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Nurse effects of patch-canopy microhabitats promote herbs community establishment in sandy land

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ABSTRACT

Seedling establishment mostly occurs beneath the canopies of shrubs which act as nurse plants. Nurse effects of patch-canopy soil microhabitats on seedling establishment of herbs were investigated by studying shrub patches in which the nurse species *Artemisia ordosica* was removed or kept in a comparative way. The results showed that keeping shrubs greatly increased soil moisture and soil organic carbon content, but greatly decreased soil temperature and soil bulk density. The herbs richness and individual numbers in patches with the canopy kept were significantly higher than those with the canopy removed ($p < 0.05$). Small shrub patches increased soil moisture and decreased the surface soil temperature more significantly than large shrub patches. Herbs richness and individual numbers in small shrub patches were significantly higher than those in large shrub patches ($p < 0.05$). The results suggested that small shrub patches, which acted as nurse plants, decreased soil temperature and soil bulk density, increased soil moisture, species richness and individual numbers under the canopies. Nurse plants can provide a favourable surface habitats for herbs in semi-arid sandy lands.

1. Introduction

Drylands cover approximately one-third of the Earth's land surface (Gaitán et al., 2014), and soil degradation in drylands is one of the major environmental issues of the 21st century in arid and semi-arid environments. Due to the effects of a series of natural and human factors, soil will remain degraded and continue to deteriorate without recovery (Lal, 2001). Pedogenic processes are mainly dependent on vegetation litter and root decomposition (Moro and Domingo, 2000; Blume et al., 2016). During the pedogenic process, the most vulnerable layer to natural or artificial soil degradation is the soil surface. In general, shrubs, dwarf shrubs or perennial grasses dominate plant patches, and soils underneath these plant patches usually show improved physical properties (Navarro-Cano et al., 2014; Torroba-Balmori et al., 2015). Compared with bare land, vegetated patches showed more infiltration, better soils, less erosion, and deep wetting fronts were in the vegetated patches (Cerdà, 1997). The relationship between vegetation and soil erosion especially splash erosion is very close (Keesstra et al., 2014; Fernández-Raga et al., 2017), management and utilization of vegetation patterns is important for the restoration of degraded lands (Ravi et al., 2010).

Interactions among plants are crucial to the emergence of unique species in the plant community (Armas and Pugnaire, 2005; Lortie and Turkington, 2008). There are three aspects in the interactions among plant species, including positive (facilitative), negative (competitive), and neutral effects (Onipchenko et al., 2009; Burke et al., 2011; Van de Voorde et al., 2011). Previous studies concerning plant interactions have mostly focused on species competition (Onipchenko et al., 2009; Burke et al., 2011; Liu et al., 2017). In recent years, some ecologists have paid more attention to the effects of nurse plants involved in facilitative plant interactions (Ren et al., 2008; Burke et al., 2011; Catorci et al., 2015). It has been demonstrated that nurse plants can create conducive conditions for the survival and growth of other plants under their canopies (Bruno et al., 2003; Padilla and Pugnaire, 2006; Valiente-Banuet and Verdú, 2007, 2008; Xiao et al., 2009). According to the theory of nurse plant effects, nurse plant refers to species of adult plants which create a favourable living environment for other species under their canopies (Padilla and Pugnaire, 2006). Perennial nurse plants can recruit species which can change the environment under their canopies in arid zones (Valiente-Banuet and Ezcurra, 1991; Brantley and Young, 2009). James et al. (2015) reported that lignum shrubs contributed to the diversity of undergrowth vegetation by facilitating the

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establishment of different species under more profitable and wetter conditions. Gómez-Aparicio (2009) reported that pre-existing vegetation had great impacts on species establishment in degraded habitats.

Nurse plants can be seen as an ecosystem servicelike what was found in olive plantations (Parras-Alcántara et al., 2016), and can also be actively used to restore agricultural land (Cerdà et al., 2017). Nurse plants can indirectly increase the diversity and quantity of beneficial microorganisms and improve the quality of soil (Casanova-Katny et al., 2011; Molina-Montenegro et al., 2015). Some large shrubs can protect the vegetation under their canopies from being eaten by herbivores in water-limited environments (Smit et al., 2007). Temperature is an important factor affecting seed germination, nurse plants can increase seed germination by their shade in harsh environments (Kos and Poschlod, 2007; Smith, 2013). Furthermore, nurse plants can regulate invasibility–diversity relationships in harsh environments (Badano et al., 2015). Determination of plant age helps to quantify the recovery rate because of the plant-facilitated poor soils, as reviewed by Navarro-Cano et al. (2015). Facilitative interactions can counteract the negative effects of harsh abiotic stress on plant and soil development in drylands (Navarro-Cano et al., 2015).

Patchy distribution patterns of vegetation are universal in semi-arid regions (Hao et al., 2016; Wu et al., 2016). Water is the main factor limiting plant growth and development, so it is necessary to improve water use efficiency (Baldy et al., 2015). The growth of vegetation is under great stress because of the harsh ecological environment of sandy lands (Tang et al., 2016). Wu et al. (2016) found that plants in the mosaic-pattern of natural shrub patches in sandy lands had positive effects on promoting the hydrological cycle as well as maintaining the soil organic carbon content and succession of local vegetation. Conservation of patchily distributed plants is particularly important for the formation of vegetation patches and litter mosaics, which can provide favourable conditions for plant growth (Kardol et al., 2006).

In general, the adaptability of organisms may vary greatly among species due to their morphological and size differences and other specific traits, including nurse shrubs especially. Shading is one of the main factors affecting seedlings establishment under shrub canopies (Gómez-Aparicio and Pugnaire, 2005). Seed germination and seedling survival were inhibited by both over-shading and lack of shading in reforestation programs (Maestre et al., 2001; Aerts et al., 2007). Research on nurse phenomenon in the water-wind erosion crisscross zone is scarce. Based on field observations and previous research on the role of large *Artemisia ordosica* plants as nurses (Wu et al., 2016), large shrub patches had greater shading effects. Therefore, in this study, we investigated the response of soil properties (soil micro-habitat, patches size, and spatial heterogeneity) to vegetation patch dynamics by carrying out field experiments on different sizes of shrub patches. The objectives were to: 1) determine which soil conditions (soil temperature, soil moisture, soil bulk density, and soil organic matter) regulate the environment under shrub canopies and affect the diversity of herbaceous communities at microhabitat scale; 2) assess the nurse effects of shrub patches of different sizes, and figure out whether small shrub patches have better soil micro-habitats for seed recruitment, seedling survival and growth than large shrub patches in harsh sandy conditions with resource and environmental constraints.

2. Materials and method

2.1. Study site and experimental design

The experimental site was located at the Liudaogou watershed (110°21′–110°23′E, 38°46′–38°51′N, 1080–1270 m) in Shenmu County, Shaanxi Province, China, in the southern part of Mu Us desert on the Loess Plateau (Wen et al., 2016; Fig. 1). The ground surface of the study site is dominated by semi-fixed, fixed, and mobile dunes, and vegetated dunes, which is dominated by vegetation with a height of < 2 m, mainly in a patchy distribution of *Artemisia ordosica* and *Salix psammophila* (Liu et al., 2014). The area has a continental semi-arid and seasonal wind climate with an average annual precipitation of 437 mm according to the National Meteorological Information Center of China. Most of the precipitation falls from June to September during intense rainstorms (Wu et al., 2016; Hao et al., 2016), accounting for approximately 62% of the total rainfall. The annual average wind speed is 2.2 m s^{-1} and the mean desiccation degree is 1.8 with 135 frost-free days. The region has a mean annual temperature of 8.4 °C (ranging from 9.7 °C in January to 23.7 °C in July), and the annual accumulated temperature above 10 °C is 3200 °C (Wang et al., 2010). The soil in the study area is aeolian sandy soil, which has a loose structure and poor corrosion resistance, and suffers wind erosion in winter and spring and water erosion in summer and autumn. Local herbivores mainly graze on annual or perennial herbs and shrubs such as *Polygala tenuifolia*, *Gueldenstaedtia stenophylla*, and *Bothriospermum chinense*. The Chinese government started to implement the “Grain to Green” program to reduce soil erosion and protect and improve the ecological environment since 1998 in the study region, and the program included measures such as grazing exclusion and the fencing of large areas of grasslands (Zhu et al., 2016). At the study site, *A. ordosica* is the dominant species and other species are also present, including *Oxytropis caerulea*, *Polygala tenuifolia*, *Euphorbia esula*, *Carex onoei*, *Ixeridium chinense*, *Pennisetum flaccidum*, *Gueldenstaedtia stenophylla*, *Gueldenstaedtia verna*, *Parthenocissus semicordata*, *Tribulus terrestris* L, *Kochia scoparia*, *Bothriospermum chinense*, *Corispermum hyssopifolium*, *Lactuca sativa*, and *Heteropappus altaicus* (Appendix 1).

Artemisia ordosica is a dwarf shrub which forms a round bush up to 30–50 cm in length, it grows in a patchy vegetation pattern with individual clumps of plants up to 180 cm in length at the canopy and has a natural growth period of 15 years (Wu et al., 2016). It has tangled woody and corky branches and stems (Huang et al., 2010). The height from the ground surface (H) and the average diameter (D) of each *A. ordosica* shrub canopy were taken based on two perpendicular measurements, and the volume (V) calculated by taking the shrub clump as a cylinder using the equation of $V = \pi r^2 H$, where $r = D/2$ (Shaltout et al., 2003). Shrub patch with a canopy diameter < 85 cm was defined as a small shrub patch, while that with a canopy diameter > 85 cm was defined as a large shrub patch. There were four types of *A. ordosica* shrub patch, including small patch with *A. ordosica* shrubs removed (T_{RS}), large patch with *A. ordosica* shrubs removed (T_{RL}), small patch with *A. ordosica* shrubs kept (T_{KS}), and large patch with *A. ordosica* shrubs kept (T_{KL}) (Table 1 and Fig. 2). Three replicate patches were randomly selected for each patch type, and there were a total 12 shrub patches in this experiment: A 30 × 30 cm quadrat was placed on each of the four corners beneath the canopy of the *A. ordosica* shrub patch, we, with the *A. ordosica* shrub patch at the centre (Fig. 2).

2.2. Determination of soil properties

Soil temperature and moisture in the first 0–5 cm soil layer underground about) beneath the canopy of each shrub patch and in open interspaces with shrub patches was measured by a Dual-range digital thermometer (Made in the USA) and a ML3 ThetaProbe Soil Moisture Sensor (Made in the UK), respectively. During the growing season, soil temperature and moisture were measured one time at 11:00 am–12:00 pm every 10 days, and the position of each measurement stayed the same. Soil bulk density (SD) was measured using soil cores of 100-cm^3 volume by the volumetric ring method. Disturbed soil samples were collected using a soil auger of 4-cm inner diameter and air-dried, and subsamples were sieved through 2-mm and 0.25-mm sieves. Subsamples of collected soil (< 0.25 mm) were used to determine the soil organic carbon content (SOC) by the dichromate oxidation method (Hao et al., 2016).

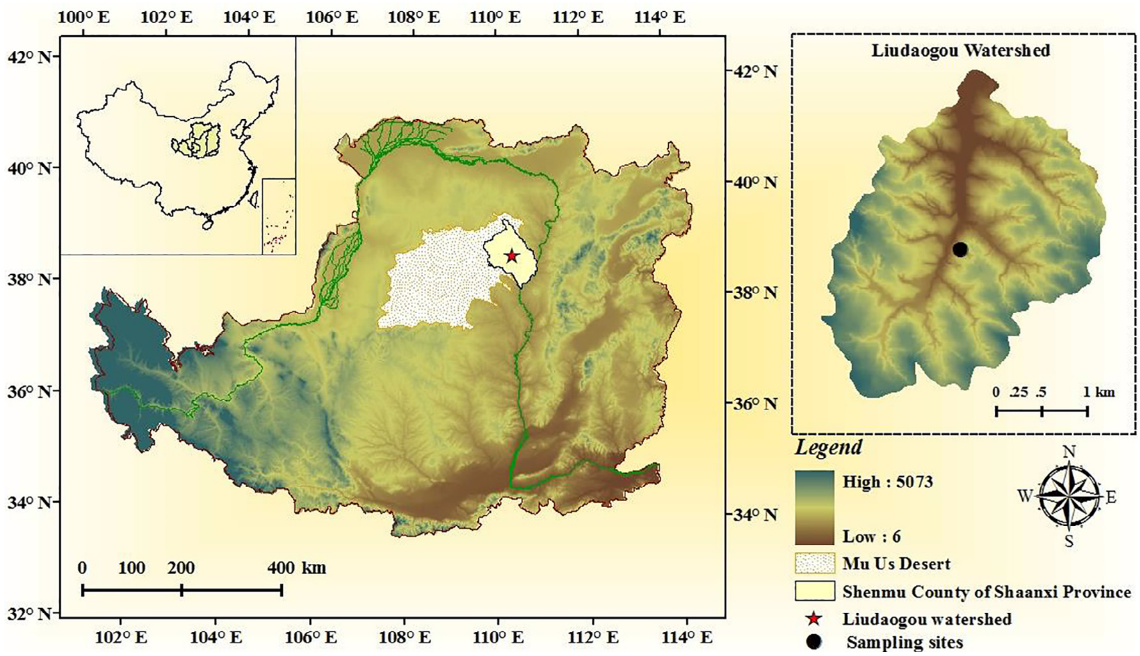

Fig. 1. Location of the study site in the Mu Us Desert on the Loess Plateau, China.

2.3. Investigations of herbaceous plants under the canopies of shrub patches

Plant species composition, the natural total height, and number of plants for each species in the quadrats were surveyed about every 10 days from June to October (four months, 122 days) in 2015. At the end of the growing season, all green shrub patches beneath the canopy and the aboveground parts of each species in each quadrat were cut, collected, placed into separate envelopes and labelled. The aboveground parts were oven dried at 75 °C for 24 h and weighed to determine the dry mass. The species richness and Shannon-Wiener diversity indices of the patch communities were calculated according to Stirling and Wilsey (2001).

2.4. Data analysis

Statistical analyses were conducted using SPSS software v. 16.0 (IBM Corporation, New York, USA). The differences in species diversity, species richness, biomass, soil temperature and moisture as well as the numbers of herbs species among the patches were compared using Duncan post hoc text following One-way analysis of variance (ANOVA). Before performing ANOVA, the normality and homogeneity of variances of the data were tested using the Levene and Sample k-s tests, respectively. Data are expressed as the means ± the standard error (SE) of the mean. Significant differences were set at the 0.05 level. Figures were created using the program of OriginPro version 9.0.

3. Results

3.1. Effects of nurse plants on soil properties

One-way ANOVA analysis indicated that soil temperate of the patch with the canopy kept was lower than that of the patch with the canopy removed (Fig. 3A). Soil temperature under the canopies small shrub patches with the canopies kept was significantly lower ($p < 0.05$) than that under large shrub patches with the canopies kept (Fig. 3A). Soil moisture in the shrub patch with the canopy kept was greatly increased by an average of 28.9% for small shrub patches, and 12.8% for large shrub patches, when compared with the patch with the canopy removed. Soil moisture of small patches was significantly higher than that of large patches (Fig. 3B). Soil bulk density of small patches was significantly lower than that of large patches ($p < 0.05$). Soil bulk density of the patch with the canopy kept was significant lower than that of the patch with the canopy removed (Fig. 3C). Furthermore, soil organic carbon content of the patch with the canopy kept was higher than that of the patch with the canopy removed (Fig. 3D).

3.2. Effects of nurse plants on the facilitated plant community

For small patches, the species richness of T_{KS} was significantly higher than that of $T_{RS,}$ T_{RL}, and T_{KL} ($p < 0.05$) (Fig. 4A). The individual numbers of herbs in T_{KS} and T_{RS} were significantly higher than that in T_{RL} (Fig. 4B). Meanwhile, compared with the patch with the canopy removed, the height of the dominant species *P. tenuifolia* and *O. caerulea* in the patch with the canopy kept were significantly lower than

Table 1
Basic information of the shrub patches.

Treatment	Canopy length (cm)	Canopy width (cm)	Shrub height (cm)	Shrub volume cubes (cm)	Size range (cm)
T_{RS}	86.67 ± 3.33	73.33 ± 3.33	55 ± 2.89	70.42 ± 2.94	< 85
T_{RL}	128.33 ± 4.41	100 ± 5.77	66.67 ± 8.82	94.36 ± 3.90	> 85
T_{KS}	96.67 ± 6.67	83.33 ± 6.67	60 ± 5.77	78.38 ± 5.90	< 85
T_{KL}	126.67 ± 3.33	100	65 ± 2.89	93.65 ± 0.80	> 85

Note: T_{RS}: small patch with *Artemisia ordosica* shrubs removed; T_{KS}: small patch with *A. ordosica* shrubs kept; T_{RL}: large patch with *A. ordosica* shrubs removed; T_{KL}: large patch with *A. ordosica* shrubs kept.

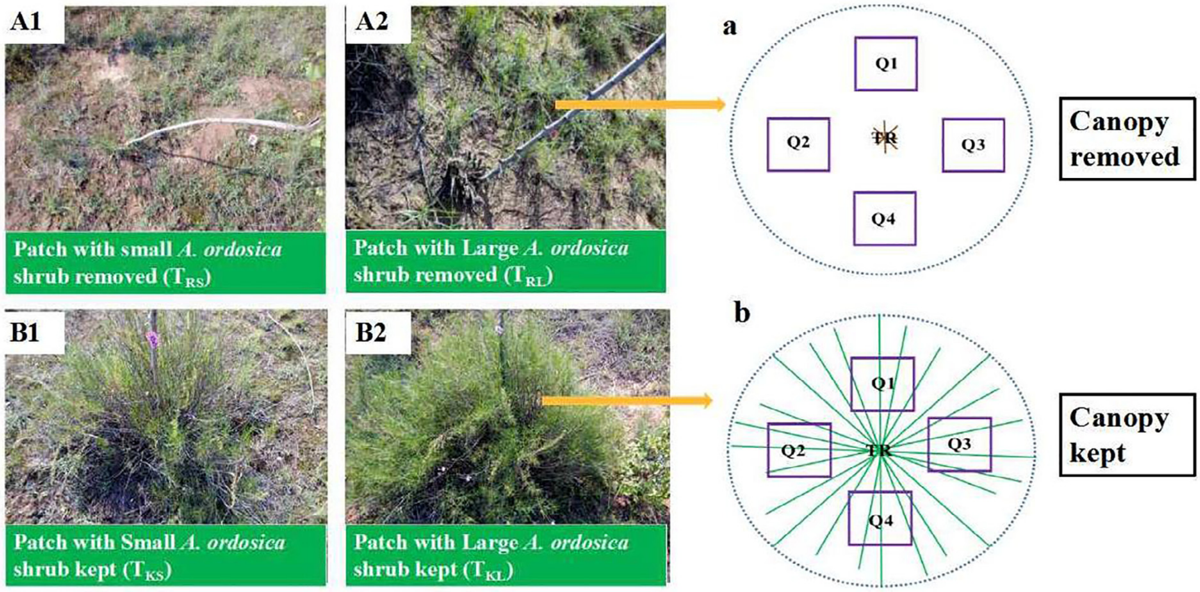

Fig. 2. The shrub patches with the canopies removed (T_{RS}, T_{RL}) and kept (T_{KS}, T_{KL}) sites. *Note:* A1: small patch with *Artemisia ordosica* shrubs removed (T_{RS}); A2: small patch with *A. ordosica* shrubs kept (T_{KS}); A3: large patch *A. ordosica* shrubs removed (T_{RL}); A4: large patch with *A. ordosica* shrubs kept (T_{KL}); a: schematic diagram of A1 and A2; b: schematic diagram of B1 and B2; TR: taproot location; Q1, Q2, Q3, Q4: the quadrats (30 × 30 cm) under the canopy of *A. ordosica.*

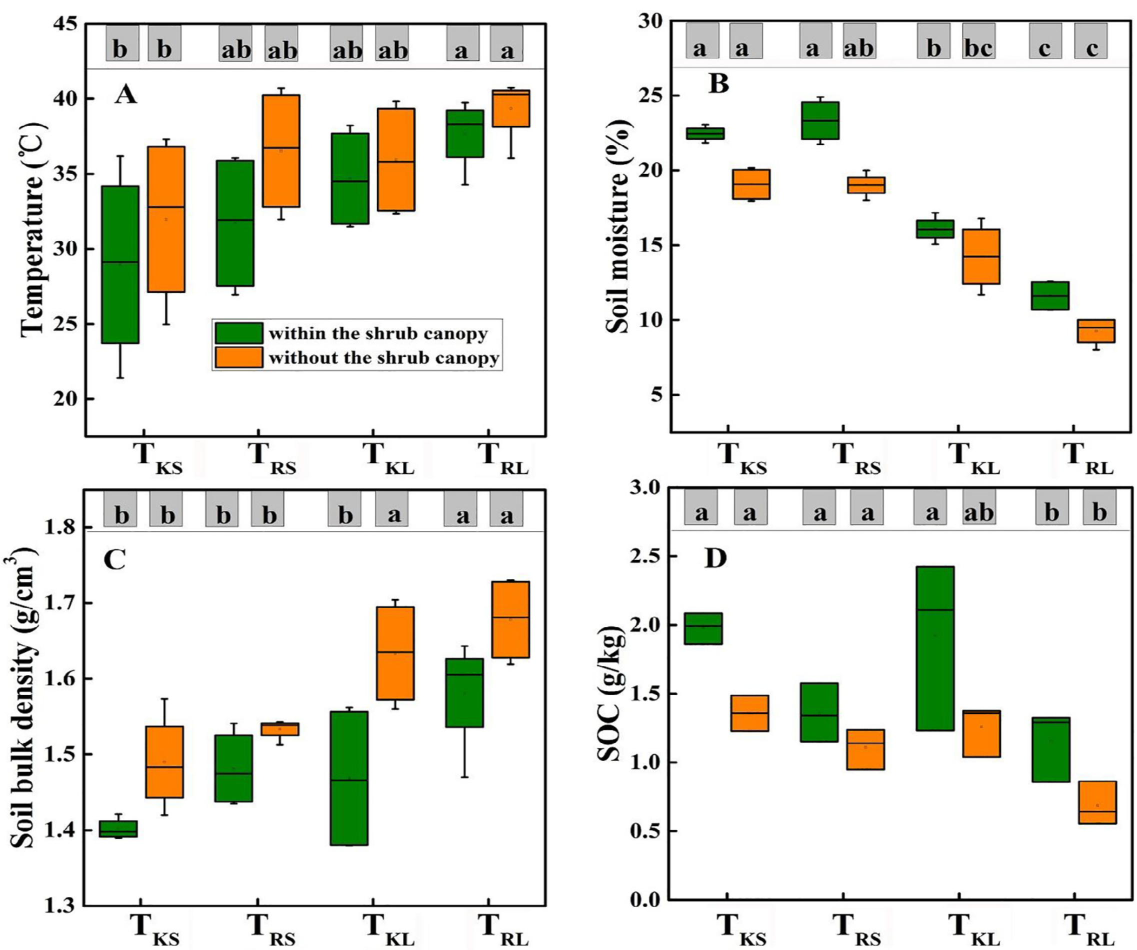

Fig. 3. One-way ANOVA analysis of soil temperature (A), soil moisture (B), soil bulk density (C), and the soil organic carbon content (D) of the shrub patches in different treatments. Lower-case letters indicate significant differences among treatments at the 0.05 level. T_{RS}: small patch with *A. ordosica* shrubs removed; T_{KS}: small patch with *Artemisia ordosica* shrubs kept; T_{RL}: large patch with *A. ordosica* shrubs removed; T_{KL}: large patch with *A. ordosica* shrubs kept.

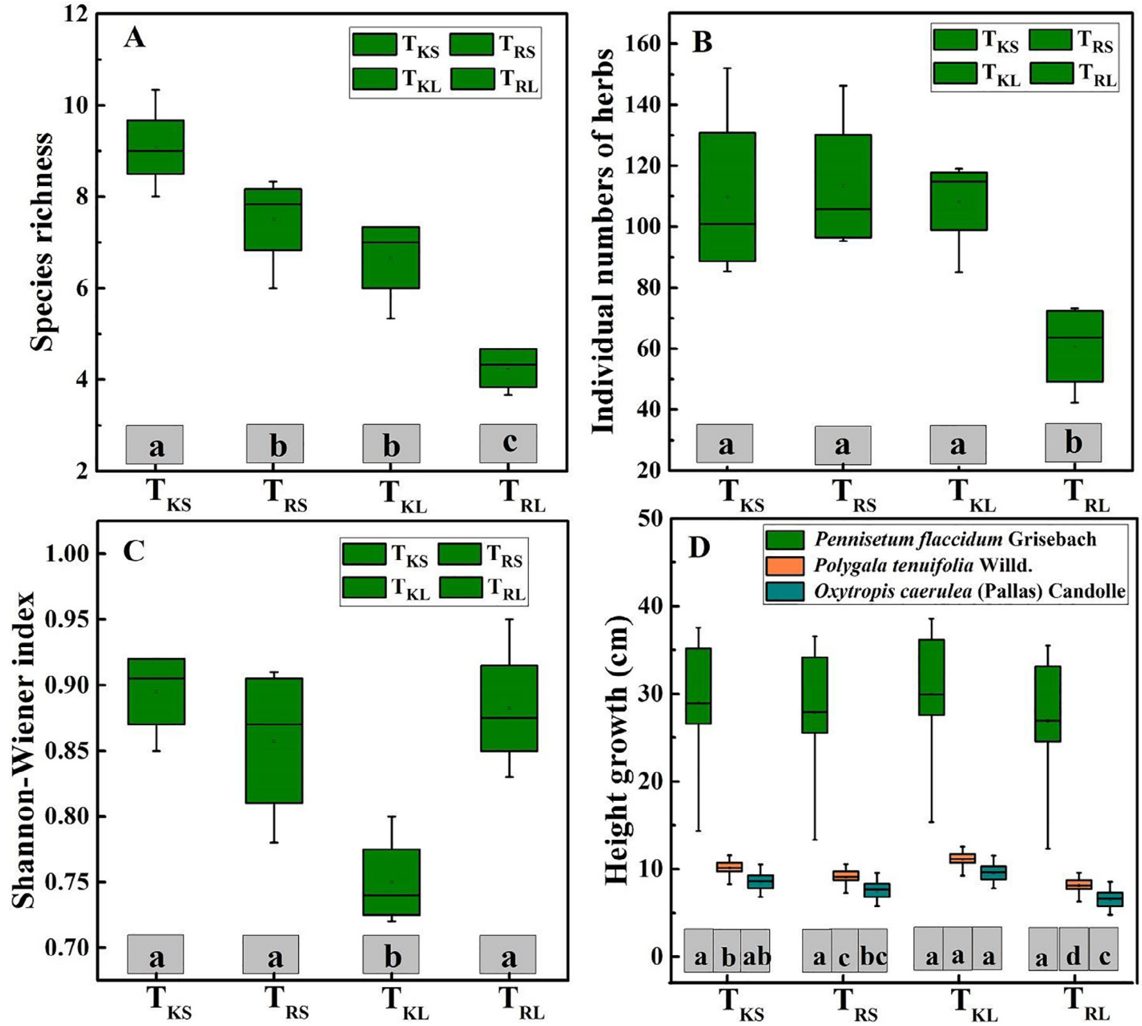

Fig. 4. One-way ANOVA analysis of species richness (A), individual numbers of herbs (B), Shannon-Wiener index (C), and plant height (D) under the canopy of the shrub patches in different treatments. Lower-case letters indicate significant differences among treatments at the 0.05 level. T_{RS}: small patch with *Artemisia ordosica* shrubs removed; T_{KS}: small patch with *A. ordosica* shrubs kept; T_{RL}: large patch with *A. ordosica* shrubs removed; T_{KL}: large patch with *A. ordosica* shrubs kept.

Table 2
Coefficients of pearson correlations among soil bulk density, soil organic carbon content, numbers of individual herbs, species richness, soil temperature, and soil moisture.

	Species richness	Individual numbers of herbs	Soil organic carbon content (g/kg)	Soil temperature (°C)	Soil moisture (%)	Soil bulk density(g/cm^3)
Species richness	1	0.72**	0.40	−0.66*	0.86**	−0.71**
Individual numbers of herbs		1	0.32	−0.09	0.71**	−0.52
Soil organic carbon content (g/kg)			1	−0.30	0.18	−0.70*
Soil temperature (°C)				1	−0.59*	0.59*
Soil moisture (%)					1	−0.58*
Soil bulk density (g/cm^3)						1

Note: **: correlation is significant at the 0.01 level (two-tailed); *: correlation is significant at the 0.05 level (two-tailed).

those in the patch with the canopy removed (Fig. 4D). However, the Shannon–Wiener diversity index during the growing season was not significantly different between the canopy kept and removed patches (Fig. 4C).

For large patches, the species richness of T_{KL} was significantly higher than that of T_{RL}, but it was lower than those of T_{RS} and T_{KS} in the growing season ($p < 0.05$) (Fig. 4A). The individual number of herbs in T_{KL} was significantly higher than that in T_{RL} ($p < 0.05$), but lower than those in T_{RS} and T_{KS} ($p > 0.05$) (Fig. 4B). The Shannon-Wiener diversity index of T_{KL} in the growing season was significantly lower than those in other treatments (Fig. 4C). Moreover, compared with the patch with the canopy removed, the growth height of the dominant species *P. tenuifolia* and *Oxytropis caerulea* in the patch with the canopy kept was significantly lower than those in the patch with the canopy removed (Fig. 4D) ($p < 0.05$).

3.3. Relationships among the Shannon–Wiener index, species richness, individual numbers of herbs, soil moisture and soil temperature

Species richness was significantly negatively correlated with soil temperature ($R = -0.59$, $p < 0.05$) and soil moisture ($R = -0.66$, $p < 0.05$), whereas soil temperature was positively correlated with soil bulk density ($R = 0.59$, $p < 0.05$). Species richness was positively correlated with soil moisture ($R = 0.86$, $p < 0.01$) and the individual numbers of herbs ($R = 0.72$, $p < 0.01$). At the end of the growing season, soil moisture showed a highly significant positive correlation with the individual numbers of herbs ($R = 0.712$, $p < 0.01$; Table 2).

4. Discussion

The results showed that shrub patches had a positive effect on soil microhabitats, soil properties, and the herbs under the patch-canopy. Shrub patches played an important role in adjusting surface soil temperature and soil moisture, reducing surface soil bulk density and increasing soil organic carbon content, and increasing species richness and the individual numbers of herbs under the canopies of the patches. Numerous studies have reported that nurse plants can indirectly increase the diversity and quantity of beneficial microorganisms and improve the quality of soil (Casanova-Katny et al., 2011; Molina-Montenegro et al., 2015). The fertile soil islands can affect the structure and function of desert ecosystems (Li et al., 2017). In this research, the nurse plant *A. ordosica* strongly influenced the soil microhabitats and the structure of the herbal plant community under its canopy. The canopy removal experiments showed that the *A. ordosica* patch with the canopy kept had a positive effect on the investigated soil physical properties, for example, it improved soil moisture and the shade of the canopy helped adjust soil temperature. Such a positive effect might be related to the formation of a drought tolerance mechanism in the vegetation during the growing season, and factors which affected the vegetation construction might change with the growing season (Dong and Zhang, 2000). A high temperature and water deficit could reduce the number of seeds in the field by reducing plant growth rate (Guilioni et al., 2003). Lower soil temperature in the soil one cm below the ground significantly increased seed recruitment in high-altitude semi-desert when compared with other deserts (López et al., 2007). The measured soil temperature and soil moisture were more favourable for plant growth under the existing shrubs than in open interspaces in this study. Soil temperature of small shrub patches was significantly lower than that of the large shrub patches. During the experimental investigation we found that gravels were present under the canopies of small shrub patches, and López et al. (2007) suggested that the presence of gravels and litter may have some protective effects under a high temperature. Soil moisture of small shrub patches was significantly higher than that of large shrub patches, unlike the results of Hao et al. (2016) and Wu et al. (2016), who reported that soil moisture of a large shrub patch was higher than that of a small shrub patch. Such a difference in the results was possibly mainly due to the micro-topographical heterogeneity which induces differences in soil variables between small and large shrub patches. Moreover, because of the abiotic stress caused by water limitation (Parsons, 1976), water-wind erosion is serious, shrub patches at different succession stages have different demand for water and nutrients in semi-arid environments. Hence, small shrub patches could provide a better shade and use less water than large patches in the growing season. Soil bulk density of small shrub patches was significantly lower than that of large shrub patches. Soil organic carbon content of small shrub patches was significantly lower than that of large shrub patches, possible due to the heterogeneity of the sampling environment at slope scale and the interaction between water erosion and wind erosion. Therefore, patches of different sizes had different environmental adaptability and would adjust their own development needs of nutrients differently. With the emergence of shrub patches and seedling growth, adult shrubs serve as nurses for seedlings, improve their water status, nutrient content, and growth rate (Armas and Pugnaire, 2005; Valiente-Banuet and Verdú, 2008; Wu et al., 2016).

Plants interact positively with the local environment, and provide favourable conditions for neighbourhood plants directly or indirectly. High-intensity disturbance are one of the causes of the fragility of the ecological environment (Austrheim and Eriksson, 2001), and grazing is a form of interference which affects species richness (Osem et al., 2002). Shrub patches can facilitate the development of the substory herbaceous species by reducing abiotic stresses or grazing damage (Callaway, 2007). The canopy of *A. ordosica* could prevent herbs under its canopy from being eaten by herbivores, thereby increasing species richness (Smit et al., 2007). The canopy removal experiments in the present study showed that *A. ordosica* had positive effects on species richness and the number of individual herbs beneath the canopy. Some typical shrubs could recruit seeds, and the micro-environment under the shrubs provided a suitable niche for seedling emergence in the water-wind erosion crisscross zone. The species richness, number of individual herbs and plant height in the patch with the canopy kept were higher than that in the patch- with the canopy removed during the growing season, indicating that the shrub patches had a positive effect on herbs under their canopies. The number of individual herbs, species richness, and plant height in small patches with the-canopies kept were higher than in large patches with canopies kept during the growing season, possibly because shrub patches of different sizes had different water use efficiency and light competition capacities (Hao et al., 2016).

Shrub patches play an irreplaceable role in the restoration of degraded terrestrial vegetation. If shrub canopy cover is lacking, the pre-existing conservation effect will disappear and the competition between plants will be stronger than facilitation (Wu et al., 2016). We found that small shrub patches with the canopies kept could increase species richness and the number of individual herbs more significantly through increasing soil moisture and adjusting soil temperature when compared with large shrub patches with the-canopies kept. There is a strong interaction between the soil and vegetation during the growth of plants. A small number of adult plants form shadows and fertile islands to create a microhabitat which is suitable for seedling survival. A small proportion of adult plants created a sub-canopy microclimate with shade and fertile islands (D'Odorico et al., 2010; Wu et al., 2016). The existence of small shrubs at large scale is the basis for maintaining the stable development and continuous renewal of shrub patches in degraded lands, due to the lower water requirement and thus a smaller survival pressure of small shrub patches than that of large shrub patches. Small shrub patches can provide a more conducive water habitats for the growth of annual herbs. In addition, the shading effect of large shrub patches is greater than that of small shrub patches, and is not conducive to herbs' photosynthesis. Therefore, it is difficult for large shrub patches to support the development of annual herbs beneath their canopies.

The present study focused on the positive effects of nurse plants in sandy lands. Hao et al. (2016) suggested that shrub patches could increase the content soil water and soil aggregates under the canopies, thus improving the supply of nutrients during succession, resulting in more organic matter and moisture, but less erosion (Keesstra et al., 2018). Nurse plants can be seen as a nature-based solution in reducing soil erosion and improving the environment (Fernández-Raga et al., 2017). Our results showed that soil temperature, moisture, and bulk density had a significant effect on the species richness and individual numbers of herbs under the canopies of shrub patches. Kos and Poschlod (2007) proposed that nurse plants provided a shade habitat for seed germination of s and seedling survival under their canopies, due to the functional complementarity between nurse species and their understory characteristics, such as root distribution, which constitutes a basic mechanism for avoiding niche overlap and thus maximized propagation (Navarro-Cano et al., 2014). In addition, the coexistence between species with different functions can facilitate species coexistence and improve species richness (Cadotte et al., 2008). Our results can be seeing long-term effects of soil management on ecosystem services (Parras-Alcántara et al., 2016), and help to understand the recovery after forest fires (Keesstra et al., 2017).

5. Conclusion

The results suggest that *Artemisia ordosica* shrubs as nurse plants are common, facilitative, and critical in semi-arid sandy areas. Compared with the shrub patches with the canopies removed, keeping the canopies of the shrub patches could significantly improve soil surface microhabitats, including maintaining soil moisture, increasing soil organic carbon content, decreasing surface soil temperature, thus providing suitable habitats for the growth of herbaceous plants. Furthermore, due to their less demand for water and nutrients, small shrub patches exhibited greater nurse effects for herbs than large shrub patches.

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Appendices

Appendix 1. Main species within the quadrats under different shrub patch treatments of *Artemisia ordosica*.

Treatments	Major plant species
T_{RS}	*Oxytropis caerulea* (Pallas) Candolle, *Polygala tenuifolia* Willd., *Euphorbia Esula* Linn., *Carex onoei* Franch.et Sav., *Ixeridium chinense* (Thunb.) Tzvel., *Pennisetum flaccidum* Grisebach, *Artemisia ordosica* Krasch., *Gueldenstaedtia stenophylla* Bunge, *Gueldenstaedtia verna* (Georgi) Boriss., *Parthenocissus semicordata* (Wall. ex Roxb.) Planch.
T_{KS}	*Heteropappus altaicus* (Willd.) Novopokr, *Gueldenstaedtia verna* (Georgi) Boriss., *Carex onoei* Franch. et Sav., *Polygala tenuifolia* Willd., *Pennisetum flaccidum* Grisebach, *Gueldenstaedtia stenophylla* Bunge, *Oxytropis caerulea* (Pallas) Candolle, *Artemisia ordosica* Krasch., *Euphorbia Esula* Linn., *Tribulus terrestris* L., *Kochia scoparia* (L.) Schrad., *Bothriospermum chinense* Bunge, *Parthenocissus semicordata* (Wall. ex Roxb) Planch.
T_{RL}	*Pennisetum flaccidum* Grisebach, *Oxytropis caerulea* (Pallas) Candolle, *Polygala tenuifolia* Willd., *Carex onoei* Franch. et Sav., *Ixeridium chinense* (Thunb.) Tzvel., *Heteropappus altaicus* (Willd) Novopokr, *Kochia scoparia* (L.) Schrad., *Corispermum hyssopifolium* L.
T_{KL}	*Oxytropis caerulea* (Pallas) Candolle, *Gueldenstaedtia stenophylla* Bunge, *Euphorbia Esula* Linn., *Polygala tenuifolia* Willd., *Heteropappus altaicus* (Willd) Novopokr., *Artemisia ordosica* Krasch., *Carex onoei* Franch. et Sav., *Pennisetum flaccidum* Grisebach, *Gueldenstaedtia verna* (Georgi) Boriss., *Lactuca sativa* L., *Kochia scoparia* (L.) Schrad., *Corispermum hyssopifolium L.*, *Parthenocissus semicordata* (Wall. ex Roxb.) Planch.

Note: T_{RS}: small patch with *A. ordosica* shrubs removed; T_{KS}: small patch with *A. ordosica* shrubs kept; T_{RL}: large patch with *A. ordosica* shrubs removed; T_{KL}: large patch with *A. ordosica* shrubs kept.

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