects on both abiotic and biological parameters, which could in turn modify the responses of litter decomposition to land uses such as grazing and mowing (Benot et al., 2014). At regional to global scales, climate change can control decomposition rates by altering organic matter decomposition in the

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soil, but also by altering the quantity and quality of inputs of plant litter (Ward et al., 2015). Thus, the combination of climate change and land-use change will affect litter decomposition in temperate grasslands, possibly in synergistic ways (Benot et al., 2014). In the present 2-year study, annual precipitation levels differed greatly between the 2 years: 188 mm in a drought year (2011) and 465 mm in a moist year (2012). This difference allowed us to investigate the effects of precipitation on litter decomposition.

In temperate grasslands, the contribution of roots to litter decomposition is important, because C inputs from roots can be up to three times the inputs from above-ground parts (Freschet et al., 2013). However, our understanding of litter decomposition is almost exclusively based on studies of above-ground plant material (Smith et al., 2014), and little is known about how climate and litter quality control the decomposition of below-ground root biomass (Solly et al., 2014). In addition, it is important to consider differences between the rates of above-ground and below-ground litter decomposition in grasslands to avoid underestimation of the total ecosystem decomposition (Bontti et al., 2009).

To better understand the effects of land use on litter decomposition processes in grassland ecosystems, we determined the production, quality, and decomposition rates of above-ground and below-ground (root) litter, and the associated changes in soil organic carbon at three land uses (grazing, mowing and exclusion) in China's Inner Mongolia autonomous region. Our overall goal was to define the main factors that regulate litter decomposition processes under these different land-use types. We hypothesized that litter production, decomposition rates, and soil carbon stocks would be higher at the grazing exclusion site than at the other sites. Furthermore, we hypothesized that above-ground litter would decompose faster than root litter due to its high nutrient content and low lignin content. We also hypothesized that decomposition rates would increase with increasing precipitation due to the improvement of soil conditions at higher water contents.

2. Materials and methods

2.1. Study site

Our study was conducted at a long-term experimental site managed by the Grassland Ecosystem Research Station of Inner Mongolia University (116°02′E to 116°30′E, 44°48′N to 44°49′N; 1505 m asl) during 2011 and 2012. The study sites are located in relatively flat land near the middle reaches of the Xilin River. The area has a typical semiarid temperate and continental climate with a dry spring and a moist summer. Fig. 1 presents the precipitation and air temperature during the study period. The mean annual precipitation was 300 mm, of which more than 70% falls during the growing season from June to August. In 2011 (a dry year), the total precipitation was 188 mm during the growing season, versus 465 mm in 2012 (a moist year). The precipitation differed dramatically between 2011 and 2012 in terms of both the total and the monthly variation, but the temperatures were comparable in both years. The mean daily air temperature showed a typical seasonal pattern for the study area, with the peak appearing from July to August in both years. Table 1 presents the soil water content for each site at two points during the growing season.

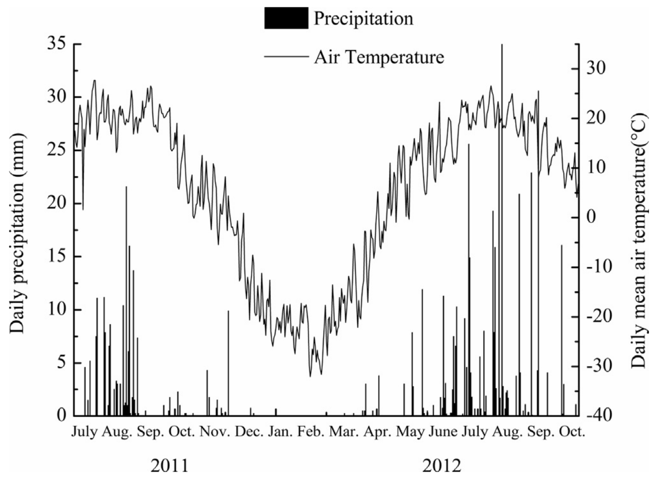

Fig. 1. Daily precipitation (bars) and air temperature (lines) at the study sites in 2011 and 2012.

We established three adjacent study sites, and assigned them to grazing, mowing, and grazing-exclusion treatments based on their history of land use, each contained three blocks as replicates. The 15-ha grazing site was grazed by 11 sheep (light grazing based on local standard) throughout the year. The 14-ha mowing site was continuously grazed from 1956 to 2008, but thereafter, was protected from grazing and was mowed in August of each year to provide fodder. The 15-ha grazing-exclusion site has been grazed from 1956 to 2008, but has been fenced since 2008 and is not mown. The vegetation at this site has recovered to some degree, the plant diversity and ecosystem stability indexes are comparable to or greater than those at the grazing and mowing sites (J.R. Gong, unpublished data). The vegetation is typical of the regional meadow steppe, and is dominated by *Stipa grandis*, *Leymus chinensis*, *Artemisia frigida*, and *Cleistogenes squarrosa*. Table 2 summarizes the vegetation characteristic at each site. The soil is classified as a Calci-orthic Aridisol according to the U.S.D.A. soil taxonomy, with low nutrient levels and a low water-holding capacity. Its depth is about 80 cm, and the soil organic matter content is 20–30 g kg^{-1}. We randomly established five plots per block, separated by at least 100 m, at each site, but with the constraint that the plots were located at least 5 m from the edge of the site to avoid edge effects.

2.2. Litter production

We estimated the annual litter production based on the peak biomass (Zhang et al., 2013). At the end of April, most of the plants begin to turn green, then reach their peak biomass in late August, and almost all above-ground grass biomass dies in October. We harvested the above-ground biomass by clipping all plants just above the soil surface from five representative 1 m × 1 m quadrats in each block in late August (i.e., the time of peak grass biomass) of 2011 and 2012. All litter was oven-dried at 65 °C to constant weight to determine the above-ground production. The litter composition was consistent with that of the vegetation at each site (Table 2).

We used the ingrowth core method to estimate root production in the upper layers (0–20 cm, 20–40 cm) of the soil profile under the three land uses over two years (May 2011–September 2011, May 2012–September 2012, the growing seasons), with five replicates per block. Ingrowth cores were created using nylon bags (20 cm deep, 15 cm in diameter, with a 2-mm mesh), which we filled with root-free soil obtained from the study site, sieved to pass through a 4-mm mesh. Soil was compressed with a metal bar

Table 1
Soil water content (0–20 cm in depth) in May and September of 2011 and 2012 in the study area.

	Soil water content (% v/v)			
Site	May 2011	September 2011	May 2012	September 2012
Grazing	0.58	0.33	1.03	0.70
Mowing	0.62	0.31	0.60	0.68
Grazing exclusion	0.62	0.36	0.83	0.67