Catena 115 (2014) 159–167

Contents lists available at ScienceDirect

Catena

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

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

Zhi-Jie Wang [a,d], Ju-Ying Jiao [a,b,*], Yuan Su [c], Yu Chen [c]

[a] State Key Laboratory of Soil Erosion and Dryland Farming on the Loess Plateau, Institute of Soil and Water Conservation, Chinese Academy of Sciences and Ministry of Water Resources, Yangling, 712100 Shaanxi, China
[b] Institute of Soil and Water Conservation, Northwest A & F University, Yangling 712100, Shaanxi, China
[c] College of Resource and Environment, Northwest A & F University, Yangling 712100, Shaanxi, China
[d] University of the Chinese Academy of Sciences, Beijing 100049, China

ARTICLE INFO

Article history:
Received 27 June 2013
Received in revised form 22 October 2013
Accepted 17 November 2013

Keywords:
Rill erosion
Sediment deposition
Tree survival and growth
Herb
Litter
"Grain for Green" project

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

---

* Corresponding author at: No. 26, Xinong Road, Institute of Soil and Water Conservation, Yangling, Shaanxi 712100, China. Tel.: +86 13474375827; fax: +86 29 87012210.
E-mail address: jyjiao@ms.iswc.ac.cn (J.-Y. Jiao).

0341-8162/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.catena.2013.11.012

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.

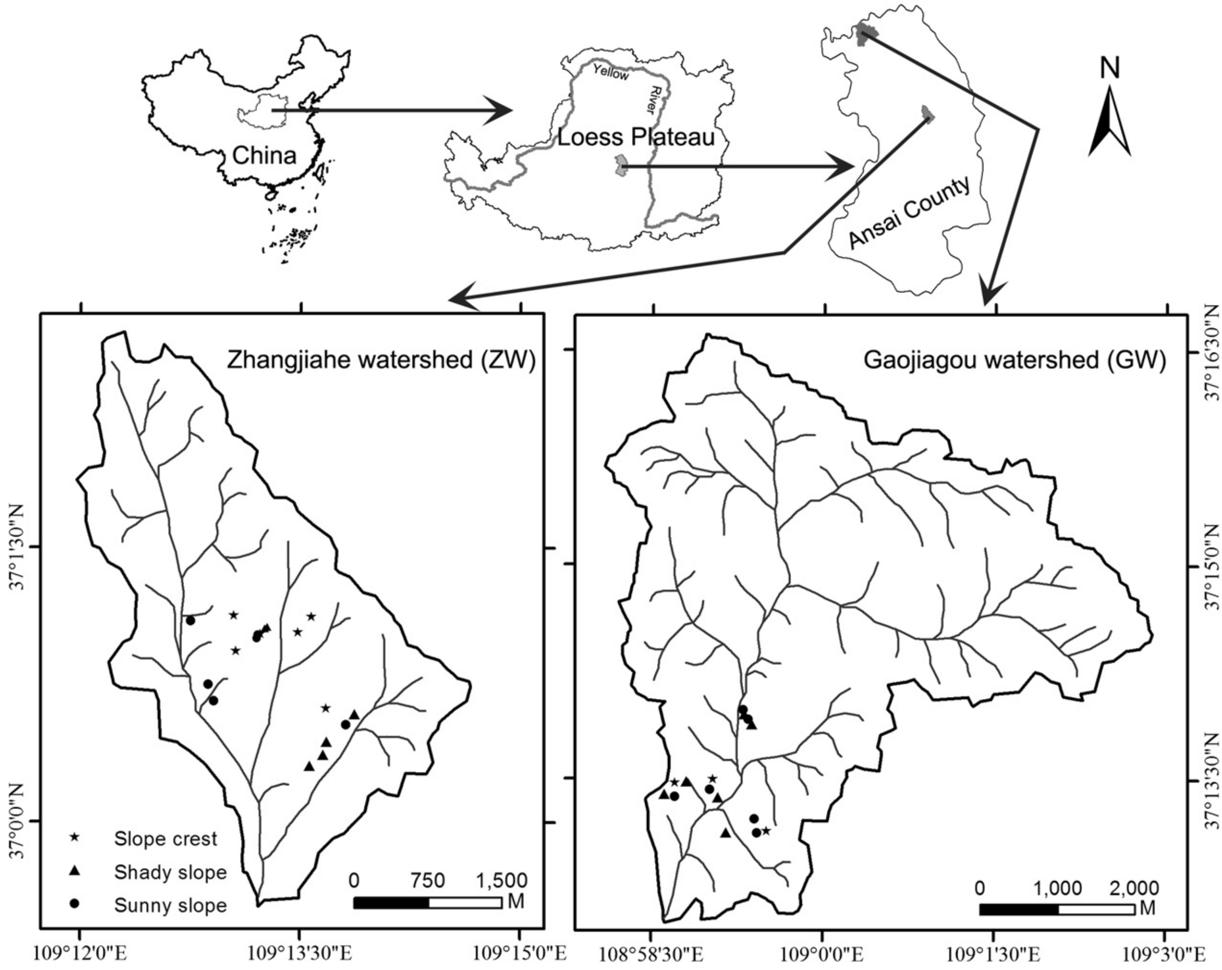

Fig. 1. Location of the Gaojiagou watershed and Zhangjiahe watershed on the Loess Plateau of China.

The equations used to calculate sediment deposition and rill erosion are as follows:Amount of sediment deposited inside FSPs (ASDF, $m^3\ FSP^{-1}$):

$$\mathrm{ASDF} = \sum_{i=1}^{n} Dd_i \times \frac{\pi \times Id_i^2}{2} \tag{1}$$

where Dd_i is the deposition depth inside the ith FSP (m), Id_i is the inside diameter of the ith FSP (m) and n is the number of FSPs.

Amount of rill erosion in upside and downside FSPs (AREF, $m^3\ FSP^{-1}$):

$$\mathrm{AREF} = \sum_{i=1}^{n} (\mathrm{AREU}_i + \mathrm{ARED}_i) \tag{2}$$

$$\mathrm{AREU(ARED)} = \sum_{j=1}^{m} \sum_{k=1}^{s} \left(Rl_{jk} \times Rw_{jk} \times Rd_{jk} \right) \tag{3}$$

where n is the number of FSPs in a 2 × 2-m^2 area, AREU_i is the rill erosion upside the ith FSP ($m^3\ FSP^{-1}$), ARED_i is the rill erosion downside the ith FSP ($m^3\ FSP^{-1}$), m is the rill number upside/downside in each FSP, s is the number of subsection of each rill, and Rl_{jk}, Rw_{jk} and Rd_{jk} are the length, width and depth of the kth subsection of the jth rill (m), respectively.

Amount of rill erosion in plots on NRS/on the non-FSP part of AFS (AREP, $m^3\ m^{-2}$):

$$\mathrm{AREP} = \frac{\sum_{i=1}^{n} \sum_{j=1}^{m} \left(Rl_{ij} \times Rw_{ij} \times Rd_{ij} \right)}{\mathrm{AP}} \tag{4}$$

where n is the rill number in each plot, m is the number of subsection of each rill, AP is the area of each plot (2 m × 2 m) and Rl_{ij}, Rw_{ij} and Rd_{ij} are the length, width and depth of the jth subsection of the kth rill (m), respectively.

Multiple-comparison and multi-way analysis of variance (ANOVA) procedures were used to compare the differences for the tree survival and growth, surface vegetation characteristics and rill erosion among the watersheds, slopes, aspects and slope positions. All values were expressed as the mean ± SD. LSD tests were performed to determine the significant differences among the sites at $P < 0.05$.

3. Results

3.1. Tree survival and growth characteristics

Table 1 shows the tree density and survival rates for the different slope aspects and positions on AFS in ZW and GW. The density ranged from 3712 to 4193 individuals ha^{-1}, with an average of 3869 individuals ha^{-1} in ZW, and ranged from 2383 to 3331 individuals ha^{-1}, with an average of 2821 individuals ha^{-1} in GW. The density of all the slope aspects and positions in ZW was higher than that in GW. However, the average survival rate of planted *R. pseudoacacia* in ZW was 37.9%, lower than that of planted *P. armeniaca* and *P. davidiana* in GW, at 58.9% ($P = 0.012$). The tree survival rate of the two watersheds was higher on the north-facing slopes than the south-facing slopes and was lowest on the slope crests, though this was not significant ($P > 0.05$).

The tree height of *R. pseudoacacia* in ZW ranged from 156.73 to 260.68 cm, with an average of 201.68 cm; the tree height of

Fig. 2. The slopes of the afforestation slope with FSPs and the natural restoration slope.

P. armeniaca and *P. davidiana* in GW ranged from 84.32 to 158.04 cm, with an average of 106.75 cm. The average canopy diameter was 99.90 and 77.26 cm in ZW and GW, respectively. The average DBH values on north-facing slopes, south-facing slopes and slope crests in GW were 1.55, 1.45 and 1.15 cm, respectively; the average DBH values on south-facing and north-facing slopes of ZW were 2.54 cm and 1.90 cm, respectively (Table 2).

3.2. Surface vegetation features

3.2.1. Herb layer

According to the field survey, there was no difference between the grass types on AFS and NRS. The main common dominant species on north-facing slopes included *A. gmelinii*, *S. bungeana*, *L. davurica*, *Heteropappus altaicus*, *A. giraldii* and *Leymus secalinus*. *Poa sphondylodes* and *Phragmites communis* were found on the north-facing slopes of GW. The main common dominant species on the south-facing slopes were *Thymus mongolicus*, *Artemisia frigida*, *S. bungeana*, *P. communis*, *Stipa grandis*, *P. sphondylodes*, *B. ischaemum*, *L. secalinus* and *L. davurica*. The main common dominant species on the slope crests were *B. ischaemum*, *S. bungeana*, *L. secalinus*, *L. davurica*, *A. gmelinii*, *P. communis*, *Artemisia scoparia* and *A. frigida*.

Fig. 4 shows the herbal coverage at the different slope aspects and positions of the two watersheds. Although not significant, the herbal coverage on the south-facing AFS of ZW was slightly higher than that on the south-facing NRS of ZW, with an average of 19.5% and 18.0%, respectively ($P = 0.531$). The herbal coverage at all the other slope aspects and positions in the two watersheds was significantly higher for NRS than AFS, with the following averages: 21.3% on the north-facing AFS of GW and 36.4% on the north-facing NRS of GW ($P = 0.000$); 19.1% on the south-facing AFS of GW and 42.2% on the south-facing NRS of GW ($P = 0.000$); 23.4% on the north-facing AFS of ZW and 33.7% on the north-facing NRS of ZW ($P = 0.000$) and 17.8% on the crest AFS of ZW and 19.0% on the crest NRS of ZW ($P = 0.073$).

3.2.2. Litter layer

On average, the litter depth of the north-facing AFS in ZW was slightly higher than that of the north-facing NRS in ZW ($P = 0.119$). However, the litter depth at the other slopes and positions in both

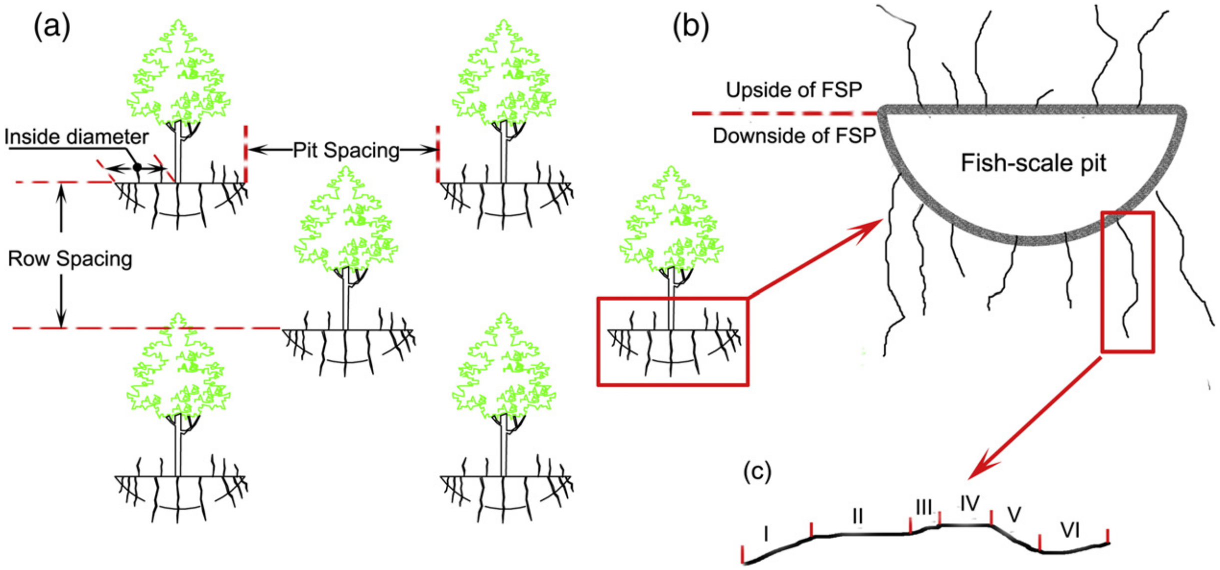

Fig. 3. The sketch map of FSPs and rill upside/downside of FSP.

Table 1
The density and survival rate of afforestation trees in GW and ZW (mean ± SD).

Slope aspect	Position	Zhangjiahe watershed		Gaojiagou watershed	
		Tree density (individuals ha^{-1})	Survival rate (%)	Tree density (individuals ha^{-1})	Survival rate (%)
North-facing slope	Upper	3712 ± 584	60.0 ± 3.7	2910 ± 211	60.0 ± 9.1
	Middle	4077 ± 383	50.0 ± 4.8	2383 ± 423	76.7 ± 7.9
	Below	4193 ± 1048	36.7 ± 6.4	3331 ± 335	46.7 ± 9.3
South-facing slope	Upper	3776 ± 130	33.3 ± 1.1	2745 ± 484	50.0 ± 9.3
	Middle	3733 ± 217	46.7 ± 3.8	2771 ± 347	66.7 ± 8.8
	Below	3776 ± 130	43.3 ± 3.8	2495 ± 408	50.0 ± 9.3
Slope crest		3816 ± 265	16.7 ± 2.2	3113 ± 380	62.1 ± 9.0

Table 2
The growth characteristics of afforestation trees in ZW and GW (mean ± SD).

Slope aspect	Position	Gaojiagou watershed			Zhangjiahe watershed		
		Tree height (cm)	DBH (cm)	Canopy diameter (cm)	Tree height (cm)	DBH (cm)	Canopy diameter (cm)
North-facing slope	Upper	95.00 ± 6.49	1.15 ± 0.13	66.25 ± 4.53	260.68 ± 19.75	2.06 ± 0.19	108.18 ± 7.92
	Middle	158.04 ± 16.49	2.14 ± 0.21	101.46 ± 8.01	209.20 ± 20.80	1.92 ± 0.25	101.2 ± 10.63
	Below	108.70 ± 7.02	1.36 ± 0.13	64.50 ± 4.82	187.27 ± 14.44	1.73 ± 0.14	101.82 ± 6.79
South-facing slope	Upper	97.86 ± 9.75	1.44 ± 0.17	66.84 ± 5.29	184.81 ± 12.53	2.24 ± 0.17	97.31 ± 6.31
	Middle	112.12 ± 0.27	1.58 ± 0.17	76.25 ± 7.96	246.39 ± 23.99	2.88 ± 0.24	115.61 ± 10.9
	Below	84.32 ± 9.77	1.32 ± 0.13	59.47 ± 5.21	156.73 ± 20.82	2.49 ± 0.34	91.95 ± 8.20
Slope crest		91.19 ± 5.43	1.15 ± 0.09	64.05 ± 3.99	166.67 ± 16.34	1.49 ± 0.14	83.25 ± 6.10

GW and ZW was significantly higher in NRS than in AFS ($P < 0.05$). The litter coverage was slightly higher on the south-facing AFS of ZW than the south-facing NRS of ZW, with averages of 10.9% and 10.8%, respectively ($P = 0.973$). The litter coverage at the other aspects and positions in the two watersheds was significantly higher on NRS than AFS, with the following averages: 22.1% on the north-facing NRS of GW and 12.4% on the north-facing AFS of GW ($P = 0.018$); 26.8% on the south-facing NRS of GW and 10.3% on the south-facing AFS of GW ($P = 0.000$); 23.1% on the north-facing NRS of ZW and 11.8% on the north-facing AFS of ZW ($P = 0.047$) and 17.3% on the crest NRS of ZW and 16.7% on the crest AFS of ZW ($P = 0.871$). On average, the litter coverage on NRS of the two watersheds was 1.7 times higher than that on AFS (Table 3).

3.3. Soil erosion and sediment deposition

3.3.1. Soil erosion

The results (Fig. 5) for AREF were 0.10 m^3 FSP^{-1} in GW, with an average of 0.05 m^3 FSP^{-1} for AREU and 0.05 m^3 FSP^{-1} for ARED, and were 0.09 m^3 FSP^{-1} in ZW, with an average of 0.05 m^3 FSP^{-1} for AREU and 0.05 m^3 FSP^{-1} for ARED. AREF was slightly higher on the north-facing slopes than the south-facing slopes in both GW and ZW, with averages of 0.11 and 0.10 m^3 FSP^{-1} in GW and 0.11 and 0.09 m^3 FSP^{-1} in ZW, though the values were not significant ($P > 0.05$). However, the AREF values on the slope crests, with averages of 0.06 m^3 FSP^{-1} in GW and 0.03 m^3 FSP^{-1} in ZW, were significantly lower than on the north-facing and south-facing slopes ($P < 0.05$).

The AREP values of the non-FSP part of the afforestation slopes in the two watersheds were 15.4 and 17.6% higher than in the NRS, though the values were not significant ($P = 0.459$ and 0.948). On average, AREP on the north-facing slopes was significantly larger than at the other aspects ($P < 0.05$) (Fig. 6).

3.3.2. Sediment deposition

The average depth of sediment deposition ranged from 4.3 to 6.7 cm in ZW and 5.3 to 6.3 cm in GW. The ASDF values in both GW and ZW were higher on the north-facing slopes (0.05 and 0.05 m^3 FSP^{-1}, respectively) than the south-facing slopes (0.04 and 0.04 m^3 FSP^{-1},

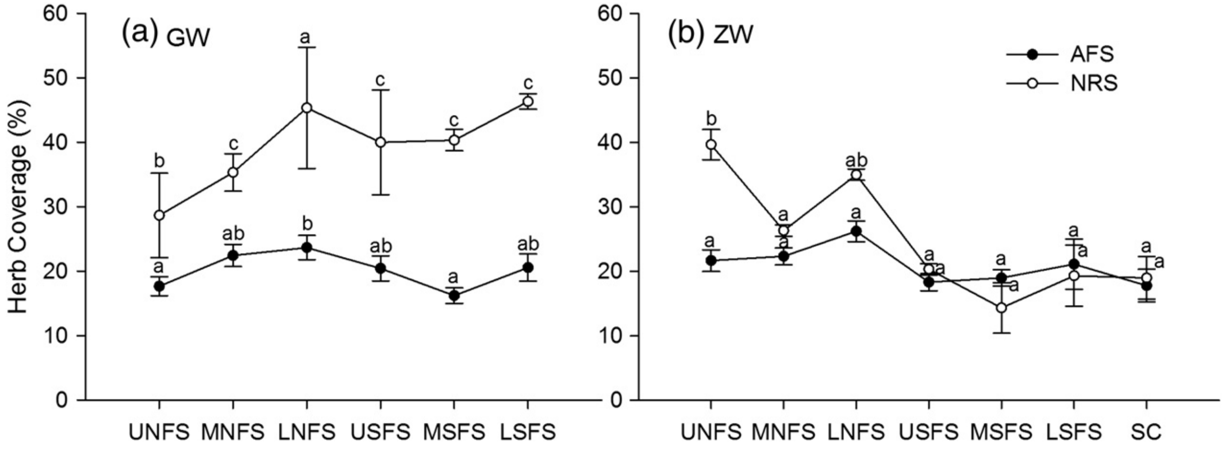

Fig. 4. Herbal coverage of AFS and NRS in GW and ZW. Notes: UNFS, upper position of north-facing slopes; MNFS, middle position of north-facing slopes; LNFS, lower position of north-facing slopes; USFS, upper position of south-facing slopes; MSFS, the middle position of south-facing slopes; LSFS, lower position of south-facing slopes; SC, the slope crest. The same letters in the same column indicate no significant differences between the sites, and different letters indicate significant differences between the sites based on the LSD test ($P < 0.05$).

Table 3
Litter cover and depth of AFS and NRS in GW and ZW (mean ± SD). The same letters in the same column indicate no significant differences between the sites, and different letters indicate significant differences between the sites based on the LSD test ($P < 0.05$).

Watershed	Slope aspect	Position	Afforestation slope		Natural restoration slope	
			Litter coverage (%)	Litter depth (cm)	Litter coverage (%)	Litter depth (cm)
Gaojiagou	North-facing slope	Upper	10.33 ± 0.96a	1.1 ± 0.2	14.33 ± 2.85c	2.0 ± 0.8
		Middle	13.67 ± 1.14a	1.0 ± 0.1	18.00 ± 1.15c	1.2 ± 0.2
		Below	13.22 ± 0.81a	1.6 ± 0.2	34.00 ± 3.79b	2.5 ± 0.3
	South-facing slope	Upper	9.22 ± 1.00a	1.0 ± 0.1	24.67 ± 2.91b	5.3 ± 1.2
		Middle	10.22 ± 1.14a	1.0 ± 0.1	25.67 ± 0.33b	6.7 ± 0.9
		Below	11.56 ± 1.56a	1.4 ± 0.2	30.00 ± 3.06b	6.0 ± 0.6
Zhangjiahe	North-facing slope	Upper	10.11 ± 1.69a	2.6 ± 0.6	22.00 ± 1.86b	3.0 ± 1.0
		Middle	13.11 ± 1.50a	3.4 ± 1.1	17.00 ± 1.15 ac	2.5 ± 1.3
		Below	12.22 ± 2.49a	3.6 ± 0.8	30.33 ± 2.40b	2.5 ± 0.5
	South-facing slope	Upper	8.44 ± 0.75a	1.5 ± 0.3	12.67 ± 1.53bc	8.3 ± 0.3
		Middle	7.67 ± 0.82a	3.3 ± 0.7	5.00 ± 0.58c	5.8 ± 0.2
		Below	16.67 ± 2.51b	3.3 ± 0.6	14.67 ± 2.60b	7.3 ± 0.3
	Slope crest		16.07 ± 2.04ab	4.8 ± 0.9	17.33 ± 2.32b	6.7 ± 1.0

respectively), though not significantly ($P > 0.05$). The values were also lower on the slope crests (0.02 and 0.04 m^3 FSP^{-1}) than on the north-facing and south-facing slopes ($P < 0.05$ in ZW and $P > 0.05$ in GW) (Fig. 9). AREF averaged 54.6% in GW and 52.8% in ZW, higher than ASDF.

4. Discussion

4.1. The survival and growth of trees afforested using FSPs

In this study, the average tree survival rate was 37.9% for planted *R. pseudoacacia* in ZW after 8 years and was 58.9% for planted *P. armeniaca* and *P. davidiana* in GW after 6 years. The survival rate on the north-facing slopes was higher than on the south-facing slopes in the two watersheds (Table 1). However, in a control field experiment in the forest zone of the Loess Plateau near Yan'an City, Cao et al. (2008) planted trees with a new planting technique in which a 60 × 60 × 60-cm^3 hole was created in the spring and lined with plastic film along the bottom and sides. The authors found that the 10-year survival rates of *R. pseudoacacia*, *P. armeniaca* and *P. davidiana* were 84.4%, 56.1% and 64.6%, respectively. Our results indicated that *R. pseudoacacia* afforested with FSPs had a low survival rate, whereas *P. armeniaca* and *P. davidiana* afforested with FSPs in the steppe zone had a similar survival rate as that in the forest zone. Regardless, the growth of all three tree species was weak compared to the results of Cao et al. (2007). For example, *R. pseudoacacia* with the conventional planting in Cao's study after 9-years it was planted was an average of 60.0% taller than that with the FSP planting in the present study after 8-years it was planted. Additionally, all the trees were less than 4 m tall and less than 10 cm at DBH in our study; the trees also exhibited a “small-aged tree” trend in the afforestation with FSPs (Han and Hou, 1996; Yu and Chen, 1996). The main reason for this result might be limited water availability. Indeed, several studies have indicated that water limitation is the major constraint to the survival and growth of afforestation trees in arid regions (Graciano et al., 2005; Ginsberg, 2000; Raffaelli, 2004). In addition, a higher tree survival rate might result in higher soil water consumption, causing relatively more soil water deficit. Moreover, the aspect was the main factor affecting soil moisture. The soil moisture of the *R. pseudoacacia* forest was generally higher on the north-facing slopes than south-facing slopes, thus the *R. pseudoacacia* forest survival rates on the north-facing slopes were higher than on the south-facing slopes (Ma et al., 2010; Zhang and Wang, 2002). Growth (such as tree height, canopy diameter and DBH) is generally higher on north-facing slopes with higher soil water storage than south-facing slopes with lower soil water storage (Wang et al., 2011a), in accordance with our study results. Furthermore, the tree density might be another possible reason for the difference in the tree survival rate and growth. Shibata (2006) found that a thin density is an effective method for producing multiple layered woodlands or improving

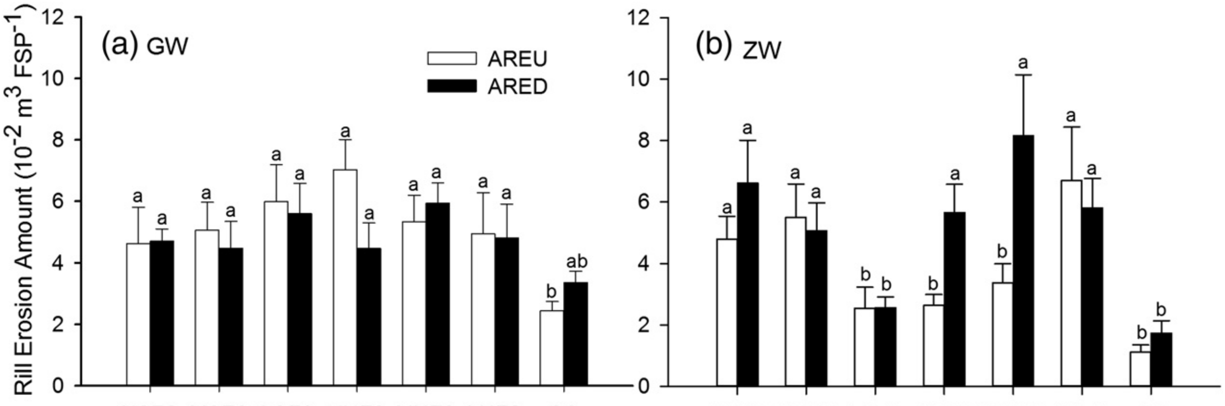

Fig. 5. Rill erosion on the upside and downside areas of FSPs in GW and ZW. Notes: UNFS, upper position of north-facing slopes; MNFS, middle position of north-facing slopes; LNFS, lower position of north-facing slopes; USFS, upper position of south-facing slopes; MSFS, the middle position of south-facing slopes; LSFS, lower position of south-facing slopes; SC, the slope crest. The same letters in the same column indicate no significant differences between the sites, and different letters indicate significant differences between the sites based on the LSD test ($P < 0.05$).

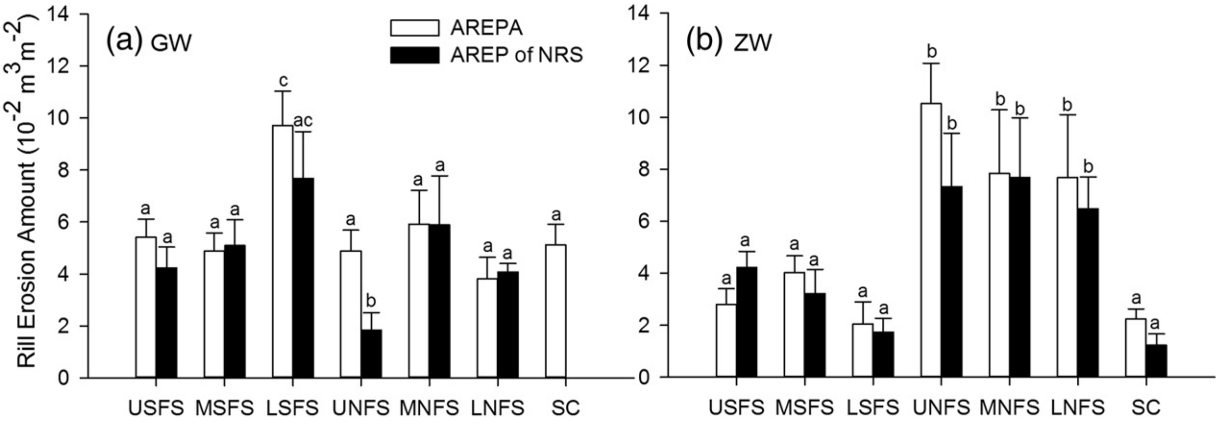

Fig. 6. Rill erosion of the non-FSP part of afforestation slopes and NRS in GW and ZW. Notes: AREPA, rill erosion amount of the non-FSP part on afforestation slopes; UNFS, upper position of north-facing slopes; MNFS, middle position of north-facing slopes; LNFS, lower position of north-facing slopes; USFS, upper position of south-facing slopes; MSFS, the middle position of south-facing slopes; LSFS, lower position of south-facing slopes; SC, the slope crest. The same letters in the same column indicate no significant differences between the sites, and different letters indicate significant differences between the sites based on the LSD test ($P < 0.05$).

the diversity of woodland structure, and the tree survival rate presented a negative correlation with the tree density in the present study ($R = -0.65, P = 0.021$) (Table 1).

4.2. Surface vegetation characteristics on afforestation slopes with FSPs

Vegetation is an important factor in controlling soil erosion and improving the natural environment: it can reduce the impact energy of precipitation, increase soil infiltration and reduce runoff and sediment (Zhou et al., 2006). It has been proven that the high vegetation coverage is helpful to reduce soil erosion (Zhao et al., 2013). Miao et al. (2012) found that the vegetation cover in the Yellow river Basin of China, especially in the water erosion region including the Loess Plateau area, increased sharply since 2000 due to the implementing of "Grain for Green" project. However, drought is a major constraint worldwide to the establishment of vegetation (Schume et al., 2004), and the Loess Plateau region poses a particular challenge for vegetation restoration because of the aridity and the extent of desertification (Cao et al., 2008). The study in Guyuan County of the Loess Plateau indicated that long-term failures of afforestation might occur as a result of water stress and the use of water demanding tree species (König et al., 2012). Several studies have shown that tree growth may have resulted in unsustainable withdrawal of moisture from the soil (Cao et al., 2007). It has been reported that the average soil water content in the 0–500-cm layer of natural herb sites or grassland was significantly more than that of afforested sites (Jiao et al., 2012; Zhao et al., 2013). Furthermore, soil desiccation is often exacerbated by forest or non-native species, which can remove large amounts of water from both the shallow soil layer and the deep soil layer (>200 cm) where moisture is less likely to be replenished by rainfall (Wang et al., 2008). Therefore, a poor afforestation survival rate might lead to reductions in the soil water consumed by tree species and a weak influence of the growth of the herb layer. The results of our study also showed that the herbal coverage in NRS was an average of 1.5 times higher than that in AFS (Fig. 4). Furthermore, the slope aspect is one of the main topographic factors that control the distribution and patterns of vegetation in mountain areas (Titshall et al., 2000) because of the decreased evapotranspiration and higher soil water content on north-facing slopes than on south-facing slopes (Jin et al., 2008; Wang et al., 2008). In agreement, the herb coverage on the north-facing slopes was generally higher than on the south-facing slopes on both AFS and NRS in the two watersheds in the present study.

The accumulation and decomposition of the litter layer provide mass organic matter and nutrients, increase soil porosity, improve soil structure and promote plant root growth (Koukoura et al., 2003; Liu et al., 2010) and can also intercept rainfall, reduce rainfall erosivity, slow surface runoff and reduce soil erosion (Bochet et al., 1998; Fakhimi et al., 2011; Molinar et al., 2001; Ross et al., 1990). Our study showed that the average litter depth and litter coverage of NRS were significantly higher than AFS in the two watersheds ($P < 0.05$). The amount of litter on north-facing slopes is higher than that on the south-facing slopes, with the crest being the lowest on the same slope gradient (Liu et al., 2010), in accordance with our study (Table 3).

4.3. The effect of FSPs on soil erosion

According to our study results, there was no significant difference in rill erosion between the non-FSP parts of AFS and NRS (Fig. 6); however, the total rill erosion on the upside and downside FSPs per ha was 2.14 times the average sediment deposition (Fig. 5, Fig. 7). In contrast, Fu et al. (2009, 2010) showed that FSPs played an important role in reducing sediment under simulated heavy rainstorm conditions in runoff plots (10 m long × 5 m wide), with an average reduction in runoff and sediment above 60% and 90%, respectively. In fact, excavated FSPs with larger-density plantings could inevitably alter the microtopography, thereby destroying the original slope structure and restraining the diversity of the vegetation structure and, thus, making a great contribution to soil degradation and soil erosion (Cerdà et al., 2009; Shibata, 2006). Moreover, while FSPs are filled with sediment or

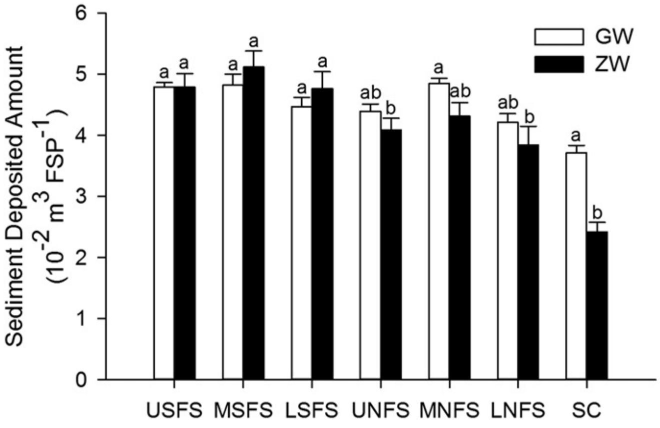

Fig. 7. Amount of sediment deposited inside FSPs in GW and ZW. Notes: UNFS, upper position of north-facing slopes; MNFS, middle position of north-facing slopes; LNFS, lower position of north-facing slopes; USFS, upper position of south-facing slopes; MSFS, the middle position of south-facing slopes; LSFS, lower position of south-facing slopes; SC, the slope crest. The same letters in the same column indicate no significant differences between the sites, and different letters indicate significant differences between the sites based on the LSD test ($P < 0.05$).

destroyed by runoff, the benefit of reduced sediment will rapidly decrease (Shi, 1996). Thus, we conclude that FSPs cannot effectively intercept sediment because of their small storage capacity. The difference in rill erosion between AFS and NRS was derived from the rill erosion in the upside and downside areas of FSPs. Moreover, natural succession requires a long time to establish a stable vegetation cover (Römermann et al., 2005) and may be unacceptably long in regions where soil erosion is a severe problem (Zhao et al., 2005). Planting trees was conducive to soil erosion control (Zhou et al., 2006), yet planted trees could cause a drying of the soil layer in the long term (Shangguan, 2007; Yang and Tian, 2004). Thus, the unsuitable afforestation measures may not ensure the success of afforestation and control soil erosion, such as the afforestation with FSPs in this study. Therefore, the efficiency of large-scale afforestation with FSPs might remain open to debate in such regions.

5. Conclusion

In conclusion, our study demonstrated that the survival rate of *R. pseudoacacia* reforested with FSPs was low (or even no survival), whereas the survival rates of *P. armeniaca* and *P. davidiana* were relatively higher. However, the growth of all three tree species was poor, showing the "small-aged tree" trend. The coverage of herb and litter was lower in AFS than NRS, and the results were significant ($P < 0.05$). The rill erosion caused by FSPs was much higher than the sediment deposition inside the pits, with no effective control of soil erosion. Therefore, we consider that large-scale afforestation with FSPs is unsuitable in the steppe zone on the hilly-gully Loess Plateau.

Acknowledgments

We thank the Knowledge Innovation Program of the Chinese Academy of Sciences (KZCX2-EW-406) and the NSFC projects (41030532) for funding this research and acknowledge the assistance of the Ansai Ecological Experimental Station for Soil and Water Conservation, CAS.

References

Bai, X.Y., Wang, S.J., Xiong, K.N., 2013. Assessing spatial–temporal evolution processes of karst rocky desertification land: indications for restoration strategies. Land Degrad. Dev. 24, 47–56.

Bochet, E., Rubio, J.L., Poesen, J., 1998. Relative efficiency of three representative material species in reducing water erosion at the micro scale in a semi-arid climate (Valencia, Spain). Geomorphology 23, 139–150.

Cao, S.X., Chen, L., Xu, C.G., Liu, Z.D., 2007. Impact of three soil types on afforestation in China's Loess Plateau: growth and survival of six tree species and their effects on soil properties. Landsc. Urban Plan. 83, 208–217.

Cao, S., Chen, L., Liu, Z., Wang, G., 2008. A new tree-planting technique to improve tree survival and growth on steep and arid land in the Loess Plateau of China. J. Arid Environ. 72, 1374–1382.

Cerdà, A., Doerr, S.H., 2007. Soil wettability, runoff and erodibility of major dry-Mediterranean land use types on calcareous soils. Hydrol. Process. 21, 2325–2336.

Cerdà, A., Giménez-Morera, A.Y., Bodí, M.B., 2009. Soil and water losses from new citrus orchards growing on sloped soils in the western Mediterranean basin. Earth Surf. Process. Landf. 34, 1822–1830.

Fakhimi, E., Mesdaghi, M., Dianati, T.G.A., Tavan, M., 2011. Relationships among forage and litter production in three grazing intensities in Nodooshan Rangeland (Yazd, Iran). J. Rangel. Sci. 1, 217–223.

Fu, S.H., Liu, B.Y., Lu, B.J., Yuan, A.P., Wang, N., 2009. Effect of soil conservation practice on runoff and sediment in upper reach of Guanting Reservoir. Sci. Soil Water Conserv. 7, 18–23 (In Chinese).

Fu, S., Liu, B., Zhang, G., Lu, B., Ye, Z., 2010. Fish-scale pits reduce runoff and sediment. Trans. ASABE 53, 157–162.

Ginsberg, P., 2000. Afforestation in Israel: a source of social goods and services. Journal of Forestry 98, 32–36.

Graciano, C., Guiamét, J.J., Goya, J.F., 2005. Impact of nitrogen and phosphorus fertilization on drought responses in *Eucalyptus grandis* seedlings. For. Ecol. Manag. 212, 40–49.

Han, R.L., Hou, Q.C., 1996. An analysis of genesis of small aged trees on the Loess Plateau. Agric. Res. Arid Areas 14, 104–108 (In Chinese with English abstract).

Jiao, J.Y., Tzanopoulos, J., Xofis, P., Mitchley, J., 2008. Factors affecting distribution of vegetation types on abandoned cropland in the hilly–gullied Loess Plateau region of China. Pedosphere 18, 24–33.

Jiao, J., Zhang, Z., Bai, W., Jia, Y., Wang, N., 2012. Assessing the ecological success of restoration by afforestation on the Chinese loess plateau. Restoration Ecology 20, 240–249.

Jin, X.M., Zhang, Y.K., Schaepman, M.E., Clevers, J., Su, Z., 2008. Impact of elevation and aspect on the spatial distribution of vegetation in the Qilian mountain area with remote sensing data. Int. Arch. Photogramm. Remote. Sens. Spat. Inf. Sci. 37, 1385–1390.

König, H.J., et al., 2012. Assessing the impact of the sloping land conversion programme on rural sustainability in Guyuan, Western China. Land Degrad. Dev. http://dx.doi.org/10.1002/ldr.2164.

Koukoura, Z., Mamolos, A.P., Kalburtji, K.L., 2003. Decomposition of dominant plant species litter in semi-arid grassland. Appl. Soil Ecol. 23, 13–23.

Li, X.H., Yang, J., Zhao, C.Y., Wang, B., 2012. Runoff and sediment from orchard terraces in southeastern China. Land Degrad. Dev. http://dx.doi.org/10.1002/ldr.1160.

Li, X.L., et al., 2013. Rangeland degradation on the Qinghai–Tibet Plateau: implications for rehabilitation. Land Degrad. Dev. 24, 72–80.

Liu, Z.Q., Shu, Q.K., Kuang, G.M., Wang, J., Li, P., Zhao, H., Zhao, L.L., 2010. Study on the distribution pattern of vegetation litter in fenced watershed in semi-arid loess hilly and gully region. Pratacult. Sci. 27, 20–24 (In Chinese with English abstract).

Liu, Z., Yao, Z., Huang, H., Wu, S., Liu, G., 2012. Land use and climate changes and their impacts on runoff in the Yarlung Zangbo River Basin, China. Land Degrad. Dev. http://dx.doi.org/10.1002/ldr.1159.

Ma, H.B., Xie, Y.Z., Wei, Q.H., 2006. Influence of different site preparing modes on species diversity of grassland plant communities in loess hilly area of southern Ningxia. J. Agric. Sci. 27, 1–4 (in Chinese).

Ma, J.X., Xiao, L., Guan, S.P., Zhang, S.J., Zhang, Y.H., 2010. Study on the relationship between the soil moisture and the site factors of *Robinia pseudoacacia* plantation forestland in Loess Plateau. Chin. J. Soil Sci. 41, 1311–1315 (In Chinese with English abstract).

Miao, C.Y., Yang, L., Chen, X.H., Gao, Y., 2012. The vegetation cover dynamics (1982–2006) in different erosion regions of the Yellow River Basin, China. Land Degradation & Development 23, 62–71.

Molinar, F., Galt, D., Holechek, J., 2001. Managing for mulch. Rangelands 23, 3–7.

Nyamadzawo, G., Shukla, M., Lal, R., 2008. Spatial variability of total soil carbon and nitrogen stocks for some reclaimed mine soils of southeastern Ohio. Land Degrad. Dev. 19, 275–288.

Pimentel, D., Kounang, N., 1998. Ecology of soil erosion in ecosystems. Ecosystems 1, 416–426.

Querejeta, J.I., Roldán, A., Albaladejo, J., Castillo, V., 2001. Soil water availability improved by site preparation in a *Pinus halepensis* afforestation under semiarid climate. For. Ecol. Manag. 149, 115–128.

Raffaelli, D., 2004. How extinction patterns affect ecosystems. Science 306, 1141–1142.

Raizada, A., Juyal, G.P., 2012. Tree species diversity, species regeneration and biological productivity of seeded *Acacia catechu* Willd. In rehabilitated limestone mines in the northwest Indian Himalayas. Land Degrad. Dev. 23, 167–174.

Renard, K.G., McCool, D.K., Cooley, K.R., Foster, G.R., Istok, J.D., Mutchler, C.K., 1997. Rainfall-runoff erosivity factor (R). Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE). Department of Agriculture, Agriculture Handbook, U.S., pp. 19–64.

Rigueiro-Rodríguez, A., Mosquera-Losada, M.R., Fernández-Núñez, E., 2012. Afforestation of agricultural land with *Pinus radiata* D. don and *Betula alba* L. in NW Spain: effects on soil PH, understorey production and floristic diversity eleven years after establishment. Land Degrad. Dev. 23, 227–241.

Roberts, J., Daniels, W., Bell, J., Martens, D., 1988. Tall fescue production and nutrient status on southwest Virginia mine soils. J. Environ. Qual. 17, 55–62.

Römermann, C., Dutoit, T., Poschlod, P., Buisson, E., 2005. Influence of former cultivation on the unique Mediterranean steppe of France and consequences for conservation management. Biol. Conserv. 121, 21–33.

Ross, S.M., Thornes, J.B., Nortcliff, S., 1990. Soil hydrology, nutrient and erosional response to the clearance of terra firme forest, Maraca Island, Roraima, northern Brazil. Geogr. J. 156, 267–282.

Schume, H., Jost, G., Hager, H., 2004. Soil water depletion and recharge patterns in mixed and pure forest stands of European beech and Norway spruce. J. Hydrol. 289, 258–274.

Shangguan, Z.P., 2007. Soil desiccation occurrence and its impact on forest vegetation in the Loess Plateau of China. Int. J. Sustain. Dev. World Ecol. 14, 299–306.

Shi, S., 1996. Impact of measures of afforestation with engineering preparation to strengthening rainfall infiltration and reducing sediment. Journal of Soil Erosion and Soil and Water Conservation 2, 55–62 (in Chinese).

Shi, H., Shao, M.A., 2000. Soil and water loss from the Loess Plateau in China. J. Arid Environ. 45, 9–20.

Shibata, S., 2006. Effect of density control on tree growth at ecological tree planting sites in Japan. Landsc. Ecol. Eng. 2, 13–19.

Sun, G., Zhou, G.Y., Zhang, Z.Q., Wei, X.H., McNulty, S.G., Vose, J.M., 2006. Potential water yield reduction due to forestation across China. J. Hydrol. 328, 548–558.

Sunström, E., Hånell, B., 1999. Afforestation of low-productivity peatlands in Sweden—the potential of natural seeding. New For. 18, 113–129.

Tang, K.L., Zhang, K.L., Lei, A.L., 1998. Critical slope gradient for compulsory abandonment of farmland on the hilly Loess Plateau. Chin. Sci. Bull. 43, 409–412 (In Chinese).

Titshall, L.W., O'Connor, T.G., Morris, C.D., 2000. Effect of long-term exclusion of fire and herbivory on the soils and vegetation of sour grassland. Afr. J. Range Forage Sci. 17, 70–80.

Van, D.A., Keenan, R.J., 2007. Planted forests and water in perspective. For. Ecol. Manag. 251, 1–9.

Wang, L., Shao, M.A., Zhang, Q.F., 2004. Distribution and characters of soil dry layer in north Shaanxi Loess Plateau. Chin. J. Appl. Ecol. 15, 436–442 (In Chinese).

Wang, L., Wang, Q.J., Wei, S.P., Shao, M.A., Li, Y., 2008. Soil desiccation for Loess soils on natural and regrown areas. For. Ecol. Manag. 255, 2467–2477.

Wang, L., Wei, S.P., Horton, R., Shao, M.A., 2011a. Effects of vegetation and slope aspect on water budget in the hill and gully region of the Loess Plateau of China. Catena 87, 90–100.

Wang, N., Jiao, J.Y., Jia, Y.F., Zhang, X.A., 2011b. Soil seed bank composition and distribution on eroded slopes in the hill–gully Loess Plateau region (China): influence on natural vegetation colonization. Earth Surf. Process. Landf. 36, 1825–1835.

Wei, J., Zhou, J., Tian, J.L., He, X.B., Tang, K.L., 2006. Decoupling soil erosion and human activities on the Chinese Loess Plateau in the 20th century. Catena 68, 10–15.

Worrell, R., Hampson, A., 1997. The influence of some forest operations on the sustainable management of forest soils—a review. Forestry 70, 61–85.

Yang, W.Z., Tian, J.L., 2004. Essential exploration of soil aridization in Loess Plateau. Acta Pedol. Sin. 41, 1–6 (In Chinese).

Yu, X.X., Chen, L.H., 1996. The countermeasures to combat small but old trees in Loess area of west Shanxi. J. Arid Land Res. Environ. 10, 81–86 (In Chinese with English abstract).

Zhang, J.G., Wang, X.P., 2002. Issue on preferential species of certain soil in re-afforestation Engineering of Gansu, Ningxia, Inner Mongolia and Shaanxi. J. Desert Res. 22, 489–494 (In Chinese with English abstract).

Zhang, X.C., Shao, M.A., Li, S.Q., Peng, K.S., 2004. A review of soil and water conservation in China. J. Geogr. Sci. 14, 259–274.

Zhao, W.Z., Xiao, H.L., Liu, Z.M., Li, J., 2005. Soil degradation and restoration as affected by land use change in the semiarid Bashang area, northern China. Catena 59, 173–186.

Zhao, X., Wu, P., Gao, X., Persaud, N., 2013. Soil quality indicators in relation to land use and topography in a small catchment on the Loess Plateau of China. Land Degrad. Dev. http://dx.doi.org/10.1002/ldr.2199.

Zheng, F.L., Tang, K.L., Zhou, P.H., 1989. Study on factors affecting rill erosion on cultivated slope land. Acta Pedol. Sin. 26, 109–116 (In Chinese).

Zhou, Z.C., Shangguan, Z.P., Zhao, D., 2006. Modeling vegetation coverage and soil erosion in the Loess Plateau area of China. Ecol. Model. 198, 263–268.