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# Environmental driving factors affecting plant biomass in natural grassland in the Loess Plateau, China

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ABSTRACT

Plant biomass is a key parameter for estimating terrestrial ecosystem carbon (C) stocks, which varies greatly as a result of specific environmental conditions. Here, we tested environmental driving factors affecting plant biomass in natural grassland in the Loess Plateau, China. We found that above-ground biomass (AGB) and below-ground biomass (BGB) had a similar change trend in the order of *Stipa bungeana* > *Leymus secalinus* > *Artemisia sacrorum* > *Artemisia scoparia*, whereas shoot ratio (R/S) displayed an opposite change trend. There was a significantly positive linear relationship between the AGB and BGB, regardless of plant species ($p < 0.05$). Furthermore, more than 50% of the AGB were found in 20–50 cm of plant height in *Compositae* plants (*A. sacrorum, A. scoparia*), whereas over 60% of the AGB were found in 20–80 cm of plant height in *Gramineae* plants (*S. bungeana, L. secalinus*). For each plant species, more than 75% of the BGB was distributed in 0–10 cm soil depth, and 20% was distributed in 10–20 cm soil depth, while less than 5% was distributed in 20–40 cm soil depth. Further, AGB and BGB were highly affected by environmental driving factors (soil properties, plant traits, topographic properties), which were identified by the structural equation model (SEM) and the generalized additive models (GAMs). In addition, AGB was directly affected by plant traits, and BGB was directly affected by soil properties, and soil properties associated with plant traits that affected AGB and BGB through interactive effects were 9.12% and 3.59%, respectively. However, topographic properties had a weak influence on ABG and BGB (as revealed by the lowest total pathway effect). Besides, soil organic carbon (SOC), soil microbial biomass carbon (MBC), and plant height had a higher relative contribution to AGB and BGB. Our results indicate that environmental driving factors affect plant biomass in natural grassland in the Loess Plateau.

## 1. Introduction

Above-ground biomass (AGB) and below-ground biomass (BGB) are important components of global terrestrial ecosystem carbon (C) stocks, and they play a critical role in global C cycling (Müller et al., 2000; Poorter and Nagel, 2000; Enquist and Niklas, 2002). Root/shoot ratios (R/S) have been used to calibrate and estimate C stocks (Tilman, 1994; Tilman et al., 1996; Tilman et al., 1997), and they have been incorporated into terrestrial ecosystem C modeling (Tao and Hunter, 2013; Thuynsma et al., 2014). Although plant biomass is highly influenced by environmental factors (Johnson and Tieszen, 1976; McCarthy and Enquist, 2007), many previous studies have demonstrated that plant biomass is influenced by specific environmental conditions (biotic and abiotic factors). Then, less is known about the interactive effects of these environmental driving factors on plant biomass (Bello et al., 2013; Owens et al., 2013; Schöb et al., 2013).

Among the environmental driving factors, plant traits are the consequence of environmental and biological selection (Zuppinger-Dingley et al., 2014; Zheng et al., 2015; Gross et al., 2017), which bridge the gap between plant biomass and ecosystem C processes, and thus providing a powerful tool for studying C storage (Kunstler et al., 2015; Wu et al., 2016; Ordonez and Svenning, 2017). Soil properties are important regulators for plant biomass, especially in nutrient poor ecosystems (e.g., Loess Plateau of China), where plant biomass is limited by soil nutrients (Van Der Heijden et al., 2008; Biederman and Harpole, 2013). Besides, soil properties play an important role in C accumulation and contribute to the process of C transformation (Baselga, 2012; Poorter et al., 2012; Farrior et al., 2013; Freschet et al., 2013). For example, soil nutrients contribute to C absorption, thus resulting in plant growth and biomass increasing (Lee et al., 2013; Reich and

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Hobbie, 2013). In addition, topographic properties are indirect factors affecting plant biomass. As such, topographic properties may be relatively homogeneous on a large spatial scale but result in micro-topographic conditions (enhance soil microbial activities) at a small scale (Liancourt et al., 2013; Marshall et al., 2014). Thus, topographic properties are often associated with specific positions in the landscape and indirectly affect plant biomass (Castilho et al., 2006; Liu et al., 2010). Owing to the varying effects of plant biomass on these environmental factors, many studies have sought to determine plant biomass by focusing on the effect of the single factor (Jones, 2013; Hertel et al., 2013; Raich et al., 2014; Poorter et al., 2012; Yang et al., 2016). However, little attention has been paid to the links and interactions between plant biomass and environmental driving factors in the Loess Plateau.

Natural grassland, one of the most widespread ecosystems in the Loess Plateau, also plays a key role in global C cycling under complex environmental conditions (Jin et al., 2014; Xu et al., 2014). Additionally, natural grassland in this region has a remarkable diversity of soil properties, plant traits, topographic properties, and biogeochemical cycling; therefore, it offers a unique opportunity to examine plant biomass in relation to environmental driving factors. Thus, a better understanding of the relative contribution of environmental driving factors to plant biomass is fundamentally important to C stocks. Despite the progress made to date, the relationships between plant biomass and its environmental driving factors remain poorly defined in this region.

Here, we examined plant biomass (ABG and BGB) and environmental driving factors in natural grassland in the Loess Plateau. First, we hypothesized that the studied plant species have no relative limitation with the abundant resources. Second, among these plant species, we hypothesized that plant biomass is well adapted to environmental conditions. Third, we hypothesized that plant biomass is influenced by environmental driving factors. To test these hypotheses, we investigated the plant biomass and environmental driving factors (soil properties, plant traits, topographic properties) for four dominant species (*A. sacrorum, A. scoparia, S. bungeana, L. secalinus*) across natural grassland in the Loess Plateau, China. The objectives of this study were to: (1) document the general patterns of AGB and BGB for these four plant species across the grassland, (2) examine the effects of environmental drivers on plant biomass, and (3) illustrate the relative contribution of environmental drivers (directly or indirectly) to plant biomass.

## 2. Materials and methods

### 2.1. Study system

The study area, Yanhe River catchment (108°45′–110°28′E, 36°23′–37°17′N), is located in the middle of the Yanhe River in the northern part of Shaanxi Province. Yanhe River catchment has a total area of 7687 $km^2$ and 90% of the area is hilly with steep slopes and cliffs (40%). The study region has a semi-arid climate with heavy seasonal rainfall and periodic flooding (Fig. 1). The average annual rainfall is approximately 548.7 mm (1970–2000), and there are distinct rainy and dry seasons. The rainy season is from June to September, with August rainfalls amounting to more than 20% of the annual total. The average annual temperature is approximately 9 °C. Most of the area has an elevation between 900 m and 1500 m. The Loess is very arable, owing to its fine grains, loose texture and high content of mineral nutrients. The dominant soil type is typical Haplic-ustic Cambisol, according to the Chinese Soil Taxonomy (Fu et al., 2000; Fu et al., 2003; An et al., 2013; Zeng et al., 2016).

### 2.2. Sampling design

A field survey was conducted at the peak of the growing season in 2016 between July and August. We focused on four dominant plant species, *A. sacrorum, A. scoparia, S. bungeana, L. secalinus*, that have high relative biomass at a coverage of > 60%; these four plant species constituted over half of the biomass in natural grassland, and the basic ecological statistics of the plant species are shown in Table 1.

The studied plant species were randomly sampled across all the study area. For sample collection and vegetation (biomass) investigation, five 50 × 50 m plots were randomly located. Within each plot, five 1 × 1 m quadrats along a diagonal line were surveyed. The distance between two adjacent plots was 1000 m. All quadrats were located a similar distance from the quadrat shore regardless of the size and edge of the grassland. In each quadrat, AGB and BGB of the studied plant species were recorded and investigated. The harvested AGB was divided into several grades on the basis of the distribution of above-ground biomass (growth strategy and nutritional allocation) by plant height. BGB was sampled by extracting a soil cylinder of approximately 25 cm in diameter and dividing into 3 grades (0–10, 10–20, and 20–40 cm) on the basis of root depth. Afterwards, BGB of the studied plants were carefully collected and separated from soil and other below-ground material. The samples were passed through a 0.5-mm mesh sieve and then washed with purified water. No attempts were made to distinguish between living and dead roots. The root shoot ratio (R/S) was defined as the ratio between AGB and BGB. All of the above-ground parts of the green plant were immediately dried for 30 min at 105 °C and then transferred to the laboratory, where they were oven-dried at 65 °C and weighed to the nearest milligram. In addition, a global positioning system (GPS, Trimble Navigation Ltd. American) was used to determine the geodetic coordinates (LAT, LON), and a compass and clinometer (Model SF-02920, China) were used to measure the slope positions and slope gradients. The definitions and quantification of topographic properties are presented in Table 2.

### 2.3. Data collection

There are some key plant traits for explaining plant biomass, such as leaf carbon concentration (LCC), leaf nitrogen concentration (LNC) and specific leaf area (SLA) (Goodness et al., 2016; Li et al., 2016). Plant height refers to the light niche of plant species. Leaf dry matter content (LDMC) is a trade-off between mechanical strength and vertical growth, which is correlated with plant growth and biomass (Duru et al., 2014; Piqueray et al., 2015; Zuo et al., 2016; Kohler et al., 2017). To decrease the relative error introduced by time and space, all plant leaf sampling was conducted in the morning (between 7:00-10:00). At least six replicates of each sample of plant leaves were collected without the petiole from different positions. The practical measurements of these plant traits for all dominant species are shown in Table 3 with the standard methodologies (Cornelissen et al., 2003; Kichenin et al., 2013). The practical measurements of the plant traits are shown in Table 4.

For each sample, five 1 × 1 m soil samples (0–10, 10–20, and 20–40 cm) were set. Five replicates along an S-shaped curve were collected with a soil corer (10 cm in diameter) and mixed together to obtain one composite sample. Each soil sample was sieved through a 2-mm mesh, air-dried, and then analyzed for soil properties. Soil organic carbon (SOC, g $kg^{-1}$) and LCC were measured by the $K_2Cr_2O_7$-$H_2SO_4$ oxidation method. Soil total nitrogen (TN, g $kg^{-1}$) and LNC were measured by the Kjeldanl procedure (UDK 140 Automatic Steam Distilling Unit, Automatic Titroline 96, Italy). Total phosphorus (TP, g $kg^{-1}$) was measured by the molybdenum antimony colorimetric method. Soil $NH_4^+$-N was measured by using a Seal Auto Analyzer. Soil microbial biomass C and N (SMC, SMN, mg $kg^{-1}$) were measured by the fumigation-extraction method and calculated with correction factors of 0.35 (kC) and 0.4 (kN), respectively (Vance et al., 1987). Each of the analyses was performed in duplicate, and the soil properties are presented in Table 3.