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Effects of plant diversity on soil erosion for different vegetation patterns

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ABSTRACT

Vegetation effectively prevents soil erosion. However the relationship between plant diversity and soil erosion remains ambiguous under various environmental conditions. To explore the role that plant diversity plays in soil erosion, this study was conducted in the Three-River-Source region, located in the hinterlands of the Qinghai–Tibet Plateau, China. After examining 99 plots within the study area, and analyzing the soil ^{137}Cs inventory within the plots, we found that with a greater number of plants distributed within an aggregation pattern, there was greater interception of the soil particles by the vegetation patch. This phenomenon results in a more developed vegetation patch that can support greater vegetation coverage and higher plant diversity than it previously could. Although a positive correlation exists between plant diversity and vegetation coverage, the relationship between the extent of soil erosion and plant diversity is modulated by the vegetation pattern. When plants are distributed in a relatively homogeneous pattern, vegetation coverage decreases with increasing plant diversity, which leads to increased soil erosion. When plants are distributed between a homogenous and a heterogeneous pattern, no relationship is found between plant diversity and soil erosion. With a heterogeneous plant distribution, vegetation coverage increases with plant diversity, and soil erosion is inhibited under such conditions.

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1. Introduction

Soil erosion is an important ecological problem that has garnered increasing attention (Boardman, 2006). Because vegetation cover can effectively prevent soil erosion, more research on the relationship between vegetation and soil erosion has recently been conducted. Nearly all of these studies have found a negative relationship between vegetation coverage (VC) and soil erosion (Marques et al., 2007; Zhou et al., 2008). The negative correlation usually extends from a linear (Greene et al., 1994) to an exponential (Marston, 1952) correlation. Similarly, because of the important role that vegetation patterns play in the progression of soil erosion, an increasing number of studies have been conducted to examine the relationship between vegetation patterns and soil erosion (Cerda, 1997; Saco et al., 2007). Most studies have found that different vegetation patterns may combine with different soil erosion processes, even with similar VCs (Boix-Fayos et al., 2007). After conducting a study in northeastern Australia, Ludwig et al. (2007) suggested that a greater intensity of soil erosion is usually more associated with heterogeneous vegetation patterns rather than homogeneous vegetation patterns. In addition, the relationship between plant diversity and soil erosion can be affected by the vegetation pattern (Bautista et al., 2007). It has been suggested that similar vegetation patterns can be better conditions for determining the relationship between plant diversity and soil erosion than areas with different vegetation patterns (Hou et al., 2014).

Aside from the vegetation pattern, several other factors, such as precipitation conditions, affect the relationship between plant diversity and soil erosion. This relationship is thus ambiguous under different environmental conditions (Bautista et al., 2007). For example, a positive correlation between plant diversity and soil erosion has frequently been observed; however, a negative correlation has also been found (Turnbull et al., 2008). After conducting research in the Netherlands, Martin et al. (2010) found that different vegetation conditions give rise to different correlations between plant diversity and soil erosion. Whether the correlation between plant diversity and soil erosion is positive or negative largely depends on the local environment.

The relationship between these conditions is complex. With respect to plant diversity, discussing the relationship between plant diversity and soil erosion is perhaps not as valuable as discussing the relationship between plant functional diversity and soil erosion (Cadotte et al., 2011). Because plants have specific functional traits, such as root diameter, root tensile strength, and plant height, a plant's effects on soil erosion can be directly expressed as the effects of the plant's functional traits on soil erosion. Indeed, plant functional traits have been found to significantly affect soil erosion (Burylo et al., 2012; Pohl et al., 2009). The effect of vegetation

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diversity on soil erosion is actually the result of the effects of plant functional diversity on soil erosion. Nonetheless, studying the relationship between plant functional diversity and soil erosion is not unproblematic. First, the functional traits within a community must be categorized. Second, each functional trait of each plant species within a community must be quantified to study the relationship between only one type of erosion and plant functional diversity. More importantly, plant functional traits change over time and cannot be precisely quantified.

It is neither easy nor effective to study plant functional traits. However, studying plant functional types can be used to overcome these shortcomings. The plant functional type refers to a vegetation group that consists of plants with similar functional traits that respond in a similar pattern to an environmental disturbance (Navarro et al., 2006). Relying on plant functional types is an effective means of studying plant diversity and soil erosion from the plot (Anderson and Hoffman, 2011) to the landscape scale (Navarro et al., 2006); however, certain details are lost in studies that focus on plant functional traits. Generally, plant functional traits increase with plant diversity in a community. Thus, studying the relationship between plant functional diversity and erosion can serve as a good substitute for studying the relationship between plant diversity and erosion and potentially reveal the relationship between each functional trait and soil erosion.

Soil erosion can be expressed by different erosion types, such as splash, runoff, and windy erosion, among others (Boardman, 2006). Different erosion processes and steps have different traits, which can be affected by different plant functional traits (Zhu et al., 2015). Soil erosion types are thus meaningful for studying the relationship between soil erosion and plant diversity or plant functional diversity. In this study, the results of soil erosion over many years were monitored using an environmental tracer. The relationship between the results and plant diversity was studied.

Recently, soil ^{137}Cs, an environmental tracer, has begun to be used more frequently to evaluate soil erosion (Fu et al., 2009; Zhang et al., 2003). The theory of this method can be described as follows. From the 1950s to the 1970s, there was global fallout from bomb-derived radiocesium. When ^{137}Cs arrives at the ground surface, it is strongly and rapidly adsorbed by soil particles. When these soil particles move, ^{137}Cs accompanies them. Consequently, it is possible to evaluate whether a site is experiencing soil loss or accumulation by monitoring the spatial pattern of ^{137}Cs (Porto et al., 2001). A site with a greater soil ^{137}Cs inventory indicates that more sediment has accumulated at this site. However, a lower ^{137}Cs inventory in a site indicates that more sediment has been transported away from the site. Monitoring the results of the soil ^{137}Cs inventory at a site can be used to quantitatively evaluate the results of soil erosion that has taken place for nearly 60 years (from the 1950s–1970s until the present) at this site.

Several conversion models can be used to estimate soil erosion by measuring the soil ^{137}Cs inventory (Parsons and Foster, 2011), including, for example, the mass balance model and the simplified mass balance model (Fu et al., 2009). Different models have different parameters and differ in their underlying assumptions (Porto et al., 2001). In this study, conversion models were not used to estimate the extent of soil erosion, to prevent mistakes from arising as a result of complex model conversion. Instead, soil erosion within different plots was compared by comparing the soil ^{137}Cs inventory within different plots.

This research was conducted in the Three-River-Source region (the headwaters of the Yellow River, the Yangtze River, and the Lancang River), which is located in the hinterlands of the Qinghai–Tibet Plateau. Because this region is the major area of origin of the main rivers in Asia, the ecological health of this region may be closely related to sustainable development throughout most of Asia (Fassnacht et al., 2015). Due to global warming and human activities, the ecosystem in this region has experienced continuous degradation, an issue that has recently begun to attract more attention (Harris, 2010; Lehnert et al., 2014). This study was conducted to provide a theoretical basis for preventing soil erosion, a major contributing factor involved in land degradation. The main aim of this study is to explore the impact of plant diversity on soil erosion.

2. Materials and methods

2.1. Study site

This study was conducted in the Three-River-Source region of the Qinghai-Tibet Plateau, China (31°39′–36°12′N, 89°45′–102°23′E) (Fig. 1). Because this region is the source of three major rivers in China, it is known as “the water tower of China”. The region is located in the hinterlands of the Qinghai–Tibet Plateau and has a total area of approximately 302,500 km^2, which amounts to nearly 12% of the Qinghai–Tibet Plateau. The altitude ranges from 2610 to 6950 m. The study area has a continental monsoon climate typical to the plateau. The annual mean temperature in this area ranges from 5.38 °C to 4.14 °C, and the annual precipitation ranges from 262.2 mm to 772.8 mm (Yi et al., 2013). Monthly mean precipitation of the study area over 40 recent years (1969–2009) are presented in Fig. 2 (Li et al., 2009). There are approximately 0.12 hundred million hm^2 of moderately or seriously degraded grassland in this region; such ecosystem degradation has garnered increased attention worldwide (Liu et al., 2008).

2.2. Field investigations

In July 2014, we investigated 99 plots throughout the Three River Headwaters region. The condition of the plots selected was: 1) flat terrain; 2) zonal vegetation; 3) no anthropogenic disturbance; 4) no gravel cover, and 5) little or no moss cover. Each plot was 0.5 by 0.5 m^2. Within each plot, we recorded VC, species number, mean height, and the number of individuals of each species directly. In addition, the plots were photographed with a digital camera held 1 m above the ground. A photo was taken of every plot to analyze the vegetation patterns (Fig. 1). Because there were few liverworts, mosses, and stones within the plots selected, these were not recorded. The distribution of soil in vertical sections according to the ^{137}Cs inventory shows little inventory at depths >40 cm. Within 40 cm, soil erosion can be analyzed satisfactorily by monitoring the ^{137}Cs inventory. Therefore, soil samples were collected at 0–40 cm depth below the group, and the internal diameter of the soil auger was 0.028 m. Within each plot, three randomly placed soil samples were collected, and then mixed together in one sample. The soil ^{137}Cs inventory of each sample was analyzed in the laboratory.

2.3. Laboratory tests

Soil samples were air-dried in a hood, and sieved using a 2-mm screen. Next, a HPGe co-axial detector coupled to a multichannel analyzer was used to determine the soil ^{137}Cs inventory for each sample. The ^{137}Cs activity was detected at 662 keV, with a counting time of approximately 30,000 s for the detection. The results provided by this test were at least 90% reliable at a 95% confidence level. Calculations of the soil ^{137}Cs inventory was referenced to standards (Fu et al., 2009).

2.4. Index calculations

As a common index in ecology, Shannon's diversity index (SHDI) was used to estimate plant diversity (Riis and Hawes, 2002). This index was calculated using the following formula:

$$\text{Shannon's diversity index} = -\sum_{i=1}^{m} (P_i \ln P_i) \tag{1}$$

P_i is the proportion of the number of all plants in a plot occupied by the number of plant species *i*. m denotes the number of species in a plot.

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