Catena 166 (2018) 328–338

Contents lists available at ScienceDirect

Catena

journal homepage: www.elsevier.com/locate/catena

Ecological stoichiometry in leaves, roots, litters and soil among different plant communities in a desertified region of Northern China

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ARTICLE INFO

Keywords:
Ecological stoichiometry
Leaves
Roots
Litters
Soil
Desertified region

ABSTRACT

Ecological stoichiometry reflects the element content and energy flow, which are important for biogeochemical cycling in ecosystems. However, the ecological stoichiometry in leaves, roots, litter and soil is largely unknown, especially in the desertified region of Northern China. Here, six dominant plant communities (*Stipa bungeana*, *Agropyron mongolicum*, *Glycyrrhiza uralensis*, *Cynanchum komarovii*, *Artemisia ordosica*, and *Sophora alopecuroides*) were collected, and the carbon (C), nitrogen (N) and phosphorus (P) contents of leaves, roots, litters and soil were measured to explore the C:N:P stoichiometry and its driving factors. The C:N:P stoichiometry in leaves, roots, litters, and soil varied widely, and the plant community had a significant effect on the C:N:P stoichiometry in this region. There were high soil C:N, C:P and N:P ratios in non-leguminous plant communities and a high leaf N:P ratio in leguminous plant communities, and the C:N and C:P ratios in leaves were higher than in those in roots in all plant communities ($p < 0.05$). A correlation analysis showed that the C, N and P contents of leaves, roots, and litter were positively related to the soil C, N and P contents of the 0–5 cm layer, and the correlation coefficients gradually weakened with the soil depth. Additionally, the soil properties (except soil P) led to increased variance of the C:N:P stoichiometry in leaves, roots, and litter, and there were strong links among the C:N:P stoichiometry in leaves, roots, litter and soil, suggesting that the variation in the C:N:P stoichiometry in leaves, roots, and litter was mainly controlled by the soil properties, which was especially true for soil microbial biomass carbon (SMBC) and nitrogen (SMBN) according to redundancy analysis (RDA). Overall, these results demonstrate that the patterns of the C:N:P stoichiometry and element distribution exhibit significant flexibility among these plant communities, providing basic data for improving the parameterization of future ecological models in the desertified region of Northern China.

1. Introduction

In terrestrial ecosystems, the balance of nutrient elements in interactions and processes is known as ecological stoichiometry (Li, 2001; Sterner and Elser, 2002; Moe et al., 2005). Ecological stoichiometry represents an organism's demand for natural resources and connects different levels of biogeochemical cycling (Bradshaw et al., 2012; Hu et al., 2018), mainly by scaling up carbon (C), nitrogen (N) and phosphorus (P) (Bai et al., 2012; Yoshihara et al., 2010). Specifically, C provides the structural basis of plants, constituting a relatively stable 50% of the dry plant biomass (Schade et al., 2003; Liu et al., 2011). N is an important constituent of proteins and plays an essential role in plant production, photosynthesis and litter decomposition (Daufresne, 2004; Chen et al., 2016). P is often regarded as the limiting element and is responsible for the cell structure and composition of DNA and RNA, and P promotes C/N transpiration and assimilation (Tilman, 1994; Tilman, 1996; Naeem and Li, 1997; Tilman, 2004; Bai et al., 2012).

In general, C:N:P stoichiometry can be used to detect nutrient limitations to characterize important ecological processes in terrestrial ecosystems (Koerselman and Meuleman, 1996; Cleveland and Liptzin, 2007; Hättenschwiler and Jørgensen, 2010). There are two important methods of detecting the C:N:P stoichiometry (Frost et al., 2002; Cross et al., 2005). First, the release of key nutrients, such as C, N, and P, occurs in a predictable way depending on the limitation of the C:N:P ratio (Elser et al., 1988; Sterner and Elser, 2002). For example, the leaf N:P ratio (mass ratio) has been suggested to be useful for assessing N or P limitation (Cleveland and Liptzin, 2007). Second, natural resources are in stoichiometric homeostasis (Hessen, 1992; Urabe and Watanabe, 1992; Sterner and Elser, 2002). At the organismal level, life stages characterized by high growth rates are often associated with high RNA

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https://doi.org/10.1016/j.catena.2018.04.018
Received 27 September 2017; Received in revised form 1 April 2018; Accepted 13 April 2018

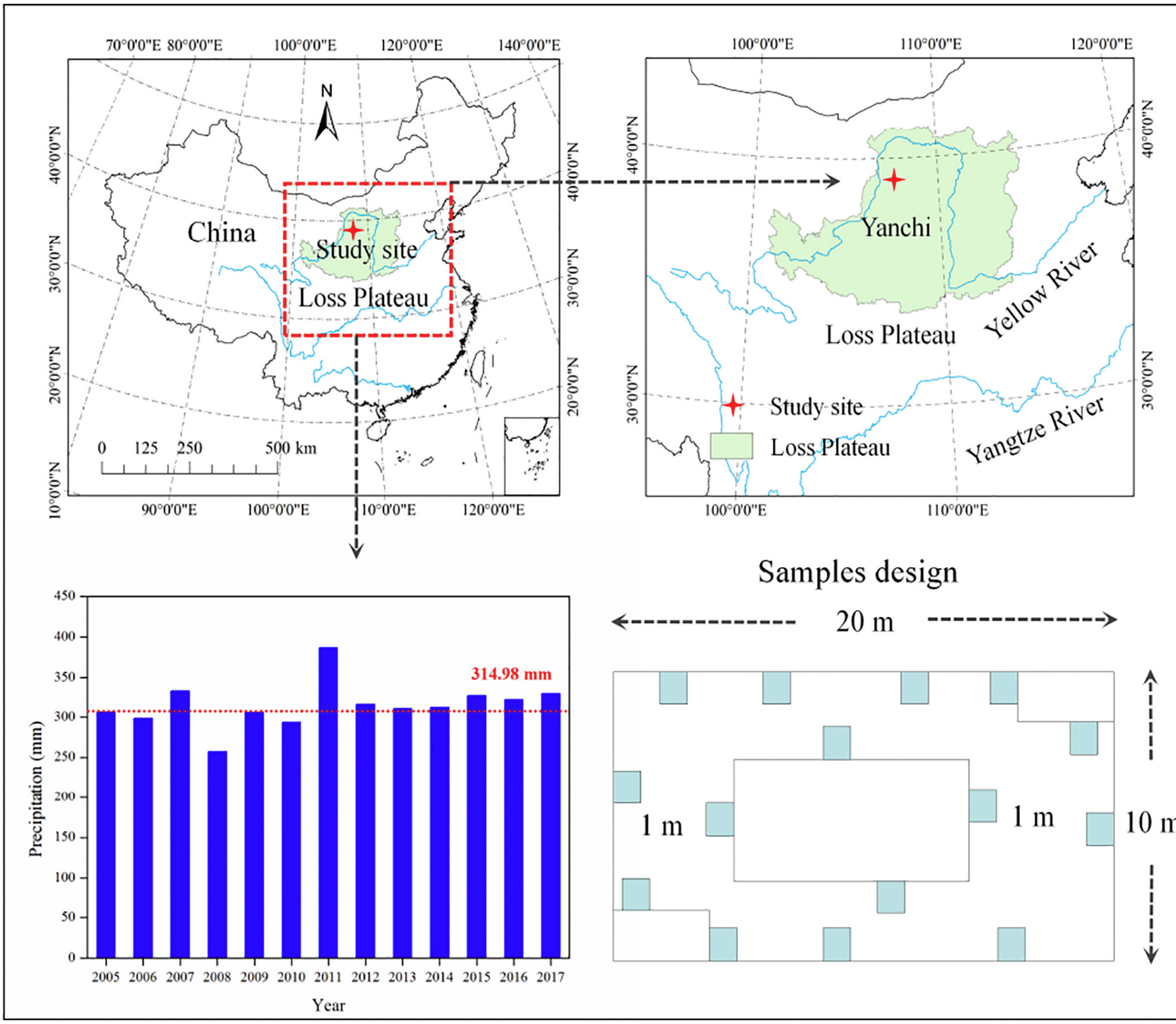

Fig. 1. Location of the study area and layout of the modified Whittaker plots (MWP) for the measurement of plant and soil samples in a desertified region of China.

contents (C:N:P ratios between 18:6:1 and 21:7:1), and therefore, organisms are able to shift their overall stoichiometry (McGroddy et al., 2004). Under this condition, to what extent do plants exhibit stoichiometric homeostasis? Soil C, N and P are affected by organic matter, litter and microbes (Mulder and Elser, 2009; Sinsabaugh et al., 2008), and plants adjust their growth rates by adjusting the ratio of C, N and P (Daufresne and Loreau, 2001; Moe et al., 2005). Litter stores nutrients and plays an important role in element cycling (Melillo et al., 1982; Manzoni et al., 2008); thus, the balance of the C, N, and P ratios is highly complex in a plant-litter-soil system (Moe et al., 2005; Manzoni et al., 2008; Manzoni et al., 2010). Therefore, evaluating the C:N:P stoichiometry in a plant-litter-soil system could improve our understanding of plant nutrient limitations and ecosystem dynamics (Redfield, 1958; Sterner and Elser, 2002).

Recently, most studies on C:N:P stoichiometry have focused on the organ level, and only a few studies have been conducted at the plant community or ecosystem levels in grasslands (He et al., 2006; He et al., 2008; Wang and Yu, 2008). A plant community is formed as a result of the adaptation of species to a specific environment and through mutual competition. Thus, the function of C:N:P stoichiometry should be explored at the community/ecosystem level in grasslands. A desertified region is an ideal region for addressing the drawbacks of the exploring C:N:P stoichiometry at a plant community level. To date, attention has been paid to C:N:P stoichiometry in this region (Liu et al., 2010; Zuo et al., 2012; Chen et al., 2016). However, no comprehensive survey of the driving factors of C:N:P stoichiometry in a plant-litter-soil system has been performed. Here, we examine the C:N:P stoichiometry and its driving factors across the desertified region in Ningxia, China. Specifically, this study had the following objectives: (1) explore the relationships among the C:N:P stoichiometry in the plant-litter-soil system; (2) examine the effect of the plant community on the C:N:P stoichiometry in the plant-litter-soil system; and (3) determine the driving factors of the C:N:P stoichiometry in this region.

2. Materials and methods

2.1. Study area

This study was conducted in the middle of the desertified region of East Ningxia (37°04′–38°10′N and 106°30′–107°41′E, average elevation 1450 m). This region has a temperate continental semiarid monsoon climate. The mean annual precipitation in this region is 180–300 mm,