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Soil properties in natural grassland, *Caragana korshinskii* planted shrubland, and *Robinia pseudoacacia* planted forest in gullies on the hilly Loess Plateau, China

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ABSTRACT

Revegetation plays an important role in controlling soil erosion and improving eco-environmental conditions on the Loess Plateau in China, yet little is known about its beneficial effect on soil properties in gully areas. In this study, we examined the relationship between three revegetation types and ten soil properties along five gully position transects on the loess hilly region of Ansai County, China. Three different vegetation restoration patterns in gullies included 1) an artificial *Robinia pseudoacacia* forest (G-Rp), 2) an artificial *Caragana korshinskii* shrubland (G-Ck), and 3) a natural grassland (G-Ng). After two decades of revegetation in the gully area, overall levels of C, N, P (except between G-Rp and G-Ck), and available K in the accumulated soil were similar between revegetation types in the gully areas. However, there were significant differences in levels of nitrate, ammonium, available P, and soil pH between the revegetated gullies. Soil properties mainly increased in quality from the top to the bottom of gully areas, except at the bottom of the G-Rp. Non-metric multidimensional scaling (NMS) ordinations and multi-response permutation procedure (MRPP) analyses indicated that soil properties significantly differed depending on revegetation types and gully positions. Our results demonstrate that soil properties could be improved by different revegetation types in the gully areas, and artificial plantations could significantly better improve available soil nutrients than natural grasslands in the gully areas. Thus, artificial revegetation could be a valuable measure for controlling soil erosion, and improving eco-environmental conditions in the gully areas of the Loess Plateau.

1. Introduction

The Loess Plateau in China has suffered from serious soil erosion and ecosystem degradation. Controlling soil erosion and establishing a healthy ecosystem on the Loess Plateau is a long-term and arduous task. It has been reported that vegetation can significantly control soil erosion (Gyssels et al., 2005; Zheng, 2006), and revegetation is the most effective and useful way not only for controlling soil erosion, but also for improving eco-environmental conditions (Molina et al., 2009a; Zhou et al., 2006). Restored vegetation can directly protect soil surfaces from soil erosion by establishing canopy, roots, litter components, and by indirectly improving physical and chemical soil properties (De Baets et al., 2007; Molina et al., 2009b; Rey, 2003). Although significant efforts to recover vegetation in the Loess Plateau can be traced back to the 1950s (Chen et al., 2007), including the implementation of the Grain-to-Green Program in 1999 (Zhou et al., 2012), the suitability of various revegetation strategies remains controversial (Cao et al., 2009; Jiao et al., 2012). Therefore, assessment of eco-environmental benefits of various revegetation practices will be helpful to make effective and sustainable guidelines for revegetation programs.

Topography, as a vital environmental factor, shapes various ecological processes, such as biological, chemical, physical, and hydrological processes (Lan et al., 2011; Sariyildiz et al., 2005; Zhang et al., 2013b). Gullies are an important topographic factor in the Loess Plateau area, accounting for 42% of the total land, and with a density of 1.5–4.0 $km \cdot km^{-2}$ (Zheng et al., 2006). In the hilly loess regions with the highest erosion rates, hills and gullies comprise approximately 56.6% and 43.4% of the total area, respectively. However, runoff volume in the gully areas comprises 59.3–83.5% of the total runoff volume, and contributes to 57.9–69.5% of the total sediment production (Liu et al., 2008). Although vegetation plays significant roles in reducing gully erosion (Valentin et al., 2005; Zheng, 2006), the lack of knowledge of the relationships between recovery vegetation types and environmental changes hampers implementation of effective revegetation program in the gully areas of the Loess Plateau.

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Revegetation in those gully areas comprises past artificial patch plantations and natural vegetations. The plant species *Robinia pseudoacacia* L. (black locust) and *Caragana korshinskii* Kom. are widely used to restore vegetation on the Loess Plateau. *R. pseudoacacia* is a North American legume deciduous woody tree species, and due to its rapid growth, high quality wood, drought tolerance, and nitrogen fixation characteristics, this exotic pioneer plant has been widely planted in afforestation programs on the Loess Plateau (Tateno et al., 2007; Zheng et al., 2011). Furthermore, *C. korshinskii* is a long-lived leguminous deciduous shrub species, and due to drought resistant, rapid sprouting growth rate, and nitrogen fixation characteristics, this native pioneer plant is widely used for revegetation in desert and semi-desert zones, and the Loess Plateau of the northwestern China (Fang et al., 2008; Jia et al., 2010). Nowadays *R. pseudoacacia* and *C. korshinskii* plantations on the Loess Plateau prevent soil erosion and degradation, and significantly improve soil fertility (Qiu et al., 2010; Xue et al., 2007; Zhang et al., 2007; Zheng et al., 2011).

Various studies indicated that revegetation on the Loess Plateau will significantly and positively affect many habitat conditions by improving the stability, nutrients, and biological properties of soil, and community biodiversity (An et al., 2013; Jia et al., 2011; Jiao et al., 2012), and (especially related to artificial plantations) negatively or potentially affect local ecological environment by reducing soil water (Chen et al., 2008; Wang et al., 2009). However, most of the reports were based on the same landforms (hilly areas), which generally have significantly diverse site conditions (e.g. microclimate, hydrology, soil nutrient, and species) compared to those in gully areas, and those differences may have a natural and potential influence on revegetation development and may further affect the changes in soil properties. To date, few studies have examined ecological changes in gullies (Gao et al., 2011; Wei et al., 2009). Gao et al. (2011) showed that soil moisture patterns in gullies differ substantially from those in uplands. Wei et al. (2009) suggested that vegetation restoration of gully should be taken with different management measures compared to hilly areas. Therefore, regarding the high proportion of gullies (42%) in the Loess Plateau, further investigations of the spatio-temporal variability in vital ecological factors and processes are required.

In a previous study, Zhang and Liu (2010) investigated the vegetation biodiversity and biomass of three different vegetation restoration patterns in gullies, where the three gullies with similar soil type, climate, and physiographic conditions and with initial plant species *R. pseudoacacia*, *C. korshinskii*, and natural grassland, representing the herbaceous, shrub, and tree flora of this region. Because the three gullies were not disturbed by grazing or human activity after vegetation establishment and a similar initial soil conditions, thus subsequent differences in soil properties may reflect the effects of successive plant communities in the three gullies. Here we collected soil samples from five gully positions in each of the three gullies. Our objectives were to (i) evaluate the differences in soil properties between gullies, and (ii) examine the differences in soil properties between gully positions. The rationale was to evaluate the effects of revegetation types on soil properties in gully areas to help practitioners for designing gully restoration.

2. Materials and methods

2.1. Study area

Ansai County (36°31′–37°20′N and 108°52′–109°26′E) covers an area of 2951 km^2 and is located in the middle of the Loess Plateau of the northern Shaanxi Province, China (Fig. 1). Ansai has a typical semi-arid continental climate with an average temperature of 8.6 °C and an average annual precipitation of 500 mm, with high variability (about 74% of the rain falls between July and September). The landform is a typical loess hilly–gullied landscape with elevations ranging from 997 to 1731 m above sea level (Zhang et al., 2013a). Gullies occupy approximately 36% of the total area (Jiao et al., 2004), with a gully density of about 4.7 km·km^{-2}. The main soils are developed from loess parent material and are classified as Calcic Cambisols (Wang et al., 2003), which are characterized by a yellow color, absence of bedding, silty texture, looseness, macroporousness, and wetness-induced collapsibility (Jiao et al., 2008). The soils have a rather homogenous silty loam texture over the county, comprising 60–75% silt, less than 15% clay, and less than 30% sand. The soil pH is more than 8.0 with a high content of $CaCO_3$ (mostly 9–14%) over the whole soil depth. In the floodplains, the soils have a relatively coarser texture, higher soil fertility and lower content of $CaCO_3$ (Lu et al., 2003). The zonal vegetation is forest–shrub–steppe, due to long-term human activities, most of the natural vegetation has been removed. Current vegetation includes a sparse secondary forest, artificial vegetation, and natural grassland, which largely consists of shrubby grassland, steppe, and low humid grassy marshland. Artificial vegetation includes peer tree species such as *R. pseudoacacia*, *Prunus armeniaca*, *Hippophae rhamnoides*, *Platycladus orientalis*, and *C. korshinskii*.

2.2. Gully sampling

For assessment of the benefits of different vegetation restoration patterns on soil properties, three south–north V-shaped gullies with similar soil type, climate, and physiographic conditions and with initial plant species *R. pseudoacacia*, *C. korshinskii*, and natural grassland, were selected to represent three widely representative vegetation restoration (herbaceous, shrub, and tree flora) patterns (Table 1):

Artificial forest restoration patterns: The artificial *R. pseudoacacia* forest gully (G-Rp) is situated in the Duntanshan watershed (Fig. 1a). Indigenous inhabitants conducted ecological restoration with non-native *R. pseudoacacia* in 1984.

Artificial shrub restoration patterns: The artificial *C. korshinskii* shrubland (G-Ck) is situated in the Duntanshan watershed and ecological restoration was conducted with *C. korshinskii* by the Ansai Research Station of Soil and Water Conservation in 1989 (Fig. 1b).

Natural restoration pattern: The natural grassland gully (G-Ng) is situated in the Zhifanggou watershed and undergoing natural vegetation succession since 1987 (Fig. 1c).

For this study, five transects along different gully slope positions (W-upper, W-lower, bottom, E-lower, and E-upper; Fig. 2) were established in each study gully. To survey vegetation and sample soil properties, ten 5 m × 5 m plots with 15–25 m intervals were set up at each transect, as described in Zhang and Liu (2010). A total of 150 plots were established, including 50 plots for each study gully.

2.3. Data collection

Composite soil samples were collected up to a depth of 0–20 cm from six points within each plot in an S-shaped pattern. Soil samples were air-dried and passed through 1- and 0.25-mm sieves. Soil organic carbon (SOC) was determined using the $K_2Cr_2O_7$ titration method (Walkley–Black method). Total nitrogen (TN) was measured using the semi-micro Kjeldahl method. Soil C:N ratio was determined according to the ratio of SOC and TN. Total phosphorus (TP) was determined colorimetrically after wet digestion with $H_2SO_4 + HClO_4$. Nitrate (NO_3^-) and ammonia (NH_4^+) were measured using a micro-diffusion technique after potassium chloride extraction. Available phosphorus (AP) was colorimetrically measured using the Olsen method. Available potassium (AK) was determined using flame photometry after extraction with 1-M NH_4OAc. Soil pH was measured at a soil-to-water ratio of 1:2.5. Bulk density (BD) was measured as the ratio of dry soil mass to bulk soil volume (Editorial, 1996). All measurements were made at the Institute of Soil and Water Conservation, Chinese Academy of Science and Ministry of Education, China.

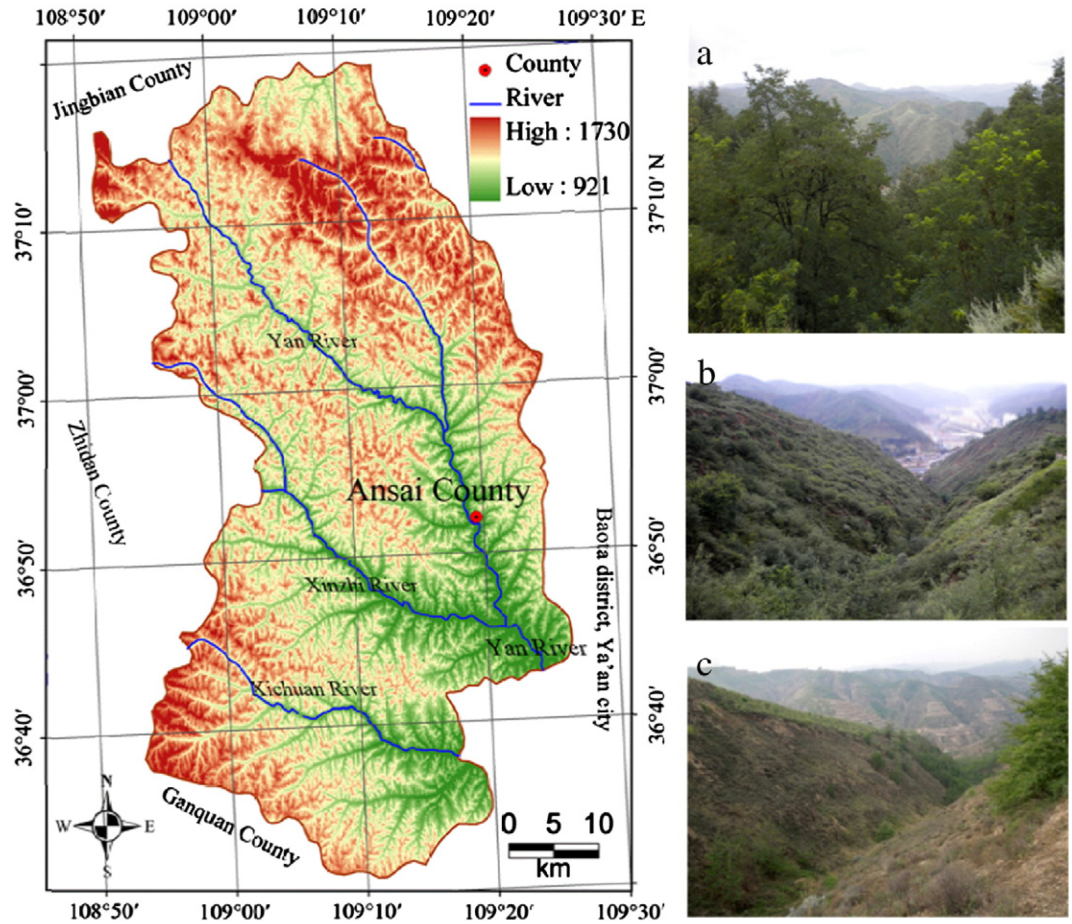

Fig. 1. DEM model of study area (revised from Zhou et al., 2012) and photographs of three revegetation gullies (b). Photograph a, the artificial *Robinia pseudoacacia* forest gully; photograph b, the artificial *Caragana korshinskii* shrubland gully; and photograph c, the natural grassland gully.

2.4. Statistical analysis

We used both univariate and multivariate approaches to explore potential effects of different vegetation restoration patterns on soil properties in the gully ecosystems. The one-sample Kolmogorov–Smirnov test (K–S) ($P < 0.05$) was used to test the normality of data. Significant differences between the variables measured among the gullies were identified using one-way ANOVA and LSD multiple comparison tests. Two-tailed paired t-tests were used to determine differences in the nine soil properties between the gullies. All the summary statistics were obtained using the SPSS 17.0. We also tested for differences in overall soil properties between the different vegetation restoration pattern gullies, using nonmetric multidimensional scaling (NMS) ordination and multi-response permutation procedure (MRPP; Mielke and Berry, 2007) by using PC-ORD version 4.0 (McCune and Mefford, 1999).

Differences in soil properties between the three different vegetation restoration pattern gullies were visualized by using NMS ordinations from relative abundance data. We constructed the model using measurements of nine soil nutrient properties in all samples ($n = 150$). Because variables ranged widely, data were transformed to proportions relative to the highest value for each variable (i.e., each value in a column was divided by the largest value in its column, creating a range from 0 to 1 for each column). NMS analysis was run with Euclidean distance, a user-supplied (4000) as the random seed for the starting configuration, 400 maximum iterations, 0.2 for the instability criterion, 4 starting axes, 40 real runs and 40 randomized runs and a 0.005 stability criterion.

MRPP was used to test for significant differences in soil properties between the different vegetation restoration pattern gullies and gully positions (Mielke and Berry, 2007). Multivariate data were grouped in multiple permutations and the strength of groupings can be tested using MRPP. MRPP results are expressed as test statistics (T), chance-corrected within-group agreement measures (A) and corresponding P values. The A statistic describes within-group homogeneity compared to that expected from randomized data, such that $A = 1$ when all samples within the group are identical to each other and $A = 0$ when the samples within the group are completely different. The MRPP used chi-squared distance with all gullies (three gullies) and all gully

Table 1
Site descriptions of three different vegetation restoration pattern gullies.

Sites	Longitude (E)	Latitude (N)	Restoration years (yr)	Gully bed length (m)	Elevation (m)	Slope degree (°)	Vegetation patterns
G-Rp	109°18′22.10″	36°51′17.38″	24	780	1100–1300	25–52	Artificial *Robinia pseudoacacia* forest
G-Ck	109°18′55.00″	36°51′25.32″	19	760	1090–1250	25–59	Artificial *Caragana korshinskii* forest
G-Ng	109°15′38.26″	36°45′4.20″	21	620	1080–1275	20–45	Natural grassland

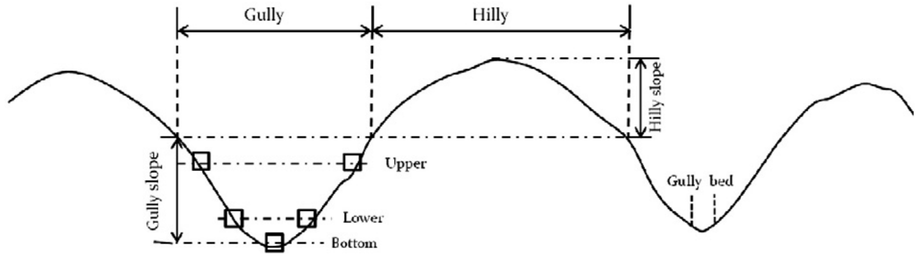

Fig. 2. Distribution of sampling quadrats (squares) along gully slope positions (upper, lower, and bottom of the gully slope) of cross sections in each study gully.

positions (3 gullies × 5 gully positions) as the a priori groupings based on nine soil variable data, and for pairwise comparisons between gullies and gully positions to test for the strength of differences between individual treatments.

3. Results

3.1. Differences in soil properties between gullies

Summary statistics for the ten soil properties from the different vegetation restoration pattern gullies are given in Table 2 and significant differences are presented in Table 3. The coefficient of variation (CV) is an index of the overall variation or heterogeneity of a given variable. In general, soil properties varied between 0.55% and 52.51% under the different vegetation restoration pattern gullies (Table 2) and the data (CV < 90%) was thus defined as moderately variable (Nielsen and Bouma, 1985). NO_3^- (CV = 26.5–52.5%) and AP (CV = 28.2–38.6%) were the two most variable of soil properties. Spatial SOC (CV = 22.7–5.45%), TN (CV = 19.0–27.6%), soil C:N (CV = 11.5–32.6%), NH_4^+ (CV = 20.7–21.4%), and AK (CV = 24.9–28.4%) moderately varied among three vegetation restoration pattern gullies. BD (CV = 7.0–10.9%), TP (CV = 5.3–5.5%), and soil pH (CV = 0.6–0.7%) had the lowest coefficients of variation (CV < 10%). No significant differences in mean SOC, TN, soil C:N ratio, AK, and BD values were observed between the three vegetation restoration pattern gullies (two-tailed t-test; Table 3). However, significant differences in AP and pH were observed between the three vegetation restoration pattern gullies. Moreover, significant differences in TP, NO_3^-, and NH_4^+ were identified between G-Rp and G-Ck, and NO_3^- content significantly differed between G-Ck and G-Ng, as well as NH_4^+ content significantly differed between G-Rp and G-Ng (Table 3). These results indicated that different restored vegetation types have strongly affected the soil contents of AP, nitrate, ammonium, and soil pH, which may be related to the biological characteristics of the dominant plant species.

The final stress for the three-dimensional NMS ordination was 18.9. Axis 1, axis 2, and axis 3 explained 24%, 55%, and 18% of the variation, respectively, thus explaining a total of 97% of variance. NMS ordination of the 150 samples based on 9 initial soil properties arrayed the samples along two axes (axes 1 and 2) that accounted for approximately 79% of the variance (Fig. 3). G-Rp was located at the upper end of axis 1 and accounted for approximately 24% of variance, whereas G-Ck was located at the lower end of axis 1. This axis positively correlated with AP ($r^2 = 0.461$), and negatively correlated with NH_4^+ ($r^2 = -0.801$), Soil C:N ($r^2 = -0.220$) (Fig. 3). Only a marginal separation among the three gullies is indicted along axis 2. This axis was positively correlated with AK ($r^2 = 0.866$), SOC ($r^2 = 0.828$), NO_3^- ($r^2 = 0.766$),

Table 2
Summary statistics for nine soil properties of three different vegetation pattern gullies.

Sites	Properties	Min	Max	Mean	SD	CV	Skewness	Kurtosis	Distribution*
G-Rp	SOC ($g \cdot kg^{-1}$)	2.30	7.94	5.40	1.32	24.44	−0.25	0.03	Y
	TN ($g \cdot kg^{-1}$)	0.28	0.84	0.56	0.13	23.21	0.01	−0.24	Y
	TP ($g \cdot kg^{-1}$)	0.48	0.63	0.57	0.03	5.26	−0.24	−0.38	Y
	Soil C:N ratio	4.70	13.58	9.64	1.11	11.51	−0.99	10.81	Y
	NO_3^- ($mg \cdot kg^{-1}$)	1.35	10.59	4.99	2.48	49.70	0.66	−0.52	Y
	NH_4^+ ($mg \cdot kg^{-1}$)	6.95	20.92	9.90	2.12	21.41	3.19	16.14	Y
	AP ($mg \cdot kg^{-1}$)	1.58	7.70	3.50	1.35	38.57	0.85	0.65	Y
	AK ($mg \cdot kg^{-1}$)	77.52	227.60	133.44	37.83	28.35	0.74	−0.32	Y
	Soil pH	8.50	8.73	8.62	0.05	0.58	−0.32	0.31	Y
	BD ($g \cdot cm^{-3}$)	0.92	1.45	1.10	0.12	10.90	1.08	1.25	Y
G-Ck	SOC ($g \cdot kg^{-1}$)	2.78	10.33	5.74	1.61	28.05	0.58	0.70	Y
	TN ($g \cdot kg^{-1}$)	0.25	1.06	0.58	0.16	27.59	0.28	0.98	Y
	TP ($g \cdot kg^{-1}$)	0.49	0.60	0.55	0.03	5.45	−0.22	−0.81	Y
	Soil C:N ratio	3.18	30.27	10.27	3.35	32.62	4.63	28.72	–
	NO_3^- ($mg \cdot kg^{-1}$)	0.68	10.48	3.98	2.09	52.51	1.03	0.99	Y
	NH_4^+ ($mg \cdot kg^{-1}$)	7.02	23.99	19.66	4.06	20.65	−2.10	4.07	–
	AP ($mg \cdot kg^{-1}$)	0.90	4.29	2.25	0.73	32.44	0.53	0.41	Y
	AK ($mg \cdot kg^{-1}$)	66.16	195.03	131.38	35.36	26.91	0.04	−1.03	Y
	Soil pH	8.56	8.83	8.68	0.06	0.69	0.06	−0.06	Y
	BD ($g \cdot cm^{-3}$)	0.95	1.37	1.09	0.08	7.00	3.20	1.29	Y
G-Ng	SOC ($g \cdot kg^{-1}$)	3.06	8.66	5.76	1.31	22.74	0.19	−0.54	Y
	TN ($g \cdot kg^{-1}$)	0.39	0.80	0.58	0.11	18.97	0.16	−0.69	Y
	TP ($g \cdot kg^{-1}$)	0.49	0.63	0.56	0.03	5.36	0.01	−0.46	Y
	Soil C:N ratio	6.82	16.41	9.97	1.47	14.74	1.85	7.01	Y
	NO_3^- ($mg \cdot kg^{-1}$)	2.09	8.88	5.24	1.39	26.53	−0.1	0.41	Y
	NH_4^+ ($mg \cdot kg^{-1}$)	9.72	29.12	18.73	3.97	21.20	0.46	0.86	Y
	AP ($mg \cdot kg^{-1}$)	0.84	2.69	1.70	0.48	28.24	0.05	−0.44	Y
	AK ($mg \cdot kg^{-1}$)	85.53	218.86	130.15	32.43	24.92	1.11	0.47	Y
	Soil pH	8.47	8.72	8.64	0.06	0.69	−0.84	0.71	Y
	BD ($g \cdot cm^{-3}$)	0.95	1.28	1.08	0.08	7.10	−0.54	0.36	Y

*Note: "Y" = normal and "–" = not tested by One-Sample Kolmogorov–Smirnov test.

Table 3
Differences in soil properties among pairwise comparisons between gullies based on two-tailed paired t-tests and F test.

Groups	Test	SOC	TN	TP	Soil C:N	NO_3^-	NH_4^+	AP	AK	pH	BD
G-Rp vs. G-Ck	F (sig.)	0.418	0.459	0.388	0.091	0.185	0.006	0.000	0.714	0.123	0.007
	t (sig. 2-tailed)	0.273	0.535	0.009	0.232	0.037	0.000	0.000	0.787	0.000	0.831
G-Rp vs. G-Ng	F (sig.)	0.762	0.251	0.958	0.122	0.000	0.001	0.000	0.140	0.143	0.023
	t (sig. 2-tailed)	0.189	0.494	0.178	0.226	0.545	0.000	0.000	0.648	0.024	0.422
G-Ck vs. G-Ng	F (sig.)	0.544	0.086	0.343	0.300	0.005	0.762	0.020	0.234	0.883	0.396
	t (sig. 2-tailed)	0.950	0.935	0.202	0.567	0.001	0.260	0.000	0.859	0.003	0.432

Note: G-Rp, artificial *Robinia pseudoacacia* forest gully; G-Ck, artificial *Caragana korshinskii* shrubland gully; G-Ng, natural grassland gully; SOC, soil organic carbon; TN, total nitrogen; TP, total phosphorus; soil C:N, soil C:N ratio; NO_3^-, nitrate nitrogen; NH_4^+, ammonia nitrogen; AP, available phosphorus; AK, available potassium; pH, soil pH; and BD, bulk density.

TN ($r^2 = 0.775$), and BD ($r^2 = 0.546$) and negatively correlated with pH ($r^2 = -0.412$) (Fig. 3).

3.2. Differences in soil properties between gully positions

Soil NO_3^- (Fig. 4e), NH_4^+ (Fig. 4f), AP (Fig. 4g), AK (Fig. 4h), soil pH (Fig. 4i), and BD (Fig. 4j) significantly differed between the gully positions. Associations between soil SOC (Fig. 4a) and TN (Fig. 4b) and vegetation restoration patterns slightly differed but are significant at the bottom of gullies. TP (Fig. 4c) also differed slightly but significantly between the three vegetation restoration patterns at W-upper gully position. However, soil C:N ratio (Fig. 4d) did not differ significantly between vegetation restoration patterns and gully positions.

Differences in soil properties between the three different vegetation restoration pattern gullies (G-Rp, G-Ck, and G-Ng) and gully positions (W-upper, W-lower, bottom, E-lower, and E-upper) were tested using MRPP (Table 4). All comparisons showed highly significant ($P < 0.001$) and significant ($P < 0.05$) differences between gully positions of G-Rp, warranting rejection of the null hypothesis on the basis of high within-group agreement and very strong separation between groups (Table 4). The lowest A value among gully comparisons is 0.066 (G-Rp vs. G-Ng) indicating that the largest differences in soil properties were between artificial tree restoration gully and natural restoration gully. The lowest A value from gully position comparisons is 0.058 (gully positions of G-Rp) indicating that the largest difference in soil properties was between gully positions of G-Rp.

4. Discussion

The revegetation of degraded land is one of the principal strategies for controlling soil erosion and improving eco-environmental conditions in the Chinese Loess Plateau, where has a fragile natural ecosystems characteristic and unique geographical conditions (Tang et al., 2008). Restored vegetation in the gully areas can play significant roles in reducing gully erosion (Valentin et al., 2005; Zheng, 2006), improving plant biodiversity (Zhang and Liu, 2010), and greatly affecting soil properties. In our study, soil properties significantly differed between the three gullies where different restoration actions were applied, and varied depending on positions within the gullies (Fig. 4 and Table 4). Our data indicated that soil properties were improved by restored vegetation, which largely varied with revegetation types and topographic factors.

4.1. Differences in soil properties between gullies

Soil properties significantly differed among the three vegetation restoration patterns in gullies (Fig. 3). In general, after two decades of revegetation in the gully areas, the overall C, N, P (except between G-Rp and G-Ck), and AK accumulated in soils at similar levels regardless of revegetation types. However, significant differences in nitrate, ammonium, AP, and soil pH were observed between gully areas with different revegetation types (Table 2). These differences were highly similar to those reported by Qiu et al. (2010), who showed differences in soil

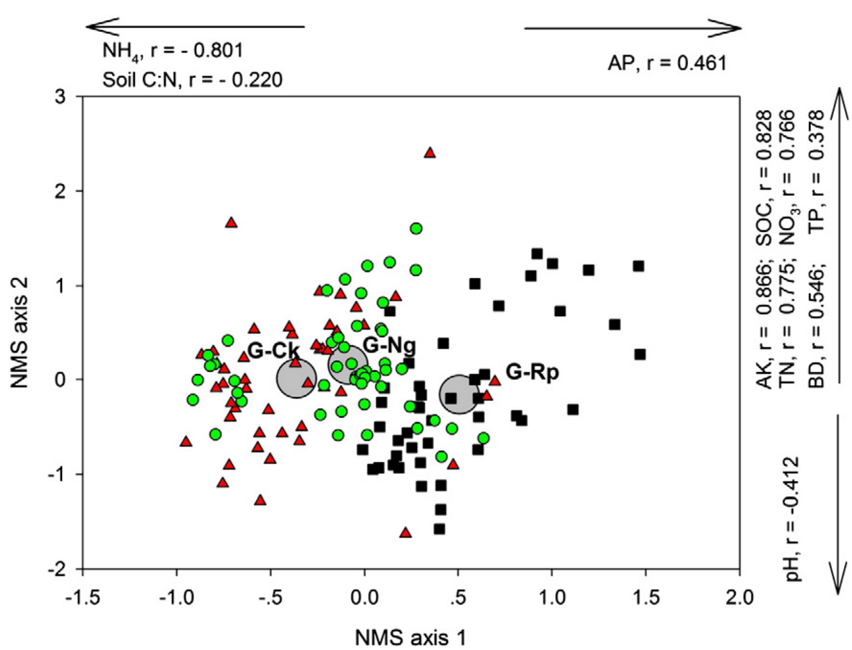

Fig. 3. Nonmetric multidimensional scaling (NMS) ordination of soil nutrient conditions of all sampling plots (n = 150) among three different vegetation restoration gullies (squares, G-Rp plots; triangles, G-Ck plots; circles, G-Ng plots). Coefficients of variation for each of the axes, and significant ($P < 0.01$) Pearson product–moment correlations between axes and individual soil properties are shown. The barycenters of sampling plots of three different vegetation restoration pattern gullies are represented by gray-filled circles. For NMS axis 1, $r^2 = 0.242$; for NMS axis 2, $r^2 = 0.546$.

properties between *R. pseudoacacia* plantations and natural grassland after 21 years growth. Some reports indicate that *R. pseudoacacia* (Xu and Liu, 2004; Xue et al., 2007) and *C. korshinskii* (Zhang et al., 2007) plantations can improve soil properties accumulated into the top soil over more than 50 years and that these changes are related to regional topographic factors.

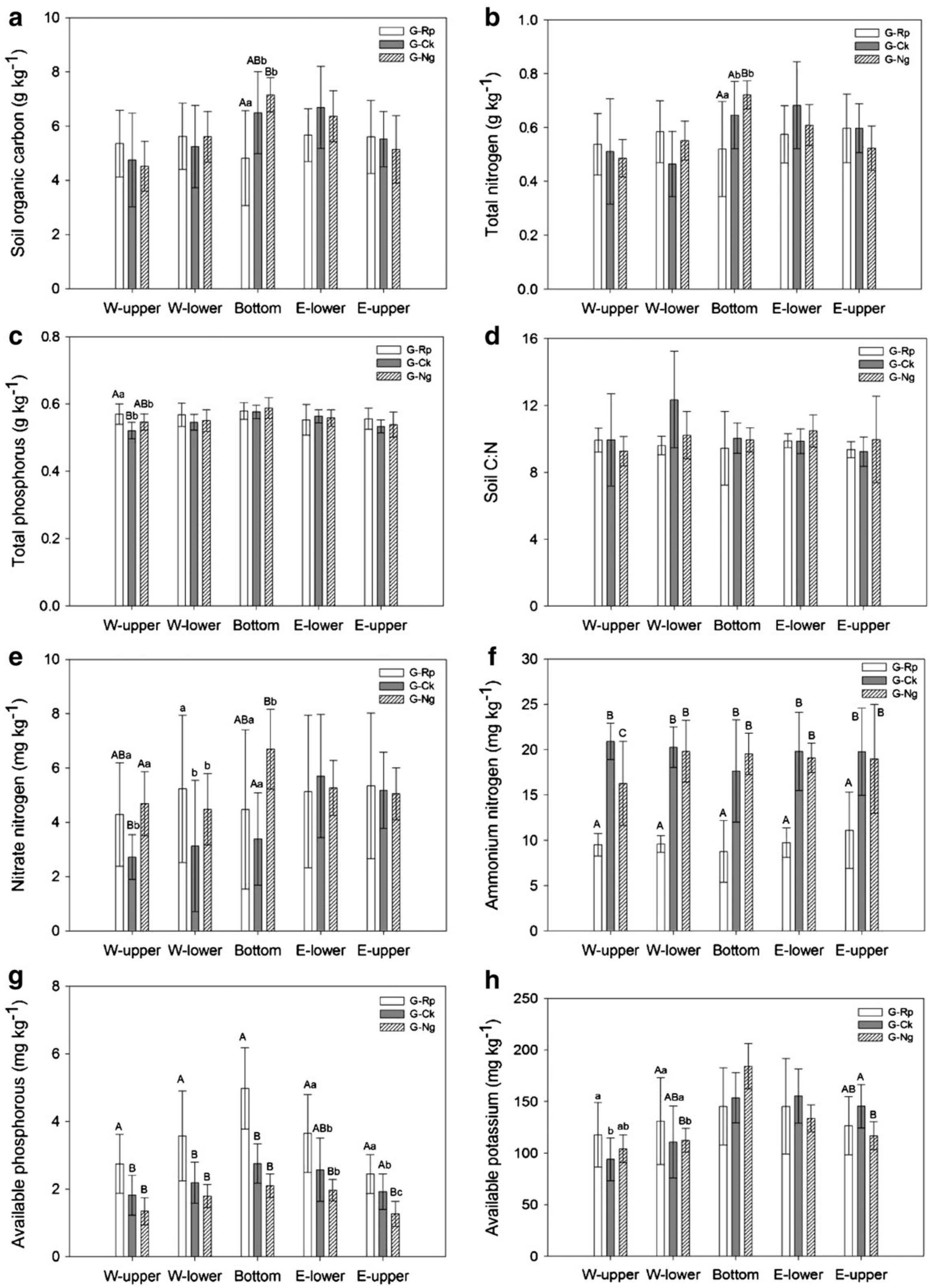

Fig. 4. Mean values (± SD) of SOC, TN, TP, soil C:N ratio, NO_3^-, NH_4^+, AP, AK, soil pH, and BD measured in three different vegetation restoration pattern gullies (G-Rp, artificial *Robinia pseudoacacia* forest gully; G-Ck, artificial *Caragana korshinskii* shrubland gully; G-Ng, natural grassland gully) with five gully positions from each gully (W-upper, W-lower, bottom, E-lower, and E-upper). Values with the same lowercase letters are not significantly different ($p < 0.05$); values with the same uppercase letters are not significantly different ($p < 0.01$).

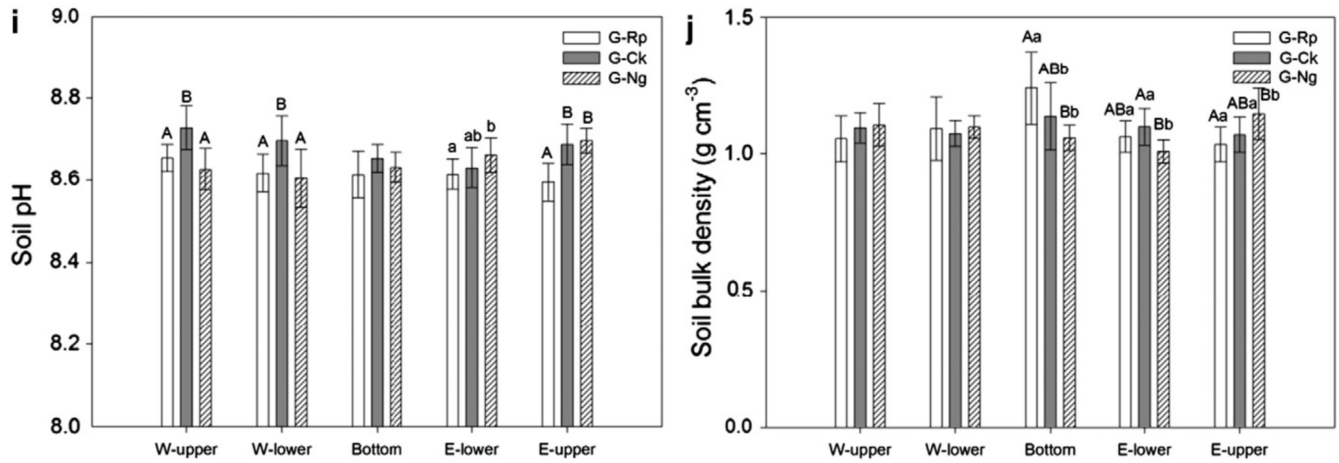

Fig. 4 (*continued*).

In the present study, there were no significant differences in SOC, TN, and soil C:N ratio between three gullies even after approximately 20 years following restoration with different vegetation types. The reasons can be attributed to the relatively shorter life cycle of grass compared to trees, with more rapid C and N cycling from leaves and roots in superficial soil (Dube et al., 2009) compared to *R. pseudoacacia* and *C. korshinskii* plantations, which continually store large amount of C and N. Previous reports show that the amount of N in litter fall was greater in black locust plantations than in oak forests (Tateno et al., 2007), indicating that black locusts store a large amount of N in the aggrading biomass and litter fall. AK content did not significantly differ among the three vegetation type gullies, presumably because AK (99–145 ppm) is naturally present at medium to high levels in loess soils (Potassium Fertilizer Group of Soil and Fertilizer Institute of Shaanxi Province, 1982), and K availability is likely to meet the requirement for plant growth (Wei et al., 2009). We assume that the soil parent material may play a dominant role for AK in loess soil compared to the biological influence of AK in loess soil. Of the measured soil properties, TP had the second smallest variability (CV = 5.3–5.5%) between the three studied gullies, and may reflect conditions across the entire Loess Plateau (Liu et al., 2013). Soil P is primarily derived from rock phosphate and can potentially be lost through soil erosion. The difference in TP between G-Rp and G-Ck may be caused by the difference in soil erosion in the early stage after planting.

The highest concentrations of nitrate and ammonium in soils were found in G-Ng and then in G-Ck. Difference in nitrate and ammonium between revegetation type gullies may contribute to plant community preferences for available N nutrition. In the Northern Hemisphere ecosystems, ammonium generally dominates over nitrate in surface soil (Huber et al., 2011; Makarov et al., 2003; Wei et al., 2009). Here, we observed that nitrate was present at about 50%, 20%, and 28% of ammonium concentrations in the top 0–20 cm soil from G-Rp, G-Ck, and G-Ng, respectively. The 50% ratio of nitrate to ammonium in *R. pseudoacacia* plantation soils agreed with a previous study by Wei et al. (2009). Soil AP is mainly formed by microorganisms metabolizing organic compounds. Significantly higher AP in G-Rp and G-Ck gullies may contribute to their diverse microorganism communities, with relative higher P mineralization capability than in G-Ng gully. There has been found that alkaline phosphatase of *R. pseudoacacia* plantation was higher than that of grassland (Qiu et al., 2010). Soil pH in G-Rp was lower (8.62 $\pm$ 0.05, Mean $\pm$ SD) than those in G-Ng (8.64 $\pm$ 0.06) and G-Ck (8.68 $\pm$ 0.06), presumably because trees can significantly influence soil acidification compared to grass (Jobbágy and Jackson, 2003) and can cause interspecific differences with the introduction of acidity (Finzi et al., 1998).

4.2. Differences in soil properties between gully positions

The Loess Plateau is composed of hill and gully landforms, where the gentle slope (loessic mao) edge line is taken as the boundary, above it is defined as hilly slopes and below it as gullies (Chen and Cai, 2006). Among different gully positions, the gully bottom generally with the lowest and relatively flat terrain has a relatively higher water and fertilizer conditions; meanwhile, the gully slope has a decreasing gradient of sunshine and temperature from upper to lower. In our study, soil properties differed with vegetation type at similar gully positions, and also between different gully positions with the same vegetation (Fig. 4 and Table 3). The differences in soil properties between vegetation types were predominantly related to nitrate, ammonium, AP, AK and soil pH. Differences in soil properties relating to gully positions may be governed by factors like redistribution of materials such as water-soluble substances, vegetation types (herbaceous, shrub, or tree), community composition (e.g., small mosaic communities), microclimate (e.g., temperature, light, and wind), and soil properties.

In the present study area, precipitation is the only source of soil water, hence, landform governs the redistribution of water and controls mass movements of land surfaces (Wei et al., 2009). Given similar vegetation, lower positions have higher water content and soil properties than upper positions along the topographic gradient, as shown in the present gullies. This was also the case for soil properties in G-Ng. The bottoms of natural grassland gully had the highest soil properties compared to slope positions, which may be attributed to a relatively higher water content and potential surplus nutrient supply from slopes, leading to a relatively high density and well growth vegetation communities as indicated by patches of *Phragmites australis*. Our data indicate that during the natural grassland succession stage, topography remained a dominant indicator of soil distributions. In contrast, G-Rp had largely diverse distributions of soil properties among gully positions (especially at the bottom position) compared to that of G-Ck and G-Ng. For example, nitrate and ammonium levels in soil were lower at the bottom of the gully than on slope positions. This observation was in agreement with a recent study (Wei et al., 2009). Hence, *R. pseudoacacia* plantations likely have a more dominant influence on soil properties than topography (at least at the bottom position). *R. pseudoacacia* trees have a significant canopy structure compared to *C. korshinskii* shrubs and grassland, and may affect the microclimate factors (e.g., temperature, light, and wind), encouraging the dominance of shade tolerant understorey vegetation, and controlling litter composition and decomposition. Distinct differences in herbaceous community compositions were observed between canopy positions (e.g., dominated by *Melica radula* Franch. or *Carex lanceolata* Boott.) and gaps (Zhang and Liu,

Table 4
Results of MRPP on soil properties of gullies and gully positions. T describes the separation between groups (dissimilarity), A is the chance-corrected within-group agreement and P is the level of significance. "All" indicates all four treatments included in the MRPP, and the remainders are MRPP pairwise comparisons of different vegetation restoration pattern gullies (lower T and higher A). G-Rp, artificial *Robinia pseudoacacia* forest gully, G-Ck, artificial *Caragana korshinskii* shrubland gully; G-Ng indicates natural grassland gully.

Groups	T	A	P
Compared in sites			
All	−41.684	0.234	<0.0001
G-Rp vs. G-Ck	−31.741	0.209	<0.0001
G-Rp vs. G-Ng	−41.943	0.270	<0.0001
G-Ck vs. G-Ng	−12.149	0.066	<0.0001
Compared in positions			
All	−6.329	0.051	<0.0001
Gully positions of G-Rp	−1.883	0.058	0.046
Gully positions of G-Ck	−7.375	0.153	<0.0001
Gully positions of G-Ng	−8.765	0.210	<0.0001

2010). The herbaceous community composition in the gap of G-Rp was similar to that of G-Ck and G-Ng (e.g., dominated by *Artemisia sacrorum* Ledeb., *Stipa bungeana* Trin.). Therefore, differences in soil variables may be a result of complex interactions between biotic processes which are moderated by plants and soil biota, and abiotic environmental processes (Hooper et al., 2000).

4.3. Other potential aspects associated with different revegetation types

Considering above- and below-ground biomass accumulation, biodiversity, anti-erodibility (e.g., gravity erosion), and microclimate, artificial vegetation may provide greater ecological benefits than natural vegetation restoration in the gully areas of the Loess Plateau. Moreover, artificial vegetation can effectively accelerate the process of vegetation restoration in the gully areas.

The above- and below-ground biomass from *R. pseudoacacia* and *C. korshinskii* may contribute to larger nutritional reservoirs than those of natural grasslands. The herbaceous biomass in G-Ng (244 ± 124 $g \cdot m^2$) was greater than that of G-Rp (175 ± 118 $g \cdot m^2$); however, it did not differ significantly from that of G-Ck (214 ± 92 $g \cdot m^2$) (Zhang and Liu, 2010). The litter mass in G-Rp (352 ± 203 $g \cdot m^2$) was greater than those of G-Ng (305 ± 161 $g \cdot m^2$) and G-Ck (298 ± 196 $g \cdot m^2$) among gullies (Zhang and Liu, 2010). Hence, the biomass of the herbaceous layer in G-Rp and G-Ck was similar to that of G-Ng. However, the biomass of *R. pseudoacacia* and *C. korshinskii* plants is likely to serve as the additional stored biomass for gully ecosystems, with approximately 100 $t \cdot ha^{-2}$ (Li et al., 2010) and 11 $t \cdot ha^{-2}$ (Chen et al., 2013) yield based on relevant data from 20-year-old plantations on the Loess Plateau (Table 5).

The number of herbaceous and woody species in G-Rp (47 and 10, respectively) and G-Ck (47 and 14, respectively) was higher than that in G-Ng (41 and 9, respectively) (Zhang and Liu, 2010), as shown in another recent study on the Loess Plateau (Jia et al., 2011). Soil properties in artificial revegetation gullies were relatively better than those in natural grassland gullies, presumably leading to an increase in the number of plant species of the artificial revegetations. After approximately 20 years of vegetation recovery, the emergence of native peer shrubs and trees indicates that vegetation communities are undergoing a benign succession process (Zhang and Liu, 2010), which may be a useful and reliable indicator of improvement in soil properties in those gullies (Li and Shao, 2006).

Different vegetation types have differences between microclimatic conditions. It has been reported that microclimatic conditions differ among grasslands, heathlands and woodlands in Australian alpine ecosystems (Huber et al., 2011), such as grasslands have lower temperatures than heathlands and woodlands. Therefore, artificial vegetation may modulate microclimates and protect undergrowth from extreme temperature by shrub and tree canopies and litters, thus such changes in microclimate potentially affect soil biotic processes.

Revegetation plays significant roles in reducing gully erosion (Rey, 2003; Valentin et al., 2005; Zheng, 2006). Artificial plantations may effectively reduce soil erodibility by increasing the vegetation cover in the gully areas. Different plant species vary in anti-erodibility and slope stability (De Baets et al., 2007). Woody vegetation, particularly trees, can help prevent shallow landslides by modifying the soil moisture regime via evapotranspiration; and providing root reinforcement within the soil mantle, the presence of plant roots can physically reinforce the shear zones, thus stabilizing slopes against a shallow landslide (Stokes et al., 2009). Therefore, artificial plantations may be superior in reducing gully erosion than that of natural grassland.

5. Conclusions

This paper reports a study on the effects of revegetation types on soil properties in the three gullies where different restoration actions were applied, located in the hilly Loess Plateau. Soil properties were sampled along five gully positions of each gully area. After two decades of revegetation in the gully area, our results demonstrate that soil properties could be improved by different revegetation types in the gully areas, and showed significantly differences depending on revegetation types and gully positions. Artificial plantations can significantly improve available soil nutrients, better than natural grasslands, and also can speed-up vegetation restoration in the gully areas.

Due to the relatively higher water and fertilizer conditions that are naturally observed in the gully areas and the slow natural restoration process, in terms of revegetation strategies on gully areas, artificial revegetation may accelerate vegetation restoration in the gully areas of the Loess Plateau. We suggest that a large number of healthy gully ecosystems can be expected on the Loess Plateau with natural restoration in the entire gully area combined with suitable measurements of artificial revegetation (e.g., priority of native pioneer woody species, initial density, and spatial configurations of plant species) at gentler gully slope and bottom positions.

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Table 5
The descriptions of surveyed sites by bulk density, biomass of herbaceous layer, litter, Shannon–Wiener index of herbaceous layer, number of herbaceous species and number of woody species (data from Zhang and Liu, 2010).

Sites	Biomass of herbaceous layer ($g \cdot m^{-2}$)	Litter ($g \cdot m^{-2}$)	Shannon–Wiener of herbaceous layer	No. of herbaceous	No. of woodys
G-Rp	174.87 ± 117.95 a	351.87 ± 202.62	1.49	47	10
G-Ck	213.98 ± 92.04 ab	297.60 ± 196.30	1.50	47	14
G-Ng	244.93 ± 124.39 b	305.32 ± 160.71	1.40	41	9

Note: Values with the same letter are not significantly different at the $p < 0.05$ level.

References

An, S.S., Cheng, Y., Huang, Y.M., Liu, D., 2013. Effects of revegetation on soil microbial biomass, enzyme activities, and nutrient cycling on the Loess Plateau in China. Restor. Ecol. 21, 600–607.

Cao, S.X., Chen, L., Yu, X.X., 2009. Impact of China's Grain for Green Project on the landscape of vulnerable arid and semi-arid agricultural regions: a case study in northern Shaanxi Province. J. Appl. Ecol. 46, 536–543.

Chen, H., Cai, Q.G., 2006. Impact of hillslope vegetation restoration on gully erosion induced sediment yield. Sci. China. Ser. D Earth Sci. 49, 176–192.

Chen, L.D., Wei, W., Fu, B.J., Lu, Y.H., 2007. Soil and water conservation on the Loess Plateau in China: review and perspective. Prog. Phys. Geogr. 31, 389–403.

Chen, H.S., Shao, M.G., Li, Y.Y., 2008. Soil desiccation in the Loess Plateau of China. Geoderma 143, 91–100.

Chen, J., Wang, J.B., Chen, J.M., Luo, Z.K., 2013. Spatial–temporal variability of *Caragana korshinskii* vegetation growth in the Loess Plateau. Sci. Silvae Sin. 49, 14–20 (in Chinese with English abstract).

De Baets, S., Poesen, J., Knapen, A., Barbera, G.G., Navarro, J.A., 2007. Root characteristics of representative Mediterranean plant species and their erosion-reducing potential during concentrated runoff. Plant Soil 294, 169–183.

Dube, F., Zagal, E., Stolpe, N., Espinosa, M., 2009. The influence of land-use change on the organic carbon distribution and microbial respiration in a volcanic soil of the Chilean Patagonia. For. Ecol. Manag. 257, 1695–1704.

Editorial, C., 1996. Soil Physical and Chemical Analysis and Description of Soil Profile. Standards Press of China, Beijing.

Fang, X.W., Li, J.H., Xiong, Y.C., Xu, D.H., Fan, X.W., Li, F.M., 2008. Responses of *Caragana korshinskii* Kom. to shoot removal: mechanisms underlying regrowth. Ecol. Res. 23, 863–871.

Finzi, A.C., Canham, C.D., Van Breemen, N., 1998. Canopy tree–soil interactions within temperate forests: species effects on pH and cations. Ecol. Appl. 8, 447–454.

Gao, X.D., Wu, P.T., Zhao, X.N., Shi, Y.G., Wang, J.W., Zhang, B.Q., 2011. Soil moisture variability along transects over a well-developed gully in the Loess Plateau, China. Catena 87, 357–367.

Gyssels, G., Poesen, J., Bochet, E., Li, Y., 2005. Impact of plant roots on the resistance of soils to erosion by water: a review. Prog. Phys. Geogr. 29, 189–217.

Hooper, D.U., Bignell, D.E., Brown, V.K., Brussaard, L., Dangerfield, J.M., Wall, D.H., Wardle, D.A., Coleman, D.C., Giller, K.E., Lavelle, P., Van der Putten, W.H., De Ruiter, P.C., Rusek, J., Silver, W.L., Tiedje, J.M., Wolters, V., 2000. Interactions between aboveground and belowground biodiversity in terrestrial ecosystems: patterns, mechanisms, and feedbacks. Bioscience 50, 1049–1061.

Huber, E., Bell, T.L., Simpson, R.R., Adams, M.A., 2011. Relationships among microclimate, edaphic conditions, vegetation distribution and soil nitrogen dynamics on the Bogong High Plains, Australia. Aust. Ecol. 36, 142–152.

Jia, G.M., Liu, B.R., Wang, G., Zhang, B.L., 2010. The microbial biomass and activity in soil with shrub (*Caragana korshinskii* K.) plantation in the semi-arid Loess Plateau in China. Eur. J. Soil Biol. 46, 6–10.

Jia, X.X., Shao, M.G., Wei, X.R., 2011. Richness and composition of herbaceous species in restored shrubland and grassland ecosystems in the northern Loess Plateau of China. Biodivers. Conserv. 20, 3435–3452.

Jiao, F., Wen, Z.M., Shi, H., Wang, F., Zhang, X.P., Yang, Q.K., Li, R., 2004. Land structure of Ansai County in the Loess Plateau. J. Mt. Sci. 22, 406–410.

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.Y., Zhang, Z.G., Bai, W.J., Jia, Y.F., Wang, N., 2012. Assessing the ecological success of restoration by afforestation on the Chinese Loess Plateau. Restor. Ecol. 20, 240–249.

Jobbágy, E.G., Jackson, R.B., 2003. Patterns and mechanisms of soil acidification in the conversion of grasslands to forests. Biogeochemistry 64, 205–229.

Lan, G.Y., Hu, Y.H., Cao, M., Zhu, H., 2011. Topography related spatial distribution of dominant tree species in a tropical seasonal rain forest in China. For. Ecol. Manag. 262, 1507–1513.

Li, Y.Y., Shao, M.A., 2006. Change of soil physical properties under long-term natural vegetation restoration in the Loess Plateau of China. J. Arid Environ. 64, 77–96.

Li, J., Wang, X.C., Shao, M.A., Zhao, Y.G., Li, X.F., 2010. Simulation of biomass and soil desiccation of *Robinia pseudoacacia* forestlands on semi-arid and semi-humid regions of China's Loess Plateau. Chin. J. Plant Ecol. 34, 330–339 (in Chinese with English abstract).

Liu, G.B., Li, M., Shangguan, Z.P., Mu, X.M., Xie, Y.S., Li, Z.B., Liang, Y.L., Zhang, W.H., Hou, Q.C., 2008. Current status and comprehensive control strategies of soil erosion for loess region in the northwestern China. Sci. J. Soil Water Conserv. 6, 16–21 (in Chinese with in English abstract).

Liu, Z.P., Shao, M.A., Wang, Y.Q., 2013. Spatial patterns of soil total nitrogen and soil total phosphorus across the entire Loess Plateau region of China. Geoderma 197, 67–78.

Lu, C.H., van Ittersum, M.K., Rabbinge, R., 2003. Quantitative assessment of resource-use efficient cropping systems: a case study for Ansai in the Loess Plateau of China. Eur. J. Agron. 19, 311–326.

Makarov, M.I., Glaser, B., Zech, W., Malysheva, T.I., Bulatnikova, I.V., Volkov, A.V., 2003. Nitrogen dynamics in alpine ecosystems of the northern Caucasus. Plant Soil 256, 389–402.

McCune, B., Mefford, M.J., 1999. 1995–2002 Multivariate analysis of Ecological Data, Version 4. MJM Software Design, Gleneden Beach, OR, USA.

Mielke, P.W., Berry, K.J., 2007. Permutation Methods: A Distance Function Approach, Second ed. Springer, New York.

Molina, A., Govers, G., Cisneros, F., Vanacker, V., 2009a. Vegetation and topographic controls on sediment deposition and storage on gully beds in a degraded mountain area. Earth Surf. Process. Landf. 34, 755–767.

Molina, A., Govers, G., Van den Putte, A., Poesen, J., Vanacker, V., 2009b. Assessing the reduction of the hydrological connectivity of gully systems through vegetation restoration: field experiments and numerical modelling. Hydrol. Earth Syst. Sci. 13, 1823–1836.

Nielsen, D.R., Bouma, J., 1985. Soil Spatial Variability. Pudoc, Wageningen.

Potassium Fertilizer Group of Soil, Fertilizer Institute of Shaanxi Province, 1982. Available potassium content and distribution of Shaanxi agriculture soil. Shaanxi J. Agric. Sci. 13–16 (in Chinese).

Qiu, L.P., Zhang, X.C., Cheng, J.M., Yin, X.Q., 2010. Effects of black locust (*Robinia pseudoacacia*) on soil properties in the loessial gully region of the Loess Plateau, China. Plant Soil 332, 207–217.

Rey, F., 2003. Influence of vegetation distribution on sediment yield in forested marly gullies. Catena 50, 549–562.

Sariyildiz, T., Anderson, J.M., Kucuk, M., 2005. Effects of tree species and topography on soil chemistry, litter quality, and decomposition in northeast Turkey. Soil Biol. Biochem. 37, 1695–1706.

Stokes, A., Atger, C., Bengough, A.G., Fourcaud, T., Sidle, R.C., 2009. Desirable plant root traits for protecting natural and engineered slopes against landslides. Plant Soil 324, 1–30.

Tang, G.A., Li, F.Y., Liu, X.J., Long, Y., Yang, X., 2008. Research on the slope spectrum of the Loess Plateau. Sci. China Ser. E-Technol. Sci. 51, 175–185.

Tateno, R., Tokuchi, N., Yamanaka, N., Du, S., Otsuki, K., Shimamura, T., Xue, Z.D., Wang, S.Q., Hou, Q.C., 2007. Comparison of litterfall production and leaf litter decomposition between an exotic black locust plantation and an indigenous oak forest near Yan'an on the Loess Plateau, China. For. Ecol. Manag. 241, 84–90.

Valentin, C., Poesen, J., Li, Y., 2005. Gully erosion: impacts, factors and control. Catena 63, 132–153.

Wang, J., Fu, B.J., Qiu, Y., Chen, L.D., 2003. Analysis on soil nutrient characteristics for sustainable land use in Danangou catchment of the Loess Plateau, China. Catena 54, 17–29.

Wang, Z.Q., Liu, B.Y., Liu, G., Zhang, Y.X., 2009. Soil water depletion depth by planted vegetation on the Loess Plateau. Sci. China. Ser. D Earth Sci. 52, 835–842.

Wei, X.R., Shao, M.A., Zhang, X.C., Shao, H.B., 2009. Landform affects on profile distribution of soil properties in black locust (*Robinia pseudoacacia*) land in loessial gully region of the Chinese Loess Plateau and its implications for vegetation restoration. Afr. J. Biotechnol. 8, 2984–2992.

Xu, M.X., Liu, G.B., 2004. The characteristics and evolution of soil nutrient in artificial black locust (*Robinia pseudoacacia*) forest land in the hilly Loess Plateau. Plant Nutr. Fertil. Sci. 10, 40–46 (in Chinese with English abstract).

Xue, S., Liu, G.B., Dai, Q.H., Wei, W., Hou, X.L., 2007. Evolution of soil microbial biomass in the restoration process of artificial *Robinia pseudoacacia* under erosion environment. Acta Ecol. Sin. 27, 909–917 (in Chinese with English abstract).

Zhang, J., Liu, G.B., 2010. The influence of plant community biomass and species diversity of different vegetation restoration patterns in the gully area of the hilly Loess Region. J. Nat. Resour. 25, 207–217 (in Chinese with English abstract).

Zhang, Z.G., Huang, J.C., Jiao, J.Y., Bai, W.J., 2007. Characteristics, spatial variability and evolution of soil nutrients on abandoned artificial forest (*Caragana korshinskii*) lands in the Loess Hilly Region. Bull. Soil Water Conserv. 27, 114–120 (in Chinese with English abstract).

Zhang, J., Liu, G.B., Xu, M.X., Xu, M., Yamanaka, N., 2013a. Influence of vegetation factors on biological soil crust cover on rehabilitated grassland in the hilly Loess Plateau, China. Environ. Earth Sci. 68, 1099–1105.

Zhang, J., Taniguchi, T., Tateno, R., Xu, M., Du, S., Liu, G.B., Yamanaka, N., 2013b. Ectomycorrhizal fungal communities of *Quercus liaotungensis* along local slopes in the temperate oak forests on the Loess Plateau, China. Ecol. Res. 28, 297–305.

Zheng, F.L., 2006. Effect of vegetation changes on soil erosion on the Loess Plateau. Pedosphere 16, 420–427.

Zheng, J.Y., Wang, L.M., Shao, M.A., Wang, Q.J., Li, S.Q., 2006. Gully impact on soil moisture in the gully bank. Pedosphere 16, 339–344.

Zheng, Y.A., Zhao, Z., Zhou, J.J., Zhou, H., Liang, Z.S., Luo, Z.B., 2011. The importance of slope aspect and stand age on the photosynthetic carbon fixation capacity of forest: a case study with black locust (*Robinia pseudoacacia*) plantations on the Loess Plateau. Acta Physiol. Plant. 33, 419–429.

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.

Zhou, D.C., Zhao, S.Q., Zhu, C., 2012. The Grain for Green Project induced land cover change in the Loess Plateau: a case study with Ansai County, Shaanxi Province, China. Ecol. Indic. 23, 88–94.