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Assessing Ecological Conditions of Microtopography for Vegetation Restoration on the Chinese Loess Plateau

Huan Ma *(***)†, Qingke Zhu, Xining Zhao* and Yuan Liu*****
*College of Water Resources and Architectural Engineering, Northwest Agricultural & Forestry University, Yangling 712100, P.R. China
**Forestry Ecological Engineering Research Center (Ministry of Education), Beijing Forestry University, Beijing 100083, P.R. China
***Powerchina Northwest Engineering Corporation, Xi'an 710065, P.R. China
†Corresponding author: Ma Huan

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ABSTRACT

Microtopographies affect large portions of the Chinese Loess Plateau after years of water erosion. Vegetation restoration has proven to be an effective way to conserve water and soil, however, studies of the influence of microtopography on naturally recovered vegetation on the Chinese Loess Plateau have long been absent. The objective of this study was to determine the influence of microtopography on the vegetation structure and plant diversity of naturally restored vegetation and compare the soil physicochemical properties of different microtopographies with those of undisturbed slopes on the Loess Plateau. We identified five types of microtopographies that are mainly shaped by runoff in the study area, and examined vegetation structures, plant diversity, soil nutrients and soil water storage compared with undisturbed slopes. The results show that vegetation communities on loess slopes are still in an early successional stage after 14 years of natural recovery. Vegetation diversity was significantly different among microtopographies. Four types of microtopography have better soil conditions for vegetation restoration; scarps are the exception. Our results suggest that microtopographies can create some better condition plots for precision designed artificial restoration of vegetation, which is necessary to accelerate the succession process on the Loess Plateau.

INTRODUCTION

The Loess Plateau in China covers a large area totalling 624,000 km^2. The soil erosion on the Loess Plateau not only leads to the degradation of local land but also sends sediment to the lower reaches of the Yellow River, increasing the flooding risk (Mcvicar et al. 2007). Vegetation restoration on the Loess Plateau has been proven to be an effective way to improve soil texture (Li et al. 2006) and decrease the soil erosion ratio (Zheng 2006). To control soil erosion, the Chinese government has historically focused on a series of vegetation restoration projects on the Loess Plateau. To pursue an endpoint in which forests can rapidly develop a closed canopy with minimal labour investment, a vegetation restoration model on the Loess Plateau in which plants are planted with the same row spacing along contours based on the site conditions of slopes using fast growing trees and shrubs has often been adopted for restoration (Zhu et al. 2012). However, these projects have met with mixed success (Jiao et al. 2012). After years of water erosion on the Loess Plateau, there are numerous potholes and gullies distributing all over slopes. This type of topographic heterogeneity can lead to the redistribution of precipitation by affecting overland flow (Liu et al. 2004) and evaporation (Price et al. 1998). The unevenness of soil water moisture and inappropriate selection of species together result in forest degradation and the development of low productivity forests with small but old trees (Zhu et al. 2012). However, better soil water conditions can also be created by the uneven surface (Mott et al. 1974). Higher species diversity can appear in the sites where the micro-environment has greater heterogeneity in both the horizontal and vertical directions, and a complex community structure implies the use of multiple environmental resources (He et al. 1997).

Topographic heterogeneity on a fine scale has long been recognized as an important factor in vegetation restoration (Rossell et al. 2009). Early in the 1960s, studies found that small topographic differences can significantly affect species distributions and succession in herbaceous communities (Zedler et al. 1969). Subsequent studies have illustrated that a small amount of heterogeneity in topography can affect the microenvironment of the understory (Beatty 1984), soil texture (Martinez-Turanzas et al. 1997), and soil nutrients

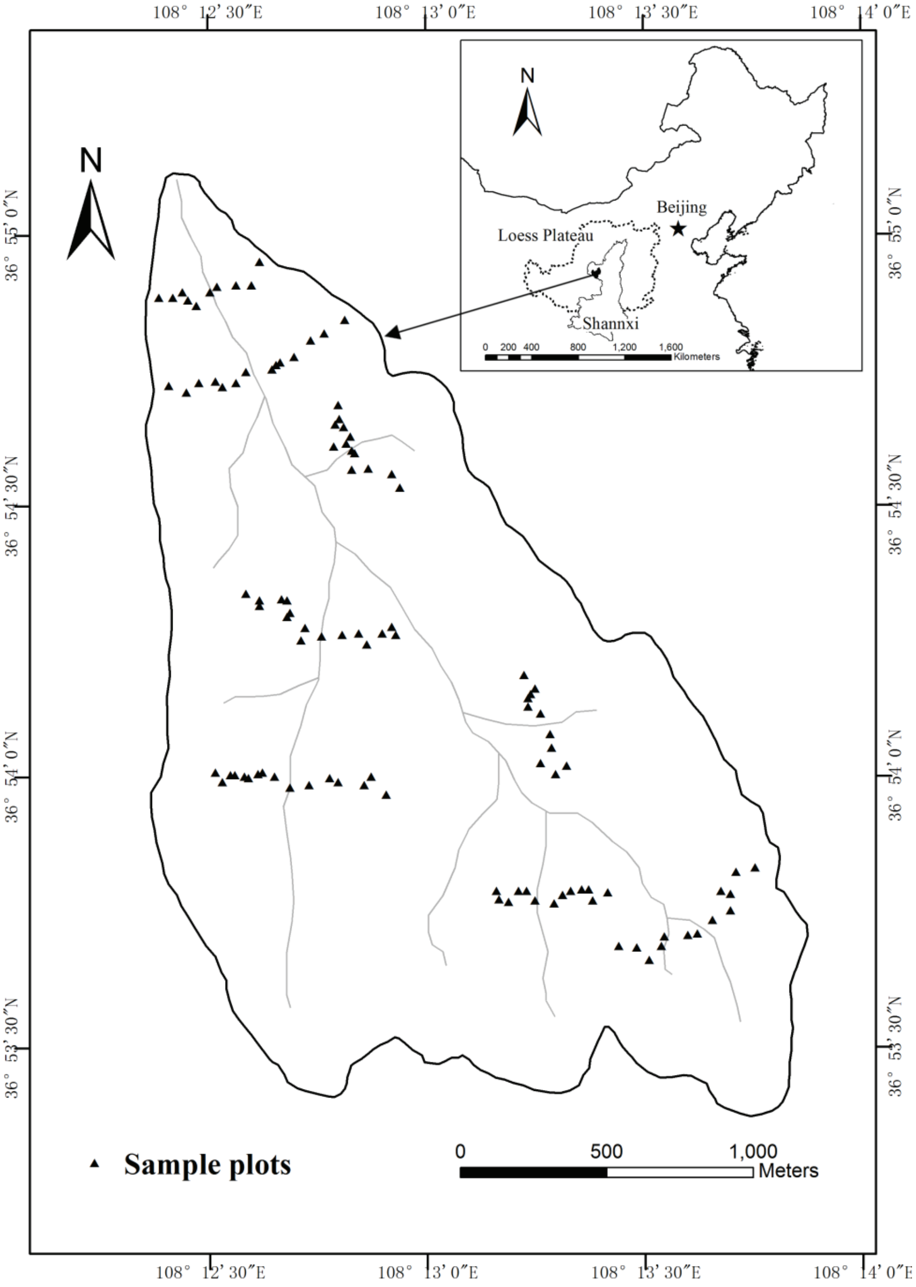

Fig.1: The distribution of sample plots in the Hegou watershed.

(Moser et al. 2009). This small topographic heterogeneity is often created by disturbances, such as tree fall (Moser et al. 2009), animal activities (Pavone et al. 1985), soil erosion (Zhu et al. 2012), sedimentation (Werner et al. 2002) and landslides (Sakai et al. 1993). These disturbances create bare soil with different characteristics that different pioneer plants can opportunistically invade, and the pioneer plants can establish communities different from those in surrounding forests (Guariguata 1990). A small amount of topographic heterogeneity can also affect the vegetation structure (Hara et al. 1996), composition (Milton et al. 1985), and succession (Gilland et al. 2014) of early successional plants and eventually the development of different late-successional communities.

Previous studies have primarily focused on microtopography in wetlands (Domínguez-Cadena et al. 2016), where the microtopography is often created by tree fall (Šamonil et al. 2016). These microtopographies, such as mounds, pools and pits, are usually on a scale of less than 5 m due to the specific hydrological and environmental conditions (Beatty 1984). Microtopographies that are created by landslides on a larger scale in hilly area were also reported (Nagamatsu et al. 1997). There are also lots of microtopographies exist in the Loess Plateau. These microtopographies were different from those mentioned in previous studies both in scale and the cause they emerged. Microtopography on the Loess Plateau was shaped by several types of soil erosion, among which water erosion is the main type (Fang et al. 2008), and on a spatial scale larger than 1 m^2. Studies have assessed the soil properties and vegetation structure responses after vegetation restoration projects on the Loess Plateau (Zeng et al. 2016), but none have addressed the effect of microtopography on edaphic or botanical factors. In addition, vegetation restoration on the Loess Plateau focuses on matching tree species with site in slope scale, whereas the small scale of topographic heterogeneity that under the slope scale may significantly impact the quality of vegetation restoration. No studies have assessed the influence of microtopography to natural recovered vegetation on the Chinese Loess Plateau. The objects of this study were to (1) analyse the impact of microtopography, relative to other topographical factors, on vegetation structure and species diversity, (2) determine the vegetation structures and species diversity among different microtopographies, and (3) compare soil physiochemical properties among different microtopographies in order to determine precisely suitable position using microtopography as an indicator for vegetation restoration on the Loess Plateau.

MATERIALS AND METHODS

Study Site

The study was conducted in the 4.25 km^2 Hegou (36°54'09" - 36°54'23" N, 108°12'50" - 108°13'01" E) watershed, located in Wuqi County, northern Shaanxi Province. The area is characterized by a temperate continental monsoon climate that is warm and dry, with an annual mean temperature of 7.8°C and mean annual precipitation of 466 mm (based on data spanning 1957-2009). The annual variation in precipitation is large, and there is an uneven distribution in different seasons, with most precipitation occurring from June to September. The soil type of this area is cultivated loessal soils. The land surface can easily be eroded and forms many types of microtopographies due to the specific character of precipitation and human activities. Fig. 1 shows the distribution of the sample plots in the Hegou watershed.

Classification of Microtopography

According to field observations, slopes in the Loess Plateau usually can be classified as undisturbed slope and disturbed slope due to the severe soil erosion. The disturbed slope part formed several kinds of microtopographies. The microtopographies on the Loess Plateau are usually larger in extent compared with those in wetlands. We defined 5 main forms of microtopography on the Loess Plateau, which are scarp, ephemeral gully, sinkhole, platform and gully (Fig. 2). Most of the slopes in the Loess Plateau are consisted of these microtopographies and the undisturbed slopes. The scarp is an area with a substantially steeper than the other parts of the slopes. The ephemeral gully is the primary stage of gully erosion development, and it is larger than a rill and smaller than a gully. The sinkhole is a crater on the ground shaped by running water. The platform is an area with a substantially gentle gradient than the other parts of the slopes. The gully is a landform created by running water, eroding sharply into soil and with a V-shaped cross section. Besides the five kinds of microtopographies mentioned above, we also took undisturbed slope, the rest of slope where no microtopography developed, into consideration as reference.

Data Collection

Vegetation data were collected in July 2012, and 8 transects were established across the watershed from the head to the outlet for four different slope aspects. Sample plots were placed in every microtopography on transects and undisturbed slopes nearby as reference. The sample size was 1 m × 1 m because shrubs and trees are rare. Along each transect, 14-17 plots were located. A total of 95 plots were recorded, within which there were 14 scarp samples, 15 ephemeral gully samples, 17 sinkhole samples, 14 platform samples, 15 gully samples and 15 undisturbed slope samples. The cover of each sample plot and species was estimated visually by two observers working together. Shrubs and trees were recorded when encountered. Slope gradient, aspect and position on slope were all recorded. We adopted the common classification of slope aspects (Zhu et al. 2012) on the Loess Plateau, which are sunny slope (157.5°-247.5° N), semi-sunny slope (112.5°-157.5° N and 247.5°-292.5° N), semi-shady slope (67.5°-112.5° N and 292.5°-337.5° N) and shady slope (0-67.5° N and 337.5°-360° N).

Soil sample plots were also taken in vegetation plots. Soil samples were taken from six points in an S-shaped pattern to a depth of 60 cm in each plot. Soil analysis was carried out according to the methods described by the Agricultural Chemistry Committee of the Chinese Soil Academy (1984): organic matter by the $K_2Cr_2O_7$ method; total N by the K_2SO_4 – $CuSO_4$ – Se distillation method; total P by the $HClO_4$ –

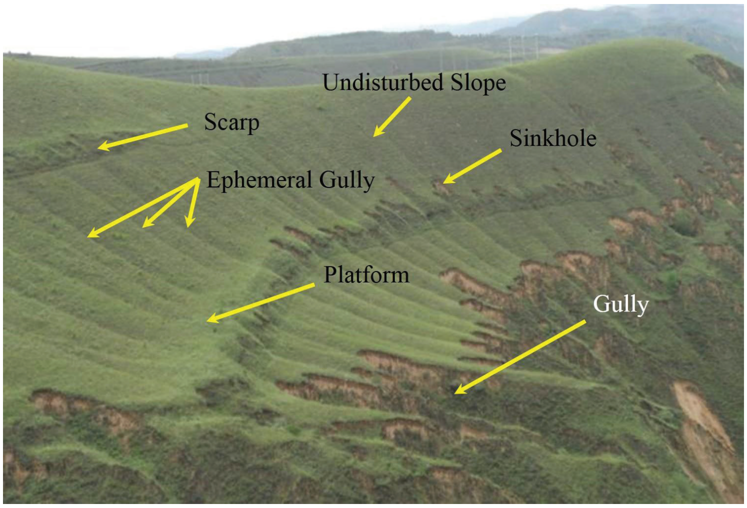

Fig. 2: Demonstration of undisturbed slope and five types of microtopographies: scarp, ephemeral gully, sinkhole, platform and gully.

H_2SO_4 colorimetric method; extractable ammonium-N by the diffusion method with 1N NaOH 10 mL, 2% H_3BO_3, and 0.005N HCl at a temperature of 40°C for 24 hours; extractable P by the 0.5 M $NaHCO_3$ extraction (1:20) colorimetric method; and extractable K with the atomic absorption spectrum method with 1 M NH_4OAC extraction (1:20, pH = 7).

For long-term observations, soil water content was monitored in fixed plots. Three PVC pipes with lengths of 2 m were pounded into the soil for each type of microtopography and undisturbed slopes. Plots that were analogous in slope gradient and aspect were arranged on the slopes to eliminate unnecessary disruption. A portable Time Domain Reflectometry (TDR) instrument was used to measure the soil water content twice per month from May 2011 to April 2012. The measurement was made from the ground surface downward to a depth of 200 cm at 20 cm intervals. For each depth interval, the soil moisture content was measured three times, and the means of the three measurements were taken as the soil moisture content of the depth interval.

Data Analysis

The measures of vegetation structure included vegetation cover, height and relative importance value (RIV). Margalef's (Clifford et al. 1976) index for species richness, the Alatalo index (Alatalo 1977) for evenness, and the Shannon-Wiener diversity index (Shannon et al. 1950) were used as the measures of plant diversity. Soil nutrient levels and soil water storage were used as measures to assess ecological conditions. The differences among microtopographies and undisturbed slopes were compared with analysis of variance (ANOVA) and a least significant difference (LSD) test using SPSS V20.0 (SPSS Inc., Chicago IL, USA). The equations used to calculate Margalef's index, the Alatalo index, the Shannon-Wiener index, RIV and soil water storage are as follows:

Margalef's index: $M_a = (S-1)/\ln N$ ...(1)

Alatalo index: $E_a = (1/\Sigma_{i=1}^{s} P_i^2 - 1)(e^H - 1)$ ...(2)

Shannon-Wiener index: $H' = -\Sigma_{i=1}^{S}(P_i \ln P_i)$ ...(3)

Relative importance value: $RIV = (C_r + H_r)/200$ ...(4)

Soil water storage: $D_w = 0.1\Sigma_1^n VSWC * H_s$ ...(5)

Where, S is the number of species, P_i is the proportion of individuals or the abundance of the i^{th} species expressed as a proportion of the total number in the community, ln is the log base-e, N is the total number of all species. C_r is relative coverage and H_r is relative height. VSWC is the soil volumetric water content of each soil layer, *n* is the number of soil layers, and H_s is the depth of each soil layer.

A canonical correlation analysis was used to examine the relationship between plant community characteristics and topographical factors. A canonical correlation analysis (CCA) is a way of making sense of cross-covariance matrices. If there are two vectors $X = (X_1, ..., X_n)$ and $Y = (Y_1, ..., Y_m)$ of random variables, and there are correlations among the variables, then a canonical-correlation analysis will find linear combinations of X_i and Y_j that have the maximum correlation with each other (Härdle et al. 2007). The two vectors here represent plant community characteristics and topographical factors. The plant community characteristics vector includes vegetation cover (X_1), average height (X_2), biomass (X_3), and Shannon-Weiner index (X_4). The topographical factors vectors include slope aspect (Y_1), slope gradient (Y_2), slope position (Y_3) and microtopography position (Y_4). The slope aspect, slope position and microtopography were all quantified as follows: sunny slope 1, semi-sunny slope 2, semi-shady slope 3, shady slope 4; top of slope 1, middle of slope 2, bottom of slope 3; and scarp 1, ephemeral gully 2, sinkhole 3, platform 4, gully 5.

RESULTS

Relationship between Topographical Factors and Plant Communities

The canonical correlation analysis shows that for topographical factors and plant communities, there are four canonical dimensions, of which only the first two are statistically significant at the 0.05 level (Table 1). Characteristic roots of the four canonical dimensions show that 70% of total information was explained by the first two dimensions. For the first canonical dimension, the linear combination of the topographical factors v_1, correlation coefficient of v_1 and raw data Y_1 indicate that slope aspect and microtopography position have an obvious positive correlation with v_1. Correspondingly, u_1, the linear combination of the plant community characteristics, has a positive correlation with the Shannon index. For the second canonical dimension, the linear combination of the topographical factors, v_2, was most relevant to microtopography position. Correspondingly, the Shannon-Weiner index has a negative correlation with the linear combination of the plant community characteristics u_2.

Vegetation Structure

A total of 64 species were found in the Hegou watershed, among which 55 species were present in the undisturbed slope plots and 64 species were present in the microtopography plots. Only 4 shrub species were found in scarps, sinkholes and gullies: *Prinsepia uniflora*, *Caragana korshinskii*, *Spiraea blumei* and *Armeniaca vulgaris.* Most (approximately 53.5%) of species belong to the Leguminoseae, Gramineae and Asteraceae (Fig. 3), which accounted for 25.5%, 16.4% and 12.7% of species, respectively. Asteraceae occupied a relatively small proportion in ephemeral gullies and undisturbed slopes, and grasses accounted for a relatively high percentage in sinkholes. A higher cover (73.33%) was recorded in gullies than in the other microtopographies ($p = 0.03$) (Table 3). The average cover in all microtopographies was greater than on undisturbed slopes, and the average height of herbs in sinkholes ($p = 0.03$) was 48.11 cm and in gullies ($p = 0.02$) was 42.00 cm, which were nearly double the heights of those in other microtopographies and slopes.

Table 2 gives the relative importance values (RIVs) greater or equal to 0.05 for species found in the Hegou watershed in microtopographies and undisturbed slopes. *Artemisia giraldii* and *Artemisia sacrorum* were the dominant species on undisturbed slopes and all microtopographies that had the maximum RIV. The accompanying species were primarily *Stipa capillata*, *Lespedeza bicolor* and *Poa annua* L. in all sites. However, scarps had *Prinsepia uniflora*, gullies had *Caragana korshinskii*, and platforms had *Phragmites*

Table 1: Canonical variables and their correlation coefficients with original variables. s, Standardized canonical coefficients for each variable; r, correlation coefficient between standardized canonical coefficients and variables; R, correlation coefficient of canonical variables Xi and Yi; **, significance level of 0.01; *, significance level of 0.05.

Canonical variable		Plant community characteristics vectors				Topographical factors vectors			
		X_1	X_2	X_3	X_4	Y_1	Y_2	Y_3	Y_4
I	s	0.079	0.238	0.368	0.804				
R = 0.644**						0.768	0.077	0.230	0.461
	r	0.633	0.503	0.557	0.287	0.833	-0.099	0.291	0.652
II	s	-0.499	-0.584	0.871	1.596				
R = 0.477*						-0.589	-0.404	-0.217	0.787
	r	-0.232	0.035	0.387	-0.721	-0.385	-0.545	0.039	0.713
III	s	-0.571	-0.009	0.842	1.403				
R = 0.366						-0.351	0.768	0.430	0.373
	r	-0.167	0.291	0.505	0.390	-0.377	0.706	0.554	0.233
IV	s	-0.600	-0.746	0.638	-3.281				
R = 0.112						0.008	0.555	-0.903	0.478
	r	0.110	-0.531	0.135	0.166	0.126	0.442	-0.779	0.106

australis as unique accompanying species. In addition, the RIV of *Artemisia giraldii* in the sinkholes was much greater than in the other microtopographies.

Plant Diversity

Table 3 presents the plant diversity indices of microtopographies in the Hegou watershed. Margalef's richness index values were in the following order: scarp > platform > gully > ephemeral gully > undisturbed slope. The scarp had the highest Margalef index value of 2.49, but the difference was not significant among the microtopographies. The Alatalo evenness index differed among the microtopographies. The maximum Alatalo index appeared in ephemeral gullies (p = 0.02) at 0.618. The minimum Alatalo index appeared in the platform (0.03) at 0.414. The Shannon-Wiener index in scarps was the highest but not significantly (p = 0.354). In general, compared with microtopographies, fewer species were distributed on undisturbed slopes in a relatively uniform pattern, implying an unstable community structure on undisturbed slopes. Among all microtopographies, scarps, gullies and ephemeral gullies had more species and more homogeneous plant distribution. Sinkholes were primarily

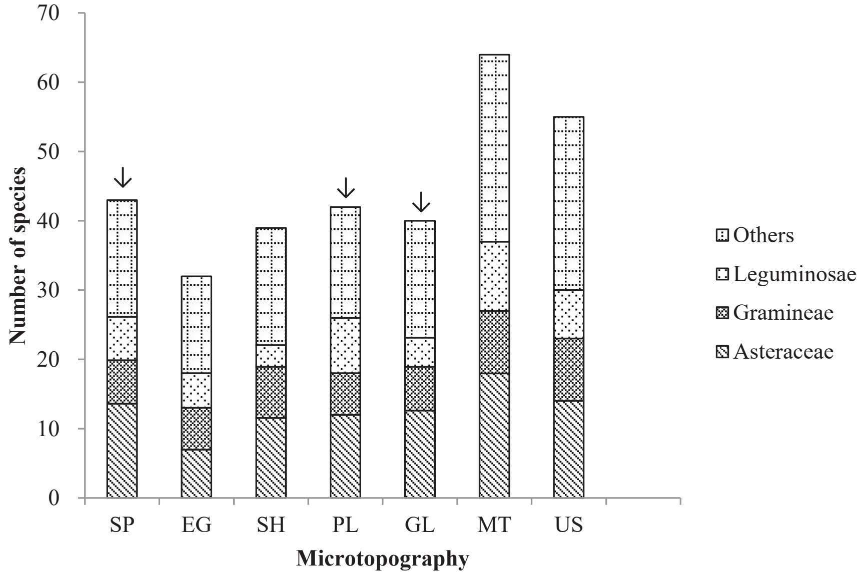

Fig. 3: Species compositions of different microtopographies in the Hegou watershed. Bars indicate the number of species in microtopographies and on undisturbed slopes. Arrows indicate plots in which shrubs appeared. SP: scarp; EG: ephemeral gully; SH: sinkhole; PL: platform; GL: gully; MT: take all the microtopographies above as a whole; US: undisturbed slope.

Table 2: Relative importance values (RIVs) for species found in the Hegou watershed across different microtopographies. SP: scarp; EG: ephemeral gully; SH: sinkhole; PL: platform; GL: gully; US: undisturbed slope.

Plant Species			Microtopography			
	SP	EG	SH	PL	GL	US
Artemisia giraldii Pamp.	0.155	1.173	0.269	0.110	0.198	0.169
Artemisia sacrorum Ledeb.	0.162	0.178	0.144	0.182	0.192	0.179
Stipa capillata Linn.	0.118	0.152		0.088	0.065	0.093
Lespedeza bicolor Turcz.	0.062	0.064		0.094		0.084
Poa annua L.			0.092	0.064	0.066	0.056
Potentilla acaulis L.	0.074					
Thymus mongolicus Ronn		0.054	0.054			
Prinsepia uniflora Batal.	0.062				0.059	
Phragmites australis				0.052		
Potentilla chinensis Ser.		0.052				
Caragana korshinskii Kom					0.050	

Table 3: Cover, average height, species richness and diversity values of microtopographies and undisturbed slopes in the Hegou watershed. SP: scarp; EG: ephemeral gully; SH: sinkhole; PL: platform; GL: gully; US: undisturbed slope. Average height was calculated excluding shrubs and tree seedlings. All values are means±SE. Letters indicate significant pairwise differences between means within a row at p = 0.05.

	Microtopography					
	SP	EG	SH	PF	GL	US
Cover (%)	68.07 ± 3.91^{b}	67.35 ± 3.87^{b}	66.39 ± 4.20^{b}	64.64 ± 3.97^{b}	74.33 ± 3.89^{a}	63.35 ± 2.29^{b}
Average height (cm)	28.00 ± 2.80^{ab}	24.57 ± 2.39^{a}	48.11 ± 4.53^{b}	23.79 ± 2.18^{a}	42.00 ± 5.56^{b}	26.30 ± 1.72^{a}
Margalef's index	2.491 ± 0.102	2.256 ± 0.093	1.984 ± 0.081	2.339 ± 0.122	2.346 ± 0.077	2.023 ± 0.082
Shannon-Wiener index	1.695 ± 0.082^{a}	1.62 ± 0.091^{ab}	1.375 ± 0.087^{b}	1.39 ± 0.120^{b}	1.58 ± 0.084^{ab}	1.36 ± 0.063^{b}
Alatalo index	0.56 ± 0.027^{bc}	0.618 ± 0.032^{c}	0.46 ± 0.029^{ab}	0.41 ± 0.037^{a}	0.52 ± 0.022^{abc}	0.517 ± 0.027^{abc}

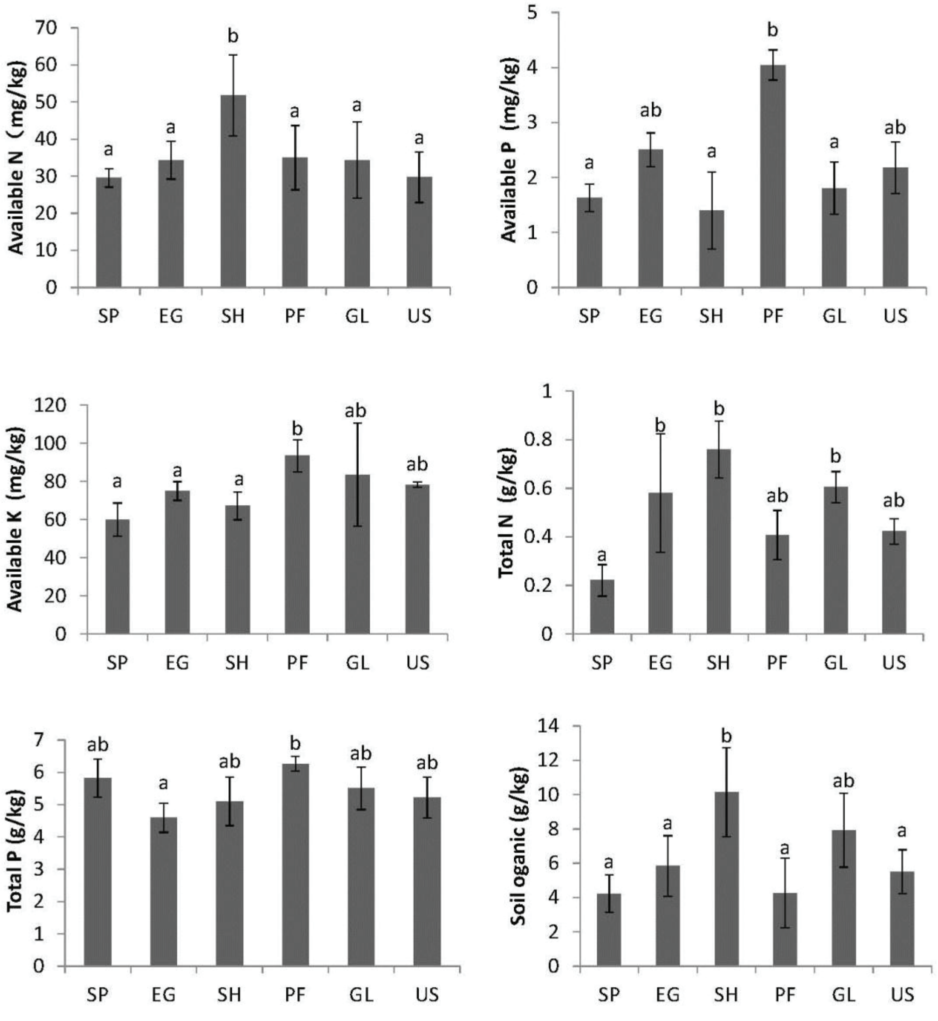

Fig. 4: The soil nutrient in the 0-60 cm layers of different microtopographies. SP: scarp; EG: ephemeral gully; SH: sinkhole; PL: platform; GL: gully; US: undisturbed slope. Bar heights indicate means, arrows indicate SE, and letters indicate significant differences at p = 0.05.

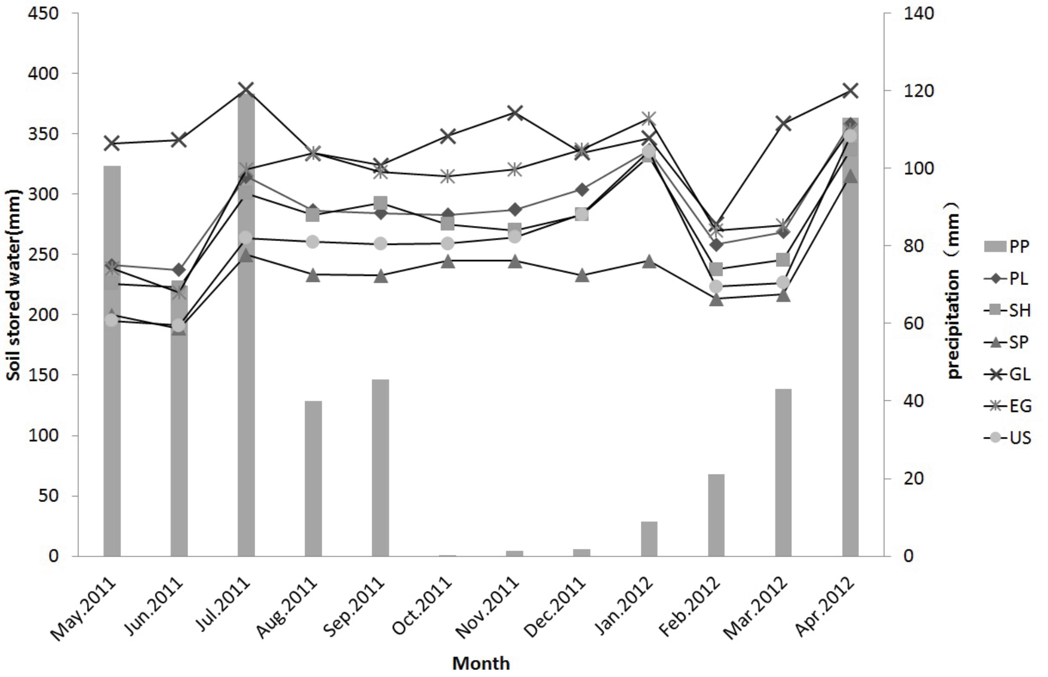

Fig. 5: Soil water storage in 180 cm of five microtopography types and an undisturbed slope from May 2011 to April 2012. SP: scarp; EG: ephemeral gully; SH: sinkhole; PL: platform; GL: gully; US: undisturbed slope; PP: precipitation.

monodominant communities, which were lower in species diversity and species evenness. Platforms showed similar characteristics with sinkhole, but the indices were slightly lower.

Soil Nutrients

Available N, total N and organic matter in sinkholes were higher than in the other microtopographies and undisturbed slopes, among which organic matter in sinkholes ($p = 0.02$) was significantly higher than the others. Available P, available K and total P in platforms were higher than the other microtopographies ($p = 0.084$) and undisturbed slopes ($p = 0.013$). The soil nutrients in ephemeral gullies were largely the same as undisturbed slopes, except the total P which was slightly lower. Scarps had the minimum content characteristics of soil nutrients compared with the other microtopography positions. Gullies were at an intermediate level of soil nutrients for all the six soil nutrients (Fig. 4)

Soil Water

Fig. 5 gives the precipitation characteristics of the Loess Plateau region in northern Shaanxi. The uneven annual rainfall makes it very dry in winter and rainy in summer. According to the soil water storage value, microtopographies and undisturbed slopes showed significant differences ($F = 11.916$, $df = 5$, $p < 0.001$), which, arranged in descending order, were gully > ephemeral gully > platform > sinkhole > undisturbed slope > scarp. Among all the microtopographies, gullies showed a remarkable ability to store water. Gullies maintained soil water at a high level and could also increase the soil water content rapidly even after a small rainfall event. The vertical distribution of the soil water content shows that water levels in the 60-180 cm depth range were significantly high (Fig. 6). Conversely, the soil water storage of the scarp ranged from 188.8 mm to 315.5 mm, with an average of 234.8 mm, which was the lowest of all the microtopographies. Scarps also have a poor holding water capacity, such that strong rainfall contributes little to increasing the soil water content (July, 2011). Generally, microtopographies more or less performed better than undisturbed slopes in storing water, except for the scarp.

DISCUSSION

Due to the influence of solar radiation, slope aspect can largely determine the soil moisture on the Loess Plateau. Therefore, slope aspect is the most important factor impacting plant growing. However, vegetation restoration practice was usually implemented under the slope scale, the plants influence factors that under slope scale should be considered. Alexander using elevation data from airborne

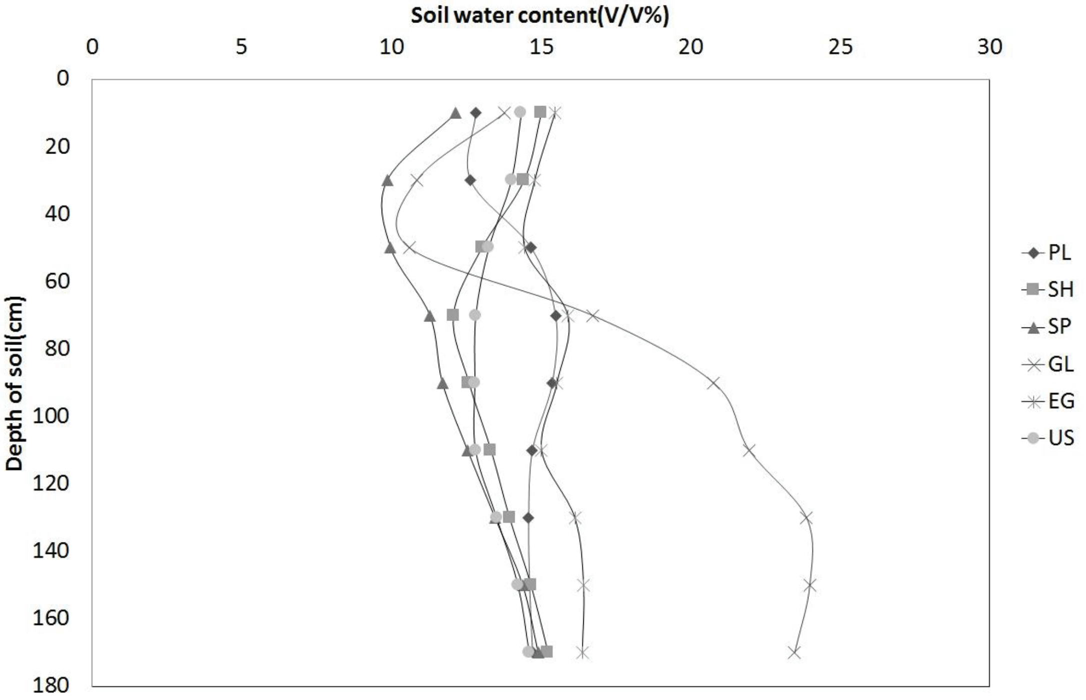

Fig. 6: Soil water content in the 0–180 cm layers of five types of microtopography and an undisturbed slope. SP: scarp; EG: ephemeral gully; SH: sinkhole; PL: platform; GL: gully; US: undisturbed slope.

laser scanner found microtopographies at a small spatial scale of a few decimetres could be an indicator of vegetation (Alexander et al. 2016). More severe disturbance to create microtopographies was also found to have potential benefits when introducing specialist species of calcareous grassland for restoration in Pegsdon Hills, Bedfordshire, UK (Wagner et al. 2016). These former studies have well illustrated that microtopographies have obvious impact to vegetation. Similarly, results of a canonical correlation analysis suggested that characteristics of microtopography were the main factors affecting the characteristics of vegetation, with the exception of slope aspect.

The vegetation species richness corresponds to habitat heterogeneity. In this study, we found that there were more species on the microtopography plots compare with undisturbed slope plots. Unlike vegetation in wetland, where excessive water in pools usually leads to lower plant cover (Sleeper et al. 2016), microtopographies on the Loess Plateau have opposite effect. Amongst all the microtopographies, plants in gullies have higher cover and plant height. Pioneer tree species with rapid growth can seize the habitat in gullies where they have an adequate water supply (Hu et al. 2007). Shrubs and pioneer tree species appeared firstly in gullies. Qin (2009) found that the dominant species and primary companion species are usually xerophytic because of the droughty soil water conditions on the Loess Plateau. However, in this study, we found hygrophytes on platforms, such as *Phragmites australis*, indicating that habitat heterogeneity come out of microtopographies. Sinkholes are a type of microtopography that can easily obtain water supply and accumulate fertile soil from runoff, which enables plants to reach greater heights. The microtopographies described above exhibited better growing environments for plants compared to undisturbed slope.

Soil nutrients can affect biomass production, species composition, and diversity (Critchley et al. 2002). Grazing exclusion was improved that had significant positive effects on improving soil nutrients (Li et al. 2016). Peng et al. (2005) showed that total N was gradually increased along with vegetation restoration years in An 'Sai on the Loess Plateau. In our study, soil nutrients content was increased in every site more or less compared with Peng's result and microtopographies performed more remarkably. Phosphorus is closely related to plant biomass (Jiao et al. 2008), and we found that it is significantly higher on platforms indicating that platforms have aggregation effect to some of the nutrient elements.

Soil water is one key factor limiting vegetation restoration (Chen et al. 2007). However, we found soil water among microtopographies that under the slope scale has significant difference. The soil stored water in gullies was approximately 100mm more that undisturbed slopes every month in the year 2011-2012. Additionally, the disturbed slope soil water content in our study was similar compared to Wang et al. (2014) found on grass land in Suide, Shannxi Province. Microtopographies, especially gullies, ephemeral gullies and platforms indeed performed relatively wetter soil condition than undisturbed slopes.

Soil and water conservation is one of the main functions of ecological restoration on the Loess Plateau (Chen et al. 2008). One of the main reasons for revegetation is to achieve the recovery goal in a short time. Some researchers advocate natural recovery as more suitable for the ecosystem on the Loess Plateau (Jiao et al. 2012) due to the shortage of precipitation. Soil desiccation is common in current reforestation activities on the Loess Plateau (Cao et al. 2010) because too many tree seedlings are planted in small watersheds, where the incoming water cannot match the water outflow. Our study indicates that soil properties vary with the heterogeneity of topography on a fine scale. Small heterogeneity of topography can lead to fertile areas on slopes, especially with regard to the soil water content. Our study shows that soil water content is significantly different within the slope scale, implying that not every plot on slopes is necessarily inappropriate for planting. In addition, our study shows that pioneer species were still dominant in the study area after 14 years of natural recovery. Previous study suggests that successful revegetation should plant a mix of grass, shrubs and trees (Fu et al. 2000). Because actively sowing species on the Loess Plateau is likely to enhance species diversity and optimize species composition (Wang 2006), it is useful to develop an effective way to restore vegetation artificially. Creating topographic heterogeneity proved to be an active and effective approach to ecological restoration (Gilland et al. 2014). However, implementing similar measures is not easy on the Loess Plateau due to the poor local economic situation. In this case, artificially vegetation restoration using naturally formed microtopographies as indicator for species choosing may be an economic and effective way.

The soil water content and appearance of shrubs imply that platforms have a higher carrying capacity for plants compared to undisturbed slopes. Sinkholes can cluster soil nutrients and collect water, which is similar to what was found in a bottomland hardwood forest in Texas (Simmons et al. 2011) Relatively better soil water conditions suggest that sinkholes can be treated as natural tree planting locations. Ephemeral gullies are the initial stage of gully erosion, which will lead to greater soil erosion as they develop (Xu et al. 2016). However, plants grow in frequent soil erosion, and deposition environment requires a greater water supply and need to be resistant to rushing runoff. Gully erosion is the primary source of sediment loss on the Loess Plateau (Li et al. 2015). In this paper, we found that gullies have a remarkable water storage capacity and maintain a surplus of water after it is taken up by plants. The emergence of aquatic plants also indicates gullies have humid environment. Species that are resistant to flooding should be chosen for vegetation restoration in gullies, and higher densities are acceptable. Slope gradient largely influences soil erosion (Fox et al. 2000), which lowers the soil water storage and soil nutrients in scarps compared with other four microtopographies. To improve ecological restoration, we suggest maintaining the status of scarps and reducing human interference during artificial vegetation restoration.

CONCLUSION

Microtopography was the second main factor affecting the characteristics of vegetation besides slope aspect on the Loess Plateau. In the natural recovery site, vegetation structure, plant diversity, soil nutrients and soil water content were significantly different across microtopographic features. According to the soil water storage value, microtopographies and undisturbed slopes arranged in descending order were gully > ephemeral gully > platform > sinkhole > undisturbed slope > scarp. An effective vegetation configuration mode requires more accurate design. Vegetation configuration on slopes should be in accordance with the microtopography. Species that require more water can be planted in gullies, ephemeral gullies and platforms. A small number of seedlings could also be planted in sinkholes to prevent further soil erosion. In addition, species planted on undisturbed slopes should have a lower water requirement compared with those planted on the microtopographies described above. Scarps should maintain the status quo and recover naturally.

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