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Seed population dynamics on abandoned slopes in the hill and gully Loess Plateau region of China

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ABSTRACT

Recovery of natural vegetation is an effective but slow approach to control the soil erosion in the Chinese hill and gully Loess Plateau region. As seed stage is particularly vulnerable to environmental conditions, characteristics of seed population should be needed to study for determining whether the recovery of natural vegetation is limited during this stage on the abandoned slopes in this region. The study was performed on three abandoned slopes in a watershed with an area of 8.27 km^2 in the Shaanxi province of China. The differences in soil seed banks were investigated in two different points in time, late March 2011 and early April 2013. Main factors of seed population dynamics, such as seed yield of dominant species, seed inputs by seed rain as well as seed outputs through seed loss by overland flow and seedling emergence, were monitored from late March 2011 to early April 2013. In this study, seed rain densities of the main later successional species, i.e., *Lespedeza davurica* (Laxm.) Schindl., *Stipa bungeana* Trin. and *Artemisia gmelinii* Web. ex Stechm., accounted for 51.5–71.6% of their own seed yields. The soil seed bank density in early April 2013 was larger than that in late March 2011. The density of seed inputs by seed rain was 10186 seeds m^{-2}, and the total seed bank, including seed rain and seeds present in the soil seed bank in late March 2011, reached a density of 15018 seeds m^{-2} during the study period. Seed densities of loss duo to overland flow and seedling emergence were 79 seeds m^{-2} from 20 species and 938 seedlings m^{-2} that belonged to 38 species during a study period, and the seed output through them accounted for 0.5% and 6.3% of the total seed bank, respectively. The study concluded that overland flow could not result in large numbers of seeds loss and seeds were accumulating in the soil seed bank due to seed rain, and vegetation succession might be limited by curbed spatial seed dispersal and seedling establishment.

1. Introduction

The Loess Plateau of China has suffered from serious soil erosion for a long time (Wang et al., 2011a). Soil erosion rate in the Loess Plateau is due to both natural and human-induced factors and the rates were approximately four times greater than those before human activities (He et al., 2006). With the increase in the Chinese population after the 1950s, more natural vegetation was destroyed, and part of grassland was turned into farmland on slopes, which aggravate soil erosion and ecological degradation (Zheng, 2006). Under this situation, vast swathes of arable lands have been abandoned to natural succession since the beginning of the "Grain for Green" program in the hill and gully Loess Plateau region in 1999. However, recovery of natural vegetation is a slow approach to control the soil erosion and the vegetation is scarce (Jing and Zheng, 2004; Zheng, 2006). Within the life cycle of plants, seed stage is particularly vulnerable to environmental conditions, and the processes of seed population dynamics occurring during this stage influence the structure of both adult populations and communities (Harper, 1977; Jiao et al., 2009). Thus, characteristics of seed population should be needed to study for determining whether the recovery of natural vegetation is limited during this stage on the abandoned slopes of the hill and gully Loess Plateau region.

Seed population is changing all the time, and seed population dynamics depend on seed inputs and outputs (Jiao et al., 2009;

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García-Fayos et al., 1995). The input of seed refers primarily to a seed rain (García-Fayos et al., 1995). Seeds disperse after ripening and then form a seed rain, which is defined as the sum of all the seeds from mother plants in a given time and area (Harper, 1977). Dispersal syndromes shape seed rain, and seed rain is also shaped by the availability of dispersal vectors, such as wind (Howe and Smallwood, 1982; Van der Pijl, 1982). Species dispersal abilities can contribute differentially to local species diversity and the similarity of species composition of seed rain to standing vegetation is an important researching content of vegetation regeneration (Yu et al., 2015).

After seed disperses, seeds remain on the soil surface until they output though seed germination or enter into soil seed bank once the seeds are buried in slopes (Chambers and McMahon, 1994). However, soil erosion interferes with natural recovery of vegetation by impacting the whole growth stages of plant for the degradation of ecosystems, especially in the seed stage (Espigares et al., 2011; Jiao et al., 2009; Tsuyuzaki and Haruki, 2008). As rainfall is mostly concentrated in few high intensity events in arid and semiarid regions (Poesen and Hooke, 1997; Rodriguez-Iturbe and Porporato, 2004), the overland flow and the transport of sediments can result in seed output through removal, which reduces the seed retention in the soil seed bank (García-Fayos et al., 1995, 2000; Jones and Esler, 2004) and thus there may be not enough seeds for germination. Furthermore, harsh environmental factors, especially drought stress and low soil fertility, can also limit seed output through germination in the arid and semiarid ecosystem.

As recruitment is the combined result of processes involved in soil seed bank dynamics and seedling establishment patterns (Harper, 1977; Mariana de et al., 2015), to some degree, characteristics of seed population can be reflected by dynamics of soil seed bank. Soil seed bank is a critical component of the dynamics, conservation and sustainable management of the ecosystems since they play critical ecological and evolutionary roles in linking the past, present, and future of a given community (Bai et al., 2004; Miao et al., 2016). Data about the similarity between standing vegetation and soil seed bank can provide information about the potential of vegetation recovery after disturbance, successional pathways after abandonment and susceptibility to biological invasions (Loydi et al., 2012). Additionally, soil seed bank data may help to evaluate whether restoration of degraded ecosystems require the addition of seeds of target species with low seed numbers (Kiehl et al., 2010).

With the deepgoing research, dynamics models drafted from a seed population perspective were established tentatively. For example, Schafer and Chilcote (1969) proposed a seed bank dynamics model on the basis of the summation of persistent seeds prevented from germination by endogenous and exogenous factors. García-Fayos et al. (1995) pointed out that seed inputs in the seed rain were greater than seed outputs through seed removal after two years, which resulted in a continuous increase in the numbers of seeds in the soil seed bank. Similarly, a model or relationship can be established through the comparison of soil seed bank at two different points in time and the dynamics of seed input and output during the two time points.

Thus, the general goal of this study was to determine whether the recovery of natural vegetation is limited during the seed stage and then to explore possible reasons for low recruitment in this stage on abandoned slopes in the hill and gully Loess Plateau region. Specifically, standing vegetation, seed yield, seed inputs (i.e., seed rain), seed outputs through seed loss by overland flow and seed germination, soil seed bank before and after seed input and output observation were quantified. We posit the following: (1) vegetation succession might be limited by curbed spatial seed dispersal through seed rain; (2) soil erosion could result in large numbers of seeds loss; (3) seedling emergence might be limited; and (4) seed inputs were less than seed outputs, and as time went on, there would be a decrease in the numbers of seeds or species in the soil seed bank.

2. Methods

2.1. Study site

The study was conducted in the Zhifanggou watershed, an area of 8.27 km^2, in the hill and gully Loess Plateau region (105°51′44″–109°26′18″E, 36°22′40″–36°32′16″N) at 1010–1431 m above sea level (Fig. 1). The watershed has a warm temperate continental monsoon climate with a mean temperature of 8.8 °C. The average annual precipitation in the area is 505 mm (1970–2010). More than 70% of the precipitation falls during the summer (June–September). The rainfall is mostly concentrated in few, high intensity, erosive rainfall events, which can produce runoffs and subsequent soil erosion. The erosive rainfall levels and its average intensities generally exceed 12 mm and 0.04 mm min^{-1}, respectively, in the Loess Plateau region (Xie et al., 2000). According to rainfall data obtained from the An'sai Ecological Experimental Station of Soil and Water Conservation (Chinese Academy of Sciences) in 2011 and 2012, the total rainfall precipitation levels were 330.7 and 525.8 mm during the rainy seasons (May–October), and the erosive rainfall levels from 11 rainfall events accounted for 64.5 and 72.7%, respectively. Loessial soil is the main soil type in the watershed and is mainly composed of sand (65%), silt (24%) and clay (11%) (Li et al., 2013).

The study watershed is located in a forest-steppe region. Although human activity, such as cultivation and overgrazing, had completely destroyed the original vegetation in the past, the current vegetation is changing significantly since the croplands were abandoned. These abandoned lands have been converted into woodlands or grasslands and occupy most of the watershed in the present (Qiu et al., 2012; Zhang et al., 2013). Previous studies have shown that four main vegetation types occur in the abandoned lands in the study area. One of the vegetation types, dominated by *Artemisia scoparia* Waldst. et Kit., constitutes the early successional stage after abandonment. The second type is dominated by *Lespedeza davurica* (Laxm.) Schindl. or *Stipa bungeana* Trin.; the third type is dominated by *Artemisia gmelinii* Web. ex Stechm. and the fourth type is dominated by *Bothriochloa ischaemun* (Linn.) Keng, which constitute the later successional stages (Jiao et al., 2008).

Three typical abandoned sunny slopes with similar vegetation and time since the agricultural abandonment (eleven years) were selected for repeated trials in the study (Fig. 1). The slope angle ranged from 11° to 38°, and the vegetation cover was approximately 30%. According to the important value of standing vegetation on the three slopes in 2011 and 2012, the second vegetation type mentioned above was widely distributed on the three typical abandoned slopes.

2.2. Field observation

2.2.1. Standing vegetation

To determine the cover and species composition of standing vegetation, nine quadrats (2 m × 2 m) were randomly marked on each slope in August 2011 and 2012. The cover was estimated using the traditional ocular method. The species composition was recorded and its identification was based on the Flora of China (Wu et al., 1994–2013). The times of a species appearing in ninety 1 m × 1 m on each slope was recorded for determine the frequency. Mean cover and mean frequency of the three slopes were calculated, respectively.