Catena 144 (2016) 177–183

Contents lists available at ScienceDirect

Catena

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

Effects of shrub patch size succession on plant diversity and soil water content in the water-wind erosion crisscross region on the Loess Plateau

Hong-Min Hao [a,b], Rong Lu [a,b], Yu Liu [a,c], Nu-Fang Fang [a,c], Gao-Lin Wu [a,c,*], Zhi-Hua Shi [a,c]

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

ARTICLE INFO

Article history:
Received 17 December 2015
Received in revised form 19 March 2016
Accepted 14 May 2016
Available online xxxx

Keywords:
Vegetation pattern
Semiarid ecosystem
Shrub patch size
Soil water content

ABSTRACT

The shrub patch pattern has important influence on the ecosystems in the arid water-wind erosion crisscross regions. The objective of this study was to examine the effects of vegetation pattern of shrub spot patch on species diversity and soil water content at the sand in slopes in water-wind erosion crisscross region on the Loess Plateau. In this study, the shrub patch size was classified to four size classes, contrasting with bare land patch, and herbaceous plants, and soil water content of the shrub patch were measured in each patch. The Shannon–Wiener indices were 0.364 and 1.074 respectively in small and large patches, which were higher than 0.231 in the bare land patch. The Richness index was 1.41 in bare land patch, which was lower than 1.704 in small shrub patch and 4.370 in large shrub patch. The above- and below-ground biomass and surface soil water content were also significantly ($p < 0.05$) higher in the shrub patch than that in the bare land patch. These results suggest that the shrub patch could significantly increased species diversity, the above- and below-ground biomass, and surface soil water content. Based on these results, the soil was aggregated in shrub patch and the vegetation pattern was successive and each cycle of vegetation pattern was benefited by its previous stage in the water-wind erosion crisscross region on the Loess Plateau.

1. Introduction

The arid and semiarid regions cover about one third of the Earth's land surface, especially the water-wind erosion crisscross region on the Loess Plateau, and they are heavily influenced by desertification (D'Odorico et al., 2013). Landscapes of water-limited systems are mosaics of fertile vegetative patches and crusted soil of low productivity (Sheffer et al., 2007). Bands (Merino-Martín et al., 2012), rings (Ravi et al., 2007), stripes (Mauchamp et al., 1993) and spots (Couteron and Lejeune, 2001) are the common vegetation patterns of ecosystems, and they are characterized by the size and shape. There are some discussions about the importance of their present study. Some scholars studied the interactions among factors such as overgrazing, recovery from anthropogenic disturbance (Segoli et al., 2008; Archer, 2010; Daryanto et al., 2013), increases in CO_2 and N deposition, reduced fire frequency and long-term climate change (Eldridge et al., 2011). In different aspects, the vegetation patterns also have various process and mechanism. Under spot vegetation pattern in the denser plant areas, runoff and sediment transport processes result in the formation of heterogeneous landscape with a mosaic of nutrient rich soil patches – known as "fertility islands" - bordered by unfertile bare soil (Charley and West, 1975). These vegetation patterns can efficiently prevent the erosion of water and soil. There are many researches on the desert shrub patch, mainly about plant community (Koyama et al., 2014;) and the soil property (Ludwig et al., 2005; Hu et al., 2009; Vásquez-Méndez et al., 2010; Zhao et al., 2010). In arid ecosystems, it was common to find islands of fertility associated with individual shrub plants (Garcia-Moya and McKell, 1970). The shrub vegetation displayed a pattern of higher soil organic matter and mineral nutrients in the vegetation patches compared with the low-cover matrix (Garcia-Moya and McKell, 1970; Rostagno et al., 1991; Mazzarino et al., 1996). Vegetated patches and their dominant shrub plants serve as protection from grazing for preferred plant species and protection from predation for small animals (Jaksić and Fuentes, 1980). However, studies of patch succession dynamics in arid and semi-arid environments have been comparatively scarce, especially the shrub spot patch at the sand in slopes.

Artemisia ordosica is one of the dominant shrubs in the semi-arid regions of China, and is an excellent sand-fixing shrub in Mu Us Desert, thereby playing an important role in fixing sand, maintaining biodiversity and ecosystem stability in the region (Yang et al., 2008). Considering the importance of the vegetation pattern of the *A. ordosica* shrub canopy patch in semi-arid regions, there is lack of research on the effects of the *A. ordosica* shrub canopy patch on the plant community and soil water content in sand in semi-arid regions. *A. ordosica* is the dominant

* Corresponding author at: State Key Laboratory of Soil Erosion and Dryland Farming on the Loess Plateau, Northwest A and F University, Yangling, Shaanxi 712100, China.
E-mail address: gaolinwu@gmail.com (G.-L. Wu).

http://dx.doi.org/10.1016/j.catena.2016.05.015
0341-8162/

species of the plant community succession in the semiarid regions. *A. ordosica* is a squat shrub and grows in a vegetation patch pattern with individual clumps of plants up to 180 cm across the canopy. Its tangled branches and stems are woody and corky (Huang et al., 2010). *A. ordosica* is long-lived about 10 years and the population recruitment was generally realized by reproduction from seed. At present, many researchers are studying the effects of *A. ordosica* on wind erosion (Yang et al., 2014). Therefore, the *A. ordosica* shrub patches could prevent the erosion of soil, and provide comfortable environment beneath the shrub canopy for the herbaceous plants. In order to manage the shrub patches to deal with the conundrum of the deteriorating environment in arid and semiarid regions; clarification of the mechanism, progress and law that governs vegetation patterns is needed.

Based on the above studies, we assumed that the shrub patches may increase the species diversity and the above- and below-ground biomass, and prevent the erosion of soil and that vegetation pattern of the shrub patches may cycle together with the accompanying herbaceous plants, and the difference of the microsites formed by different sizes shrub individuals may contribute to the cycling (formation, development and decline of shrub patch). So, we hypothesized that the plant species diversity, above- and below-ground biomass, and the soil water content should be greater under shrub canopies than that in their respective interspaces, and the shrub patches will appear in the environment with the dynamics of soil water in the water-wind erosion crisscross region on the Loess Plateau.

2. Materials and methods

2.1. Study sites and design

The study site was located at the Liudaogou watershed (110°21′–110°23′E, 38°46′–38°51′N, H: 1080–1270 m) of Shenmu County in the southern part of the Mu Us desert, it belongs to the water-wind erosion crisscross region on the Loess Plateau. There is continental semiarid and seasonal wind climate, with an average annual precipitation of 437 mm. Most of the precipitation falls mostly from June to September during intense rainstorms. Mean annual potential evapotranspiration is 785 mm. The soil of this study is an Aeolian sandy soil (particle size was >0.05 mm), which suffers wind erosion in spring and winter, and water erosion in summer and autumn (She et al., 2014). As such, the Chinese government implemented "the Grain to Green" program to reduce soil erosion in 1998 in the study region (Xu et al., 2006).

At the study site, the dominat species was *Artemisia ordosica* (*A. ordosica*, with some common species, such as *Artemisia sphaerocephala*, *Salix cheilophila*, *Lespedeza davurica*, and *Astragalus adsurgens*). *A. ordosica* is a squat shrub and grows in a vegetation patch pattern with individual clumps of plants up to 180 cm across the canopy. Its tangled branches and stem are woody and corky (Huang et al., 2010). *A. ordosica* is long-lived about 10 years and the population recruitment is generally realized by reproduction from seed. A single shrub plant can facilitate the development of the understory herbaceous species (Callaway, 2007) by decreasing abiotic stress or grazing damage (Facelli and Temby, 2002; Weedon and Facelli, 2008; Cushman et al., 2010). Four categories of *A. ordosica* shrub patch size (canopy diameter) were designed in this study: Small Shrub Patch (SSP) (<60 cm), Middle Shrub Patch (MSP) (60–95 cm), Large Shrub Patch (LSP) (>95 cm), Dead Shrub body Patch (DSP) (>95 cm) patches. Canopy diameter (diameter of the crown of the shrub) was measured at 40 cm above ground level.

2.2. Plant community investigations

In each quadrat, all green, aboveground plant parts of each species was cut, collected, and put into separate labeled envelops. To measure the belowground biomass, we used Complete Excavation method (get the entire root from the soil) to collect the entire root, and we measured the depth and width of the root. The roots and aboveground plant parts were dried at 65 °C for 24 h and weighed to determine the dry biomass.

The Richness Index, Shannon–Wiener diversity index and Pielou evenness index of the patches communities were calculated using the following functions (Stirling and Wilsey, 2001):

Richness index (R):

$$R = S$$

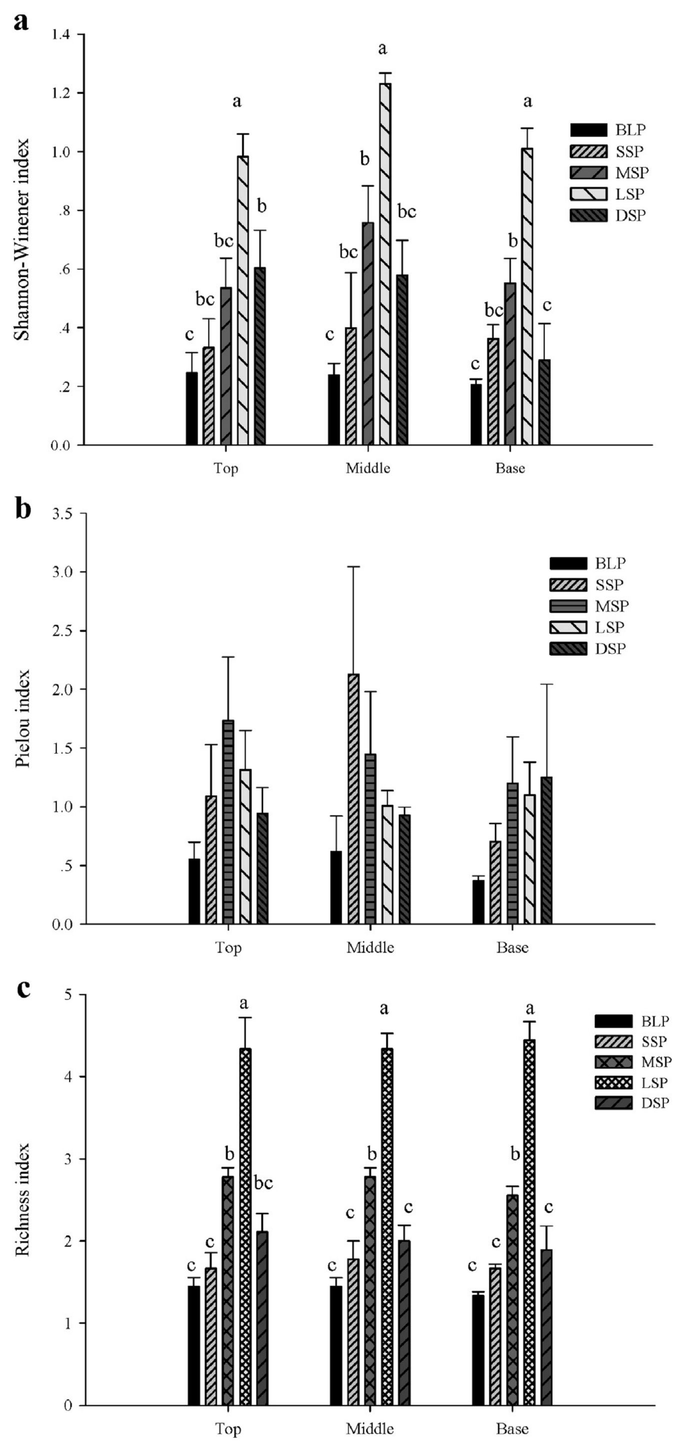


Fig. 1. Shannon–Wiener index (a), Pielou evenness index (b) and Richness index (c) of five patches at three different positions at the slope. Different letters indicate significant differences at $p < 0.05$ among the different patches at the same position at the slope.

Table 1
The above- and below-ground biomass (g/m^2) of different patches on three positions at the slope.

Index	Patch type	Position of the slope		
		Top	Middle	Base
Aboveground biomass (g/m^2)	BLP	3.53 ± 1.24c	3.29 ± 2.15c	1.60 ± 0.74d
	SSP	20.34 ± 3.36c	18.65 ± 8.73c	13.48 ± 5.15d
	MSP	159.05 ± 17.53bc	121.41 ± 32.41b	98.76 ± 20.96c
	LSP	524.03 ± 118.93a	347.74 ± 40.10a	455.08 ± 16.91a
	DSP	252.99 ± 37.28b	198.74 ± 32.66b	180.44 ± 33.67b
Belowground biomass (g/m^2)	SSP	8.49 ± 1.70c	6.33 ± 2.73d	6.85 ± 3.19b
	MSP	47.86 ± 8.89b	26.97 ± 4.85c	30.76 ± 8.62b
	LSP	120.23 ± 14.56a	107.07 ± 4.68a	106.35 ± 16.42a
	DSP	54.16 ± 17.10b	50.57 ± 6.10b	33.96 ± 5.09b

Note: The data in the table is mean ± SEM. Different superscript lowercase letters indicate a significant difference at 0.05 level among the different patches at the same position at the slope. BLP: bare land patch; SSP: small shrub patch; MSP: middle shrub patch; LSP: large shrub patch; DSP: dead shrub patch. Values followed by different lowercase letters within rows are significantly different at p<0.05.

Table. 2
Pearson correlation coefficients among positions, Shannon–Wiener index (H), Pielou evenness index (E), Richness index (R), below-ground biomass (BGB), above-ground biomass (AGB), root-shoot ratio (R/S), and soil water content (SWC).

	H	E	R	BGB (g/m^2)	AGB (g/m^2)	R/S	SWC (%)
Positions	−0.075	−0.187	−0.034	−0.139	−0.105	0.039	−0.530
H		0.26	0.953*	0.886*	0.857*	−0.365	0.658*
E			0.296	−0.184	0.195	−0.122	0.228
R				0.923*	0.901*	−0.392	0.653
BGB (g/m^2)					0.976*	−0.513	0.749*
AGB (g/m^2)						−0.605*	0.819*
R/S							−0.484

Note: Shannon–Wiener index (H), Pielou evenness index (E), Richness index (R), below-ground biomass (BGB), above-ground biomass (AGB), root-shoot ratio (R/S), and soil water content (SWC).
* Indicates significant difference at $p < 0.05$.

Shannon–Wiener diversity index (H):

$$H = -\sum_{i=1}^{S} PiLog_2Pi$$

Pielou evenness index (E):

$$E = \frac{H}{\ln(S)}$$

where S is the total number of species and *Pi* is the mass ratio of *i*th species biomass to the total biomass in the patch community.

2.3. Soil sampling and determination

Soil samples were taken in the quadrats of each block near the belowground biomass sampling points. Soil samples were collected from ten layers (0–10, 10–20, 20–30, 30–40, 40–50, 50–60, 60–70, 70–80, 80–90, 90–100 cm) in three places within each quadrat using a soil core and a soil drilling sampler (9 cm inner diameter), and samples taken at the same layer were then mixed to make a single sample. The soil water content at the time of sampling was determined subtracting the weight of the oven-dried core samples from the weight of the fresh samples (Caviezel et al., 2014). The soil sandy surface was difficult to get using soil drilling sampler at 0–5 cm layer, so the soil was mixed with the soil at 5–10 cm layer.

2.4. Data analysis

Figures were created using SigmaPlot version 8.0 (Systat software Inc., San Jose, CA, USA). All datas were expressed as SEM (mean ± standard error of mean). Statistical analyses were conducted by using SPSS software v. 16.0 (IBM Corporation, New Youk, USA). The differences in species diversity, biomass, root-top ratio and soil water content of vegetation community among patches were compared by using one-way analysis of variance (ANOVA) procedures. Significant differences were evaluated at 0.05 level.

3. Results

3.1. Effects of shrub patch size succession on plant community

The bare land patch was the lowest both in Shannon–Wiener index (top of the slope: 0.25 ± 0.07; middle: 0.24 ± 0.04; base: 0.21 ± 0.02) and Richness index (top: 1.44 ± 0.11; middle: 1.44 ± 0.11; base: 1.33 ± 0.05) in three positions of the slope. The two indices were increasing with the growth of the patch. When the patch grew to the

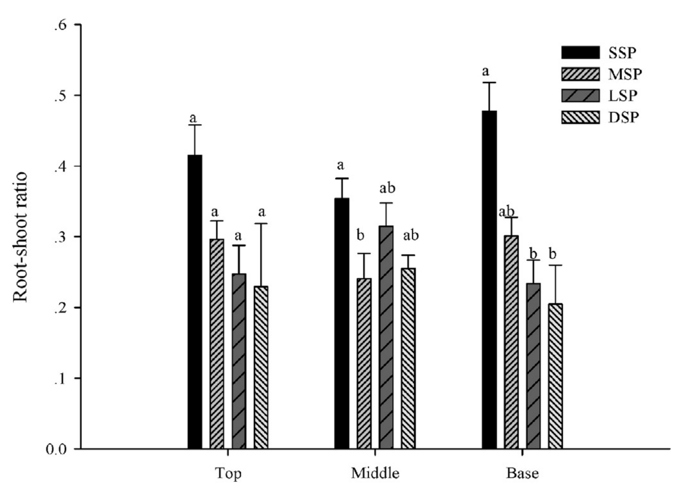
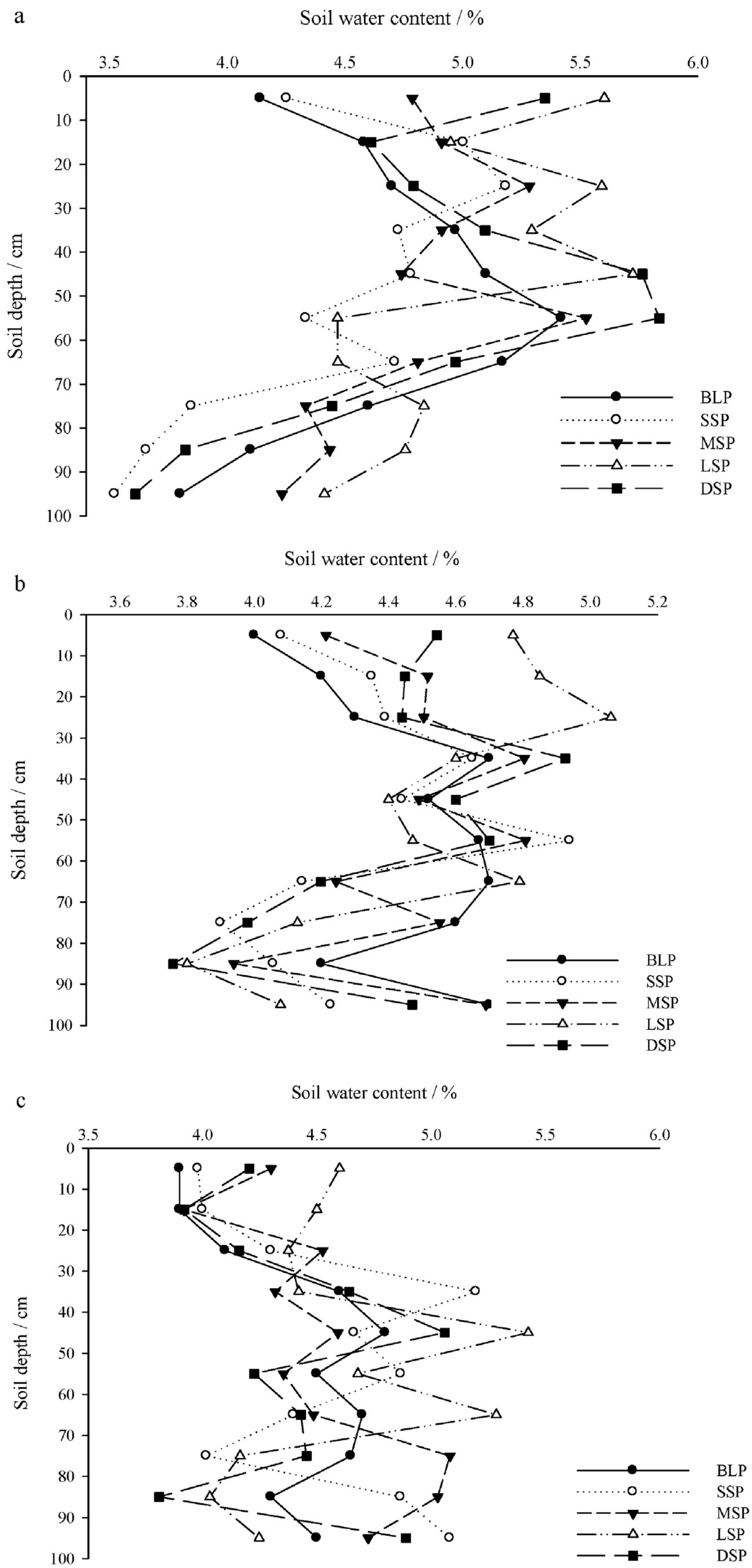


Fig. 2. The root-shoot ratio of different *A. ordosica* shrub patches at different positions at the slope. Different letters indicate significant differences at $p < 0.05$.


a
Soil water content / %
3.5 4.0 4.5 5.0 5.5 6.0
Soil depth / cm
0 10 20 30 40 50 60 70 80 90 100
BLP
SSP
MSP
LSP
DSP
b
Soil water content / %
3.6 3.8 4.0 4.2 4.4 4.6 4.8 5.0 5.2
Soil depth / cm
0 10 20 30 40 50 60 70 80 90 100
BLP
SSP
MSP
LSP
DSP
c
Soil water content / %
3.5 4.0 4.5 5.0 5.5 6.0
Soil depth / cm
0 10 20 30 40 50 60 70 80 90 100
BLP
SSP
MSP
LSP
DSP

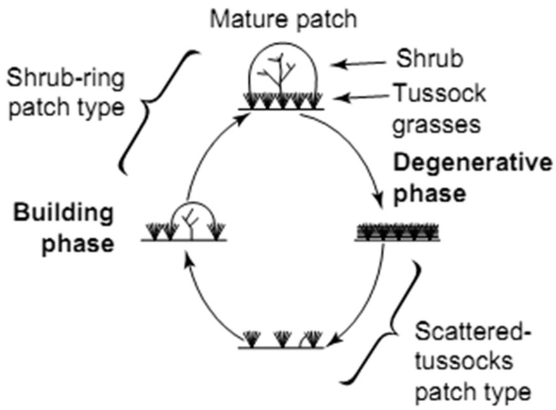


Fig. 4. Shrub patch dynamics (Aguiar and Sala, 1999).

large shrub patch, the Shannon–Wiener index (top: 0.98 ± 0.08; middle: 1.23 ± 0.04; base: 1.01 ± 0.07) and Richness index (top: 4.33 ± 0.38; middle: 4.33 ± 0.19; base: 4.44 ± 0.22) reached the peak, and were significantly higher than other four patches ($p < 0.05$). However, when the patches were to die (called dead body patches), the two indices were significantly ($p < 0.05$) decreased to 0.60 ± 0.13 (top), 0.5 ± 0.12 (middle), 0.29 ± 0.13 (base) and 2.11 ± 0.22 (top), 2.00 ± 0.19 (middle), 1.89 ± 0.29 (base). There was a similar trend at the three positions on the slope. For the Pielou evenness index, there was no significant difference among the five patches in three positions of the slope ($p < 0.05$), ranging from 0.37 to 1.73 (Fig. 1).

In the three positions, the bare land patch aboveground biomass were 3.53 ± 1.24 g m^{-2} (top), 3.29 ± 2.15 g m^{-2} (middle) and 1.60 ± 0.74 g m^{-2} (base), and the large patch aboveground biomass were 524.03 ± 118.93 g m^{-2} (top), 347.74 ± 40.10 g m^{-2} (middle) and 455.08 ± 16.91 g m^{-2} (base). For the belowground biomass, the small patch was 8.49 ± 1.70 g m^{-2} (top), 6.33 ± 2.73 g m^{-2} (middle), 6.85 ± 3.19 g m^{-2} (base). In the large shrub patch, the belowground biomass (top: 120.23 ± 14.56 g m^{-2}, middle: 107.07 ± 4.68 g m^{-2}, base: 106.35 ± 16.42 g m^{-2}) reached the peak at three positions on the slope (Table 1). (See Table. 2.)

3.2. The root-shoot ratio of shrub patch response to geomorphology

At the top position, there was no significant difference among the four shrub patches, and at the middle position, the root-shoot ratio was significantly larger ($p < 0.05$) in the small patch (0.35 ± 0.04) than the middle shrub patch (0.24 ± 0.03), at the same time, there was no significant difference with the large and dead patches. At the base position, however, the root-shoot ratio was significantly higher ($p < 0.05$) for the small shrub patch (0.48 ± 0.03) than the large (0.23 ± 0.03) and dead (0.20 ± 0.02) patches, and there was no significant difference in the middle shrub patch (0.30 ± 0.04) than in other three shrub patches (Fig. 2).

3.3. Effects of shrub patch size succession and geomorphology on soil water content

In the surface soil layer (0–10 cm), the soil water content was higher in large shrub patch (top: 5.60%; middle: 4.77%; base: 4.60%) than that in the other four patches, especially significantly ($p < 0.05$) higher than bare land patch (top: 4.14%; middle: 4.01%; base: 3.90%) and small shrub patch (top: 4.25%; middle: 4.08%; base: 3.98%). In the soil layers of 0–30 cm, the soil water content was increasing with the increasing soil depth. In the soil layers of 30–70 cm, the soil moisture content was fluctuating with the increasing soil depth. And, in the three positions of the slope, the soil desication emerged at the 70–100 cm (Fig. 3).

3.4. Relationship between plant community feature and soil water content

Correlation analyses showed that surface soil water content was positively related to positions ($R = -0.530, p < 0.05$), Shannon–Wiener index ($R = 0.658$, $p < 0.05$), richness index ($R = 0.0.653$, $p < 0.05$), below-ground biomass ($R = 0.749, p < 0.05$) and above-ground biomass ($R = 0.819$, $p < 0.05$), while it was non-significant positively related to evenness index ($R = 0.228$, $p > 0.05$) and root/shoot ratio ($R = -0.484, p > 0.05$). There were significant positive correlations between above-ground biomass and Shannon–Wiener index ($R = 0.857$, $p < 0.05$), richness index ($R = 0.901$, $p < 0.05$), and below-ground biomass ($R = 0.976$, $p < 0.05$). Shannon–Wiener index was significantly positive related to richness index ($R = 0.953$, $p < 0.05$).

4. Discussion

This study results confirmed the effectiveness of the vegetation pattern of *A. ordosica* shrub patch in improving the species diversity, the above- and below-ground biomass, and surface soil water content. *A. ordosica* shrub patch strongly influenced the structure of herbaceous plant community in our research. Consistent with the previous researches, the *A. ordosica* shrub patch could provide comfortable microenvironment for the herbaceous plants, as shown by the increased plant diversity index with increasing size of the shrub patch. Previous studies (Noy-Meir, 1973; Noy-Meir, 1981; Sala and Aguiar, 1996) showed increases in plant above- and below-ground biomass and diversity. Li et al. (2013) discovered that above-ground biomass and cover are higher within shrub patches than at their interspaces. Such conclusions of previous studies could be brought about by small canopy size and unstable root which caused inefficient water sequestration from rain or runoff by the small shrub patch. From the results of our research, the heterogeneity of the water distribution, in the spot pattern, could result in the promotion of above- and below-ground biomass, as well as the plant species diversity However, about the Pielou evenness index and root-shoot ratio, there was no unified view.

In this study, we measured the soil water in different size shrub patches and bare land and agreed with the main trend about the shrub patch, known as "fertility islands" (Charley and West, 1975; Hibbard et al., 2001), so shrub patch could provide comfortable protection for the plants that grew under the canopy (Brantley and Young, 2009). In our research, the surface soil water content was positively related with species diversity, richness, and above- and below-ground biomass. The surface soil water content was higher in the shrub patches than that in the bare land patch, leading higher species diversity and above- and below-ground biomass in the shrub patches. Maybe, the reason was that the precipitation was less precipitation. Changes in the microenvironments (i.e., increased water infiltration and lower soil water evaporation from the soil) due to the presence of small size shrub patches are dominantly occurring within densely vegetated patches compared to those of bare-soil patches (Soriano and Sala, 1986; Rostagno et al., 1991).

In this study, compared with the bare land patch, the vegetation pattern of shrub patch increased species diversity and richness, and surface soil water content. In addition, the indices were advanced with the increase of the shrub patch size. The different size shrub patches had different features. When the shrub patch was small, it was not large enough to afford protection for the herbaceous plant. With the shrub growing, the shrub patch could be considered as "fertility islands" and aerial protection. Wind and animal action were the major dispersal

Fig. 3. Surface soil water content of five patches at three positions at the slope. (a) top, (b) Middle, (c) Base. BLP: bare land patch, SSP: small shrub patch, MSP: middle shrub patch, LSP: large shrub patch, DSP: dead shrub patch.

agents (Mauchamp et al., 1993; Aguiar and Sala, 1994; Aguiar and Sala, 1997), in spotted vegetation. So, shrubs could catch seeds and guard them from the erosion of wind and water (Ma and Liu, 2008; DeFalco et al., 2009; Giladi et al., 2013). The positive and negative effects coexist. On the one hand, the plant shrubs formed habitats benefiting to themselves, decreasing the death ratio of seedlings (D'Odorico et al., 2010), and on the other hand, adult shrubs increased seedling survival by ameliorating the microenvironment or by deterring herbivory (Aguiar et al., 1992), and adult plants could also reduce seedling survival by decreasing light or water availability (Franco and Nobel, 1988; Mauchamp et al., 1993). As the shrub grew up to the limit of its life history, the surrounding favourable environments with aerial protection it created would collapse, thus the situations of multi-species plants coexistence would break up. The seedlings around the mother shrub would conduct the next succession process (Fig. 4). Thus, the microsites formed by the shrub patches would be in favor of the later shrub patches, forming the spot vegetation pattern in arid and semiarid lands. The vegetation pattern was successive and each cycle was benefited by its previous stage in the water-wind erosion crisscross region on the Loess Plateau.

5. Conclusion

The shrub patch pattern was important and had considerable consequences in the semiarid ecosystem processes and their associated feedbacks. The *A. ordosica* shrub patch pattern had significant ($p < 0.05$) effects on plant community and soil water content in semiarid regions. The aspects addressed in the study as follows: i) the succession process was from individual shrub patch to multi-species plants pattern. ii) the plant diversity, above- and below-ground biomass, and soil water content was higher in shrub patches than the bare land patches; iii) the community plant diversity, above- and below-ground biomass, and soil water content was increasing with the growing of the shrub canopy patch; iv) the shape and structure of different size shrub patches was successive from small shrub patch to dead shrub body patch. The microsites formed by the shrub patches would be in favor of the later shrub patches, forming the patch-mosaic vegetation pattern in the water-wind erosion crisscross region on the Loess Plateau.

Acknowledgements

We thank editors and two anonymous reviewers for their valuable comments and suggestions on the manuscript. This research was funded by the National Natural Science Foundation of China (NSFC41371282, 41390463, 41525003), the "Light of West China" Program of CAS (XAB2015A04) and Project of Natural Science Foundation of Shaanxi Province (2014KJXX-15).

References

Aguiar, M.R., Sala, O.E., 1994. Competition, facilitation, seed distribution and the origin of patches in a Patagonian steppe. Oikos 70, 26–34.
Aguiar, M.R., Sala, O.E., 1997. Seed distribution constrains the dynamics of the Patagonian steppe. Ecology 78, 93–100.
Aguiar, M.R., Sala, O.E., 1999. Patch structure, dynamics and implications for the functioning of arid ecosystems. Trends Ecol. Evol. 14, 273–277.
Aguiar, M.R., Soriano, A., Sala, O.E., 1992. Competition and facilitation in the recruitment of seedlings in Patagonian steppe. Funct. Ecol. 6, 66–70.
Archer, S.R., 2010. Rangeland conservation and shrub encroachment: new perspectives on an old problem. Wild Rangelands: Conserving Wildlife while Maintaining Livestock in Semi-Arid Ecosystems, pp. 53–97.
Brantley, S.T., Young, D.R., 2009. Contribution of sunflecks is minimal in expanding shrub thickets compared to temperate forest. Ecology 90, 1021–1029.
Callaway, R.M., 2007. Positive Interactions and Interdependence in Plant Communities. Springer, Dordrecht, NL, US, pp. 443–444.
Caviezel, C., Hunziker, M., Schaffner, M., Kuhn, N.J., 2014. Soil–vegetation interaction on slopes with bush encroachment in the central Alps–adapting slope stability measurements to shifting process domains. Earth Surf. Process. Landf. 39, 509–521.
Charley, J.L., West, N.E., 1975. Plant-induced soil chemical patterns in some shrub-dominated semi-desert ecosystems of Utah. J. Ecol. 63, 945–963.
Couteron, P., Lejeune, O., 2001. Periodic spotted patterns in semi-arid vegetation explained by a propagation-inhibition model. J. Ecol. 89, 616–628.
Cushman, J.H., Waller, J.C., Hoak, D.R., 2010. Shrubs as ecosystem engineers in a coastal dune: influences on plant populations, communities and ecosystems. J. Veg. Sci. 21, 821–831.
Daryanto, S., Eldridge, D.J., Wang, L., 2013. Spatial patterns of infiltration vary with disturbance in a shrub-encroached woodland. Geomorphology 194, 57–64.
DeFalco, L.A., Esque, T.C., Kane, J.M., Nicklas, M.B., 2009. Seed banks in a degraded desert shrubland: influence of soil surface condition and harvester ant activity on seed abundance. J. Arid Environ. 73, 885–893.
D'Odorico, P., Fuentes, J.D., Pockman, W.T., Collins, S.L., He, Y., Medeiros, J.S., Litvak, M.E., 2010. Positive feedback between microclimate and shrub encroachment in the northern Chihuahuan desert. Ecosphere 1, 1–11.
D'Odorico, P., Bhattachan, A., Davis, K.F., Ravi, S., Runyan, C.W., 2013. Global desertification: drivers and feedbacks. Adv. Water Resour. 51, 326–344.
Eldridge, D.J., Bowker, M.A., Maestre, F.T., Roger, E., Reynolds, J.F., Whitford, W.G., 2011. Impacts of shrub encroachment on ecosystem structure and functioning: towards a global synthesis. Ecol. Lett. 14, 709–722.
Facelli, J.M., Temby, A.M., 2002. Multiple effects of shrubs on annual plant communities in arid lands of South Australia. Austral Ecol. 27, 422–432.
Franco, A.C., Nobel, P.S., 1988. Interactions between seedlings of *Agave deserti* and the nurse plant *Hilaria rigida*. Ecology 69, 1731–1740.
Garcia-Moya, E., McKell, C.M., 1970. Contribution of shrubs to the nitrogen economy of a desert-wash plant community. Ecology 51, 81–88.
Giladi, I., Segoli, M., Ungar, E.D., 2013. Shrubs and herbaceous seed flow in a semi-arid landscape: dual functioning of shrubs as trap and barrier. J. Ecol. 101, 97–106.
Hibbard, K.A., Archer, S., Schimel, D.S., Valentine, D.W., 2001. Biogeochemical changes accompanying woody plant encroachment in a subtropical savanna. Ecology 82, 1999–2011.
Hu, W., Shao, M.A., Wang, Q.J., Horton, R., 2009. Temporal changes of soil hydraulic properties under different land uses. Geoderma 149, 355–366.
Huang, L., Zhang, Z.S., Li, X.R., 2010. Sap flow of *Artemisia ordosica* and the influence of environmental factors in a revegetated desert area: Tengger Desert, China. Hydrol. Proc. 24, 1248–1253.
Jakšić, F.M., Fuentes, E.R., 1980. Why are native herbs in the Chilean matorral more abundant beneath bushes: microclimate or grazing? J. Ecol. 68, 665–669.
Koyama, A., Sasaki, T., Jamsran, U., Okuro, T., 2014. Shrub cover regulates population dynamics of herbaceous plants at individual shrub scale on the Mongolian steppe. J. Veg. Sci. 26, 441–451.
Li, X.Y., Zhang, S.Y., Peng, H.Y., Hu, X., Ma, Y.J., 2013. Soil water and temperature dynamics in shrub-encroached grasslands and climatic implications: results from Inner Mongolia steppe ecosystem of North China. Agric. For. Meteorol. 171, 20–30.
Ludwig, J.A., Wilcox, B.P., Breshears, D.D., Tongway, D.J., Imeson, A.C., 2005. Vegetation patches and runoff-erosion as interacting ecohydrological processes in semiarid landscapes. Ecology 86, 288–297.
Ma, J.L., Liu, Z.M., 2008. Spatiotemporal pattern of seed bank in the annual psammophyte *Agriophyllum squarrosum* Moq. (Chenopodiaceae) on the active sand dunes of northeastern Inner Mongolia, China. Plant Soil 311, 97–107.
Mauchamp, A., Montaña, C., Lepart, J., Rambal, S., 1993. Ecotone dependent recruitment of a desert shrub, *Flourensia cernua*, in vegetation stripes. Oikos 68, 107–116.
Mazzarino, M.J., Bertiller, M.B., Sain, C.L., Laos, F., Coronato, F.R., 1996. Spatial patterns of nitrogen availability, mineralization, and immobilization in northern Patagonia, Argentina. Arid Land Res. Manag. 10, 295–309.
Merino-Martín, L., Breshears, D.D., Moreno-de las Heras, M., Villegas, J.C., Pérez-Domingo, S., Espigares, T., Nicolau, J.M., 2012. Ecohydrological source-sink interrelationships between vegetation patches and soil hydrological properties along a disturbance gradient reveal a restoration threshold. Restor. Ecol. 20, 360–368.
Noy-Meir, I., 1973. Desert ecosystems: environment and producers. Annu. Rev. Ecol. Syst. 4, 25–51.
Noy-Meir, I., 1981. Spatial effects in modelling of arid ecosystems. In: Goodall DW, RA Perry and KMW Howes (eds) Arid Land Ecosystems. Structure, Functioning and Management. IBP 17, 411–432.
Ravi, S., D'Odorico, P., Okin, G.S., 2007. Hydrologic and aeolian controls on vegetation patterns in arid landscapes. Geophys. Res. Lett. 34 (L24 s23).
Rostagno, C.M., Del Valle, H.F., Videla, L., 1991. The influence of shrubs on some chemical and physical properties of an aridic soil in north-eastern Patagonia, Argentina. J. Arid Environ. 20, 179–188.
Sala, O.E., Aguiar, M.R., 1996. Origin, Maintenance, and Ecosystem Effect of Vegetation Patches in Arid Lands. Proceedings Vth International Rangeland Congress, Salt Lake City, Utah, Rangelands in a Sustainable Biosphere. pp. 29–32.
Segoli, M., Ungar, E.D., Shachak, M., 2008. Shrubs enhance resilience of a semi-arid ecosystem by engineering and regrowth. Ecohydrology 1, 330–339.
She, D.L., Liu, D.D., Xia, Y.Q., Shao, M.A., 2014. Modeling effects of land use and vegetation density on soil water dynamics: implications on water resource management. Water Res. Manag. 28, 2063–2076.
Sheffer, E., Yizhap, H., Gilad, E., Shachak, M., Meron, E., 2007. Why do plants in resource-deprived environments form rings? Ecol. Complex. 4, 192–200.
Soriano, A., Sala, O.E., 1986. Emergence and survival of *Bromus setifolius* seedlings in different microsites of a Patagonian arid steppe. Israel J. Bot. 35, 91–100.
Stirling, G., Wilsey, B., 2001. Empirical relationships between species richness, evenness, and proportional diversity. Am. Nat. 158, 286–299.
Vásquez-Méndez, R., Ventura-Ramos, E., Oleschko, K., Hernández-Sandoval, L., Parrot, J.F., Nearing, M.A., 2010. Soil erosion and runoff in different vegetation patches from semiarid Central Mexico. Catena 80, 162–169.
Weedon, J.T., Facelli, J.M., 2008. Desert shrubs have negative or neutral effects on annuals at two levels of water availability in arid lands of South Australia. J. Ecol. 96, 1230–1237.

Xu, J., Yin, R., Li, Z., Liu, C., 2006. China's ecological rehabilitation: unprecedented efforts, dramatic impacts, and requisite policies. Ecol. Econ. 57, 595–607.
Yang, H.X., Zhang, J.T., Li, Z.D., Wu, B., Zhang, Z.S., Wang, Y., 2008. Comparative study on spatial patterns of *Artemisia ordosica* populations in the Mu Us sandy land. Acta Ecol. Sin. 28, 1901–1910.
Yang, Y.S., Bu, C.F., Mu, X.M., Shao, H.B., Zhang, K.K., 2014. Interactive effects of moss-dominated crusts and *Artemisia ordosica* on wind erosion and soil moisture in Mu Us Sandland, China. Sci. World J. (649816).
Zhao, P.P., Shao, M.A., Melegy, A.A., 2010. Soil water distribution and movement in layered soils of a dam farmland. Water Res. Manag. 24, 3871–3883.