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The efficiency of large-scale afforestation with fish-scale pits for revegetation and soil erosion control in the steppe zone on the hill-gully Loess Plateau

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ABSTRACT

To reduce the rate of soil erosion and improve the environment, the Chinese government launched the "Grain for Green" project in 1999, and afforestation with fish-scale pits (FSPs) is one of the main measures of this project in the steppe zone on the Loess Plateau. In this study, tree survival and growth, vegetation recovery and differences in soil erosion between afforestation with FSP slopes (AFS) and natural restoration slopes (NRS) were analyzed, and the suitability of afforestation with FSPs in the steppe zone of the Loess hilly–gully region was assessed by field survey. We found that the average tree survival rate was 37.9% for planted *Robinia pseudoacacia* and was 58.9% for planted *Prunus armeniaca* and *Prunus davidiana*. All three tree species afforested using FSPs exhibited a "small-aged tree" trend due to the poor growth conditions. The coverage of both the herb and litter on NRS was an average of 1.5 and 1.7 times higher than that on AFS, respectively. There was no significant difference with regard to rill erosion between the non-FSP part of the afforestation slopes and NRS. However, the total amount of rill erosion in the upside and downside FSPs was 2.14 times higher than the amount of sediment deposited inside FSPs after 8 years. Therefore, we conclude that afforestation with FSPs is not effective in controlling soil erosion and improving vegetation recovery. Large-scale afforestation with FSPs is unsuitable in the steppe zone on the hilly-gully Loess Plateau.

1. Introduction

Soil erosion is one of the most serious environmental problems in the world, especially in China (Bai et al., 2013; Li et al., 2012, 2013; Liu et al., 2012; Pimentel and Kounang, 1998). The Loess Plateau of China has long suffered from considerable soil erosion (Wei et al., 2006; Zhang et al., 2004). Cultivated slope land, which accounts for up to 70% of the arable land in loess hilly and gully areas (Tang et al., 1998), is a major factor associated with serious soil and water losses (Shi and Shao, 2000). To control soil and water losses and improve the environment in the Loess Plateau, the Chinese Central Government issued the "Grain for Green" policy in 1999 for the restoration of vegetation in this area. Croplands (particularly slope lands) have been extensively shifted to forest lands and grasslands (Jiao et al., 2008; Wang et al., 2011a). Afforestation, as one of the main measures of the "Grain for Green" project for the ecological recovery, has been widely implemented in the steppe zone on the Loess Plateau. Indeed, several studies have indicated that afforestation is a potential strategy to help conserve the soils on degraded land by reducing soil erosion and improving the natural environment, such as stabilizing steep slopes, building up of soil organic carbon in the top soil, and allowing for secondary succession to take place (Roberts et al., 1988; Zhou et al., 2006; Nyamadzawo et al., 2008). However, the choice of tree species can have a strong impact on soil and understorey development. The unsuitable tree species might cause the acidification of soil, and influence the pasture production and reduce floristic understorey plant diversity and inhibit regeneration of other species (Raizada and Juyal, 2012; Rigueiro-Rodríguez et al., 2012). Furthermore, drought is a major constraint worldwide to the production of common vegetation types, such as forests (Raffaelli, 2004). In particular, revegetation of arid regions is primarily water-limited (Ginsberg, 2000), and growth reductions caused by drought can significantly affect afforestation success, particularly if a lack of moisture reduces survival after planting (Graciano et al., 2005). Soil moisture is generally deficient in planted forests in the arid and semiarid areas of the Chinese Loess Plateau as a result of the low annual precipitation, overly high planting density and unsuitable choice of tree species (Wang et al., 2004). Furthermore, planted trees consume more of the limited available soil water, leading to soil drying and increased hydrophobicity, which

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reduces rainfall infiltration to recharge underground water reserves and threatens ecological sustainability (Cao et al., 2007; Cerdà and Doerr, 2007; Sun et al., 2006). Thus, afforestation is also considered as a land use activity that threatens water resource security (Van and Keenan, 2007).

Drainage and fertilization are regarded as important measures for good tree growth on peat lands in Sweden in efforts to provide detention storage, improve the survival of planted trees and control soil and water losses (Sunström and Hånell, 1999). Indeed, soil preparation is reported to be an important measure for the success of the natural establishment of trees by improving the soil conditions for plant growth (Querejeta et al., 2001; Worrell and Hampson, 1997). In many regions of China, semicircular rainwater retention basins, also known as “fish-scale pits” (FSPs), which are built on the slopes in an alternating pattern similar to the arrangement of the scales of a fish, are used as a transitional measure for afforestation (Fu et al., 2010; Wang et al., 2011b). It was shown that FSPs in the forest-steppe and steppe zones of the Loess Plateau can improve the species diversity of plant communities and such soil environmental parameters as soil organic matter, capillary porosity and nitrogen content, thereby increasing productivity of the land (Ma et al., 2006). Fu et al. (2009, 2010) also evaluated the effect of FSPs on reductions in runoff and sediment yield under simulated rainfall and found that the average reduction was 18% for runoff and 76% for sediment with heavy rainstorms in the Beijing area. However, the fish-scale pits did not effectively resolve the problem because of their small capacity for runoff and sediment. Most of the fish-scale pits are filled up by sediment or destroyed by runoff within several years (Wang et al., 2011b). Furthermore, little is known about the effect of FSPs on soil erosion and vegetation recovery on the afforestation slopes in the steppe zone of the Loess Plateau under natural conditions. Therefore, whether large-scale afforestation with FSPs actually plays a positive role in the Loess Plateau is an urgent question that needs to be addressed.

Thus, to assess the efficiency of FSP afforestation in the steppe zone on the Loess Plateau, we intend to address the following questions: (1) whether the tree survival and growth with FSP afforestation is good? (2) Whether the afforestation with FSP slopes (AFS) influence the surface vegetation and litter compared with the natural restoration slopes (NRS)? (3) Whether afforestation with FSPs reduces soil erosion efficiently compared with natural restoration?

2. Materials and methods

2.1. Study site

The study sites are the 10.77 km^2 Zhangjiahe watershed (ZW) (109°11′58″–109°14′39″E, 36°59′33″–37°2′40″N) and the 27.31 km^2 Gaojiagou watershed (GW) (108°58′5″–109°2′52″E, 37°12′31″–37°16′36″N) located in the Yan River Basin of Ansai County, North Shaanxi Province, China (Fig. 1). The elevation ranges from 1118 to 1 505 m for ZW and 1245 to 1 463 m for GW. The main soil type is loess soil, with a small amount of alluvial soil and dark loessial soil. The climate is characterized by cold dry winters and warm moist summers. The mean annual precipitation is approximately 500 mm, mostly occurring in a few heavy storms. The widely distributed and most representative grass species are *Bothriochloa ischaemum*, *Stipa bungeana*, *Artemisia gmelinii*, *Lespedeza davurica* and *Artemisia giraldii* (Jiao et al., 2008).

The “Grain for Green” project was implemented in Ansai County from 1999 to 2006. The area of afforestation with FSPs was approximately 411.02 km^2. The selected AFS in ZW in this study were forested in September–October 2003; the main tree species is *Robinia pseudoacacia*. The selected AFS in GW were forested in September–October 2000 with *R. pseudoacacia* and reforested in March–April 2005 with *Prunus armeniaca* and *Prunus davidiana* because almost all the *R. pseudoacacia* individuals had died. All the tree species planted in the two watersheds were 1-year-old containerized seedlings. These data were collected from the “Grain for Green” office of Ansai County, Shaanxi Province (Fig. 2).

2.2. Data collection

The original tree and shrub vegetation in the study area have been removed long ago through human activities (Jiao et al., 2008, 2012), therefore, the natural restoration slopes were taken as control to assess the efficiency of FSP afforestation in the present study. Field data were collected in September 2011. Three north-facing slopes, three south-facing slopes and three slope crests afforested using FSPs were selected in each watershed. And nine corresponding slopes with natural restoration were also selected in each watershed. Each slope was divided into upper, middle and lower positions, and 10 FSPs were randomly chosen at each slope position and each slope crest. A total of 420 FSPs were chosen in the two watersheds. Additionally, 3 plots (2 m × 2 m) were established at each position to compare the vegetation characteristics and soil erosion between AFS and NRS. The plots on the afforestation slopes were located adjacent to FSPs, and there were no FSPs inside the plots; a total of 243 plots were surveyed.

In each FSP, the species, survival, height, diameter at breast height (DBH) and canopy planar projected diameter of the trees were recorded. The pit spacing, row spacing, inside diameter and sediment depth in each FSP were also measured (Fig. 3a). In each plot, the type, species composition and coverage of the herb community and the depth and coverage of litter were investigated; the coverage of each plot was estimated visually by two observers working together. The slope aspect of each position was measured using a global positioning system.

Afforestation with FSPs inevitably changes the micro-topography due to FSP excavation and divides the original slope into non-FSP and FSP parts. In addition, the FSP part can produce new soil erosion in upside and downside FSPs, particularly in the preliminary afforestation stage. Therefore, to assess the effect of FSPs on soil erosion, we compared the difference in soil erosion between the non-FSP part and NRS by a plot survey. The soil erosion in the upside and downside FSPs and the sediment deposited inside the FSPs were also investigated. Rill erosion accounts for more than 70% of the amount of slope erosion (Renard et al., 1997; Zheng et al., 1989) and is a convenient and easily visualized measure in field investigations. Therefore, the number, depth, length and width of rills in the upside and downside areas of each FSP (Fig. 3b) and in each plot were measured to estimate soil erosion with AFS and NRS. For this, the rill in the upside and downside FSPs was the rill that ended at the upside FSP and originated from the downside FSP, respectively. Subsection measurement was adopted to measure the length, width and depth of each rill due to the irregular rill shape. The length, width and depth of each subsection were measured firstly, and then were added the corresponding data of each subsection together to calculate the amount of rill erosion (Fig. 3c).

2.3. Data analysis

The pit spacing and row spacing were used as the measures of afforestation density. The tree species, survival rate, tree height, DBH and planar projected diameter of canopy were used as the indicators to assess the tree survival and growth. The measures of surface vegetation characteristics included the herb community types, herbal coverage, litter depth and litter coverage. The inside diameter and the depth of sediment deposited in each FSP were used as the measures of the amount of sediment deposited. The number, depth, length and width of rills in each plot and upside/downside of each FSP were used as the measures of the amount of rill erosion.