

Postprint: Effects of Rare and Endangered *Ammopiptanthus mongolicus* and Associated Species on Soil Characteristics in West Ordos

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Abstract

To investigate the effects of desert shrubs and their associated species on the spatial heterogeneity of soil particle size and nutrients beneath shrub canopies, this study examined mixed communities of *Ammopiptanthus mongolicus*-*Sarcozygium xanthoxylon* and individual *A. mongolicus* plants in the West Ordos National Nature Reserve, using surrounding unvegetated bare sand as a control (CK). Comparative analysis was conducted on soil particle size characteristics, nutrient accumulation patterns, and the relationships between nutrients and particle size composition under different shrub distribution types. The results showed that: (1) The volume percentages of soil clay, silt, and fine sand under individual *A. mongolicus* increased by 0.8%, 0.8%, and 0.71%, respectively, compared with *A. mongolicus*-*S. xanthoxylon*. With decreasing shrub species richness, soil particle size became progressively finer, sorting became poorer, fractal dimension decreased, soil particle distribution gradually became asymmetric, and particle composition concentrated toward fine materials. (2) Soil organic matter and alkali-hydrolyzable nitrogen contents increased by $1.85 \text{ g} \cdot \text{kg}^{-1}$ and $8.18 \text{ mg} \cdot \text{kg}^{-1}$, respectively, with increasing shrub species. Individual *A. mongolicus* exhibited stronger enrichment effects on organic matter and available phosphorus, but slightly weaker accumulation of alkali-hydrolyzable nitrogen compared with *A. mongolicus*-*S. xanthoxylon*. (3) Soil available phosphorus content showed a significant positive correlation with fine sand content in *A. mongolicus*-*S. xanthoxylon* ($P < 0.05$), while soil alkali-hydrolyzable nitrogen and available potassium showed significant positive correlations with coarse sand in *A. mongolicus* ($P < 0.05$). Both *A. mongolicus*-*S. xanthoxylon* and *A. mongolicus* could effectively promote soil particle fining and significantly improve soil nutrients, but the presence of the associated species *S. xanthoxylon* reduced the enrichment effects of *A. mongolicus* on organic matter and available phosphorus.

Full Text

Abstract

This study was conducted to explore the influence of desert shrubs and their associated species on soil particle size and nutrient spatial heterogeneity under shrubs. The mixed community of *Ammopiptanthus mongolicus* and *Sarcozygium xanthoxylon* and a single plant of *A. mongolicus* in the Western Ordos National Nature Reserve were selected as the research samples. The surrounding bare sandy land without vegetation cover was used as control. The soil particle size characteristics, nutrient accumulation changes, and the relationship between nutrients and particle size composition under different shrub distribution types were analyzed. The results were as follows: (1) Compared with the mixed community of *A. mongolicus*-*S. xanthoxylon*, the volume percentages of soil clay, silt, and fine sand of the single *A. mongolicus* increased by 0.8%, 0.8%, and 0.71%, respectively. As the types of shrubs decrease, soil particle size became smaller in turn, sorting deteriorated, the fractal dimension became smaller, the soil particle distribution gradually became asymmetric, and the particle composition was concentrated at fine particles. (2) The contents of soil organic matter and alkali-hydrolyzable nitrogen increased by $1.85 \text{ g} \cdot \text{kg}^{-1}$ and $8.18 \text{ mg} \cdot \text{kg}^{-1}$, respectively, with the increase in shrub species. The accumulation of organic matter and available phosphorus by a single *A. mongolicus* was stronger than that by *A. mongolicus*-*S. xanthoxylon*; however, the accumulation of alkali-hydrolyzable nitrogen was slightly poorer than that of *A. mongolicus*-*S. xanthoxylon*. (3) *A. mongolicus*-*S. xanthoxylon* available soil phosphorus content was significantly positively correlated with fine sand content ($P < 0.05$), and *A. mongolicus* available soil nitrogen and potassium were significantly positively correlated with coarse sand ($P < 0.05$). *A. mongolicus*-*S. xanthoxylon* can effectively promote soil granulation and significantly improve soil nutrients. However, the presence of the associated species *S. xanthoxylon* reduced the enrichment of organic matter and available phosphorus by *A. mongolicus*.

Keywords: soil mechanical composition; nutrient enrichment; relict plant; west Ordos region

Introduction

The Western Ordos National Nature Reserve in Inner Mongolia is located in an ecologically fragile transition zone from desertified grassland to grassland desert. This region has ancient geological history and complex, diverse habitats. As desertification intensifies, the living conditions for organisms in this area continue to deteriorate, and desert shrubs have become the main vegetation type due to their strong drought and cold resistance, playing an important role in maintaining the stability of desert ecosystems and improving soil physicochemical properties. Shrub characteristics directly affect their ability to intercept sand materials, thereby altering soil particle size composition and nutrient accumulation. Different degradation degrees of shrubs significantly affect the soil

physicochemical properties of nebkhas. In the Minqin Oasis, the soil physicochemical properties of nebkhas decline with the degradation of *Tamarix*.

Different types of shrubs exhibit significant differences in soil element accumulation and utilization efficiency. In the Badain Jaran Desert, the contents of soil organic matter, total carbon, and total nitrogen in *Tamarix* nebkhas are significantly higher than those in *Nitraria tangutorum* and *Caragana korshinskii* nebkhas, mainly because *Tamarix* has dense branches, large interception area, and abundant litter, resulting in stronger sand material interception and nutrient accumulation capabilities than the other two shrubs. The soil particle size composition of nebkhas varies significantly under different habitats. In Yanchi, *Caragana* shrubs significantly increased the medium sand content and reduced soil clay; in Wulate, *Caragana* shrubs significantly increased very fine sand and fine sand contents while reducing soil clay content. Under the same habitat, different shrub species have different particle size compositions. In the Western Ordos region, the contents of soil clay, silt, and very fine sand in *Tetraena mongolica*, *Ammopiptanthus mongolicus*, and *Sarcozygium xanthoxylon* nebkhas decrease sequentially.

Previous studies have deeply explored the influence of single shrubs on soil microenvironments and achieved rich results, but research on the effects of composite shrub communities on soil characteristics is relatively scarce. *Ammopiptanthus mongolicus*, as an endangered relict plant endemic to the Western Ordos region, plays an important role in soil improvement, windbreak and sand fixation, and maintaining ecosystem stability. *Sarcozygium xanthoxylon*, as one of the associated species of *A. mongolicus*, often appears near *A. mongolicus* communities. Based on this, this study selected *A. mongolicus* communities and *A. mongolicus*-*S. xanthoxylon* mixed communities as research objects to compare and analyze the changes in soil particle size and nutrients between single and composite communities, aiming to reveal the effect of associated species in composite communities on soil microenvironments and provide a theoretical basis for protecting endangered species resources.

1.1 Study Area Overview

The study area is located in the Baiyin Engel Nature Reserve in Western Ordos, Inner Mongolia (40°08' ~40°23' N, 107°02' ~107°19' E). The reserve is deep inland, spanning two vegetation zones of desertified grassland and grassland desert, belonging to the transition zone from temperate desertified grassland to grassland desert. The region has a mean annual temperature of 7.6°C, large diurnal temperature variation, mean annual sunshine duration of 3192.5 h, abundant sunshine, mean annual precipitation of 156.83 mm, significant regional differences in precipitation increasing from northwest to southeast, mean annual evaporation of 198.37 mm, and mean annual wind speed of 4.1 m · s⁻¹ with strong winds and abundant sand, predominantly from southwest and southeast directions. Due to the Yanshan Movement and wind erosion from the Ulan Buh Desert, the study area belongs to a wavy plateau landform. The soil types are mainly zonal

gray desert soil and azonal aeolian sandy soil. The constructive species in the reserve are mostly xerophytic shrubs, among which rare and endangered species such as *A. mongolicus*, *S. xanthoxylon*, *Tetraena mongolica*, and *Helianthemum songaricum* account for 17.8% of the plant species in the reserve.

1.2 Sample Plot Selection and Vegetation Survey

In mid-July 2020, a field survey was conducted in the Baiyin Engel Nature Reserve. Representative flat terrain sections with no obvious undulation, where *A. mongolicus* communities and the associated species *S. xanthoxylon* communities were distributed, were selected as experimental sample plots. Three 100 m × 100 m sample plots were established. The distribution, quantity, plant height, and crown diameter (east-west and north-south directions) of *A. mongolicus* and *S. xanthoxylon* shrubs in each sample plot were investigated (Table 1).

[Figure 1: see original paper]

Table 1 Distribution and growth status of shrubland communities

Note: Data in the table are mean ± standard deviation; different lowercase letters in the same column indicate significant differences in shrub height and crown diameter under different distribution conditions ($P < 0.05$).

1.3 Sample Collection and Measurement

Based on the vegetation survey in the sample plots, three single *A. mongolicus* plants with similar morphology, good growth, and no degradation symptoms, and three *A. mongolicus* plants with roots connected and canopies mixed with *S. xanthoxylon* were selected as research objects. Using the shrub center as the center of a concentric circle with the crown radius as the radius, the edge of the canopy was taken as the sampling point. Soil samples were collected by stratified sampling in four directions (east, south, west, and north) at the edge using a soil auger. The sampling depths were 0–5 cm, 5–10 cm, 10–20 cm, and 20–30 cm. Soil samples from the four directions of each shrub at each soil layer were mixed evenly, with three replicates for each distribution type. Bare sandy land without vegetation cover at a distance of 10 times the crown diameter from the shrub center was used as blank control (CK), with the same sampling depths.

The collected soil samples were brought back to the laboratory, air-dried in a cool and ventilated place, and sieved for soil particle size composition and nutrient determination. Soil particle size composition was analyzed using the laser diffraction method. Soil organic matter (SOM) was determined by the potassium dichromate oxidation-external heating method; alkali-hydrolyzable nitrogen (AN) by the alkali diffusion method; available phosphorus (AP) by the sodium bicarbonate extraction-molybdenum antimony colorimetric method; and available potassium (AK) by the ammonium acetate extraction-flame photometry method.

1.4 Soil Particle Parameter Models

According to the USDA soil particle size classification standard, soil particle diameter was divided into seven grades: very coarse sand, coarse sand, medium sand, fine sand, very fine sand, silt, and clay, with standards of 1000-2000 μm , 500-1000 μm , 250-500 μm , 100-250 μm , 50-100 μm , 2-50 μm , and $<2 \mu\text{m}$, respectively. The Φ value representing particle size parameters was converted using the Kumdein formula: $\Phi = -\log_2 d$, where d is the sand particle diameter (mm).

Soil particle fractal dimension was calculated by the soil particle volume fractal model:

$$\frac{V(r < R_i)}{V_T} = \left(\frac{R_i}{R_{\max}} \right)^{3-D}$$

where: r represents soil particle diameter (mm); R_i represents the diameter of a certain particle size grade (mm); $V(r < R_i)$ represents the volume percentage of soil particles smaller than R_i grade; V_T represents the total volume percentage of particles in all grades; R_{\max} represents the maximum particle diameter (mm); and D represents the soil fractal dimension.

1.5 Soil Nutrient Accumulation Characteristics

The Relative Interaction Intensity (RII) index was used to represent the enrichment of shrub nebkha soil:

$$\text{RII} = \frac{X_n - X_i}{X_n + X_i}$$

where: X_n and X_i represent the nutrient content around shrub roots and in blank control at the same depth, respectively. When $\text{RII} > 0$, it indicates that the shrub has an enrichment effect on the nutrient content; when $\text{RII} < 0$, it indicates that the shrub has a reducing effect on the nutrient content. The farther the RII value is from zero, the stronger the effect.

1.6 Data Processing and Analysis

Microsoft Excel 2010 was used to organize the sample plot survey results and calculate soil average particle size, sorting coefficient, skewness, kurtosis, and fractal dimension. SPSS 26 was used for one-way ANOVA of the average values of soil particle size composition, various parameter indexes, and available nutrient contents, and OriginPro was used to plot the calculated data.

The average particle size (d), sorting coefficient (δ), skewness (SK), and kurtosis (Kg) were calculated using the following formulas:

$$\text{Average particle size: } d = \frac{\sum_{i=1}^n d_i f_i}{\sum_{i=1}^n f_i}$$

$$\text{Sorting coefficient: } \delta = \sqrt{\frac{\sum_{i=1}^n (d_i - d)^2 f_i}{\sum_{i=1}^n f_i}}$$

$$\text{Skewness: } SK = \frac{\sum_{i=1}^n (d_i - d)^3 f_i}{\delta^3 \sum_{i=1}^n f_i}$$

$$\text{Kurtosis: } Kg = \frac{\sum_{i=1}^n (d_i - d)^4 f_i}{\delta^4 \sum_{i=1}^n f_i}$$

2 Results and Analysis

2.1.1 Soil Particle Size Composition Under Different Shrub Distribution Types

As shown in Table 2, the soil particle size composition in the study area was dominated by sand particles, with fine sand (44.25%-62.11%) having the highest content, while clay and silt were relatively low, with total average content less than 12.89%. Under different shrub distribution conditions, the *A. mongolicus*-*S. xanthoxylon* soil had the lowest total content of clay and silt (11.28%), while the single *A. mongolicus* soil had the highest total content of clay and silt (12.77%), slightly higher than that of bare sandy land (12.77%, $P < 0.05$). Further analysis of sand particles revealed that the average volume percentage of fine sand in *A. mongolicus* soil was significantly higher than that in *A. mongolicus*-*S. xanthoxylon* and bare sandy land ($P < 0.05$).

Table 2 Composition of soil particles on different shrub distribution

Note: Data in the table are mean \pm standard deviation; uppercase letters indicate differences among different sampling points at the same depth ($P < 0.05$); lowercase letters indicate differences among different soil depths at the same sampling point. The same below.

2.1.2 Soil Particle Size Parameters Under Different Shrub Distribution Types

The average particle size in the study area ranged from 2.39 to 2.96 Φ . There were significant differences in average particle size among different soil layers of *A. mongolicus*-*S. xanthoxylon*, *A. mongolicus*, and bare sandy land ($P < 0.05$), with fluctuation ranges from small to large being: *A. mongolicus*-*S. xanthoxylon* < *A. mongolicus* < bare sandy land. Under different shrub distribution conditions, the sorting coefficient of each soil layer ranged from 1.27 to 1.94, with poor sorting. Except for the 5-10 cm soil layer of *A. mongolicus*-*S. xanthoxylon* being extremely negatively skewed, the skewness of *A. mongolicus*-*S. xanthoxylon* was near-symmetric in other soil layers; the kurtosis range of *A. mongolicus* and bare sandy land was 1.25-3.09. According to the classification standard, *A. mongolicus*-*S. xanthoxylon*, *A. mongolicus*, and bare sandy land belong to leptokurtic (1.46-1.69), very leptokurtic (1.25-2.00), and very leptokurtic (1.28-

3.09) types, respectively. The higher the soil clay content, the larger the fractal dimension. The fractal dimension ranged from 2.80 to 2.96, decreasing in the order: *A. mongolicus*-*S. xanthoxylon* > *A. mongolicus* > bare sandy land.

Table 3 Soil particle parameters on different shrub distribution

2.2 Soil Nutrient Variation Characteristics Under Different Shrub Distribution Types

Soil nutrient contents under different shrub distributions in the study area showed significant differences ($P < 0.05$). The contents in each soil layer from high to low were: *A. mongolicus*-*S. xanthoxylon* > *A. mongolicus* > bare sandy land. The contents of SOM, AN, AP, and AK in the 0-30 cm soil layer of *A. mongolicus*-*S. xanthoxylon* were $5.36 \text{ g} \cdot \text{kg}^{-1}$, $16.00 \text{ mg} \cdot \text{kg}^{-1}$, $19.39 \text{ mg} \cdot \text{kg}^{-1}$, and $111.21 \text{ mg} \cdot \text{kg}^{-1}$, respectively, which were $1.85 \text{ g} \cdot \text{kg}^{-1}$, $8.18 \text{ mg} \cdot \text{kg}^{-1}$, $3.51 \text{ g} \cdot \text{kg}^{-1}$, and $16.00 \text{ mg} \cdot \text{kg}^{-1}$ higher than those of bare sandy land, respectively. With increasing soil depth, the contents of SOM, AN, and AP in *A. mongolicus*-*S. xanthoxylon* and *A. mongolicus* soils all decreased, while AK content showed a trend of first decreasing and then increasing; in bare sandy land, SOM and AN contents decreased with increasing depth, while AP and AK contents showed a trend of first decreasing and then increasing.

[Figure 2: see original paper]

Both *A. mongolicus*-*S. xanthoxylon* and *A. mongolicus* had significant positive effects on soil nutrient accumulation (Figure 3). With increasing soil depth, the RII values of SOM, AN, and AP in *A. mongolicus*-*S. xanthoxylon* and *A. mongolicus* soils all decreased. The enrichment effect of *A. mongolicus*-*S. xanthoxylon* on SOM and AP was lower than that of *A. mongolicus*, while the accumulation effect on AN was better than that of *A. mongolicus*. The RII values of SOM and AP in *A. mongolicus*-*S. xanthoxylon* and *A. mongolicus* at 0-20 cm were all greater than 0, indicating positive nutrient enrichment, while the RII of AN in bare sandy land was less than 0, indicating no nutrient enrichment phenomenon.

[Figure 3: see original paper]

2.3 Relationship Between Soil Particle Composition and Nutrients

As shown in Figure 4, *A. mongolicus*-*S. xanthoxylon* AP was positively correlated with clay, silt, and fine sand contents, and negatively correlated with coarse sand, medium sand, and very coarse sand contents, among which AP was significantly positively correlated with fine sand ($P < 0.05$). *A. mongolicus* AN was negatively correlated with silt content, while AK was positively correlated with coarse sand, with a significant correlation ($P < 0.05$). There was no significant correlation between *A. mongolicus*-*S. xanthoxylon* AN, AK, and particle size composition. *A. mongolicus* SOM was positively correlated with

clay and silt, and negatively correlated with sand particles, among which SOM was significantly positively correlated with fine sand ($P < 0.05$).

[Figure 4: see original paper]

3.1 Soil Particle Characteristics Under Different Shrub Distribution Types

Western Ordos has a temperate continental monsoon climate. The surface soil particle size composition is closely related to wind-sand activities, and vegetation also has a great influence. With the appearance of aboveground vegetation, surface roughness increases, thereby disturbing the surface flow field. In this study, both shrub communities and bare sandy land soil particle size composition were dominated by sand particles, with fine sand having the highest content. This is because wind erosion causes the loss of fine particles from soil. In the sample plots, the fine sand content in the 0–30 cm soil layer under *A. mongolicus* was higher than that in bare sandy land because the presence of shrubs prevented fine particles under the canopy from being eroded, and the aboveground parts could block, decompose, and disperse near-surface wind speed during wind-sand flow transport, reducing wind speed and sand-carrying capacity, causing some particles to settle and resulting in changes in surface sediment particle size distribution.

Different vegetation types have obvious differences in soil particle size composition due to differences in height, branch density, and morphological structure. As vegetation grows and populations succeed, the sand-blocking ability of vegetation also changes. The canopy area and density of *A. mongolicus*-*S. xanthoxylon* mixed shrub community are larger than those of single *A. mongolicus*, and the fine sand content in the 0–5 cm soil layer of *A. mongolicus*-*S. xanthoxylon* is higher than that in the 0–5 cm soil layer of *A. mongolicus*. However, the fine sand content in the 0–5 cm soil layer of bare sandy land is greater than that in the *A. mongolicus* soil layer, which contradicts the results of Li et al. The reason may be that *A. mongolicus* shrubs in the study area show degradation phenomena, resulting in weakened interception capacity for wind-sand flow, and wind erosion migrates and loses fine soil particles under the shrubs, reducing fine particle content.

Soil particle size characteristics are not only the reflection of wind transport and sorting of source materials but also reflect the impact of obstacles on wind-sand flow transport. The sorting coefficients of *A. mongolicus*-*S. xanthoxylon*, *A. mongolicus*, and bare sandy land increase sequentially, with poor sorting, indicating that although shrubs have weak sorting effects on sediments, the sorting of *A. mongolicus*-*S. xanthoxylon* and *A. mongolicus* is slightly better than that of bare sandy land, and shrubs still play a certain protective role against wind erosion. Skewness reflects the symmetry of soil particle size frequency curves, indicating the distribution characteristics of coarse and fine soil particles. The stronger the kurtosis, the more concentrated the sample particle size distribu-

tion. In this study, the particle size distribution of *A. mongolicus*-*S. xanthoxylon* was more symmetric than the other two, with wider and flatter kurtosis, indicating asymmetric particle distribution and overall concentration in a certain range, with weaker performance in changing soil particle size composition than the other two. The reason may be related to this.

3.2 Soil Nutrient Content Variation Characteristics Under Different Shrub Distribution Types

The growth, development, and succession of vegetation affect the accumulation, distribution, and cycling of soil nutrients. In this study, the contents of SOM, AN, AP, and AK in the 0-30 cm soil layer of *A. mongolicus*-*S. xanthoxylon* and *A. mongolicus* were all significantly higher than those in bare sandy land, showing positive nutrient enrichment effects. Soil nutrients are concentrated in fine particles. Shrub canopy intercepts fine particles in wind-sand flow and redistributes surface soil resources. Large amounts of fine particles deposit under shrubs, affecting the spatial distribution and cycling of nutrients and gradually increasing soil nutrient content under shrubs, while nutrient content in bare sandy land without vegetation cover decreases correspondingly. In this experiment, the contents of SOM, AN, AP, and AK in each soil layer of *A. mongolicus*-*S. xanthoxylon* and *A. mongolicus* rhizosphere were all higher than those in bare sandy land. Different shrub soil nutrient indicators have different enrichment degrees, and soil nutrients are highly correlated with plant root secretions. As a leguminous nitrogen-fixing plant, *A. mongolicus* root secretions can effectively increase soil AN content. The AP content in *A. mongolicus*-*S. xanthoxylon* soil at 0-20 cm was significantly higher than that in bare sandy land, but *A. mongolicus* did not show enrichment effect, which may be related to the selective absorption of soil nutrient elements by *A. mongolicus* and *S. xanthoxylon* shrubs. Vegetation type, decomposition and utilization of litter, and other factors also cause changes in soil nutrient content. In this study, *A. mongolicus* is an evergreen broadleaf shrub with far less litter than other species, while *S. xanthoxylon*, as the first deciduous shrub in desert areas, has much more litter under its canopy than *A. mongolicus*. Therefore, there are large vertical variations in soil nutrients under *A. mongolicus*-*S. xanthoxylon* and *A. mongolicus* shrubs. The reason for the positive nutrient enrichment effect at 30 cm depth is that nutrients in bare sandy land are more likely to diffuse vertically, intensifying leaching and infiltration. In this study, SOM and AN contents showed a decreasing trend with soil depth, possibly because both *A. mongolicus* and *S. xanthoxylon* are deep-rooted desert shrubs with large nutrient consumption in deep soil layers. In addition, the accumulation of litter on the soil surface is decomposed by microorganisms to increase surface nutrient content, but surface nutrients cannot enter deep soil, so soil nutrients decrease with increasing soil depth.

Conclusion

Through analysis of soil particle size composition and nutrient content in surface soil (0-30 cm) under different shrub distribution types in the Baiyin Engel Nature Reserve of Western Ordos, the following conclusions were obtained:

1. Fine sand particles had the highest content in the study area, with average volume percentage greater than 44.25%, while clay and silt contents were lower, with total content less than 12.89%. The volume percentages of clay, silt, and fine sand in single *A. mongolicus* soil were all greater than those in *A. mongolicus* mixed with the associated species *S. xanthoxylon*. The soil particle size of *A. mongolicus-S. xanthoxylon*, *A. mongolicus*, and bare sandy land became finer in turn, sorting deteriorated, fractal dimension became smaller, soil particle distribution gradually became asymmetric, and particle composition concentrated at fine particles.
2. The contents of SOM and AN increased by $1.85 \text{ g} \cdot \text{kg}^{-1}$ and $8.18 \text{ mg} \cdot \text{kg}^{-1}$, respectively, with the increase of shrub species. The enrichment effect of single *A. mongolicus* on SOM and AP was higher than that of *A. mongolicus-S. xanthoxylon*, while the accumulation effect on AN was slightly lower than that of *A. mongolicus-S. xanthoxylon*. There were correlations between soil particle size composition and nutrient content. *A. mongolicus-S. xanthoxylon* AP was significantly positively correlated with fine sand content ($P < 0.05$), while *A. mongolicus* AN and AK were significantly positively correlated with coarse sand ($P < 0.05$).
3. *A. mongolicus-S. xanthoxylon* and *A. mongolicus* significantly improved soil fertility, but the presence of the associated species *S. xanthoxylon* reduced the enrichment of organic matter and available phosphorus by *A. mongolicus*.

References

- [1] Guo Yanpei, Gheyret Gheyur, Liu Tongyan, et al. Distribution patterns and climate limitations of typical shrublands in northern China[J]. *Scientia Sinica (Vita)*, 2021, 51(3): 346-361.
- [2] West N E, Stark J M, Johnson D W, et al. Effects of climatic change on the edaphic features of arid and semiarid lands of western North America[J]. *Arid Land Research and Management*, 1994, 8(4): 307-351.
- [3] Teng Zeyu, Xiao Shengchun, Chen Xiaohong, et al. The soil bacterial condition beneath five shrub species in the central Alxa[J]. *Journal of Desert Research*, 2021, 41(4): 34-44.
- [4] Dong Xue, Hao Yuguang, Xin Zhiming, et al. Fractal features of soil and their relationship with soil fertility under three shrub species in Otindag sandy land[J]. *Acta Prataculturae Sinica*, 2020, 29(6): 172-181.

- [5] Xu Wenxuan, Liu Wei, Yang Weikang, et al. *Rhombomys opimus* contribution to the fertile island effect of tamarisk mounds in Junggar Basin[J]. Ecological Research, 2012, 27(4): 775-781.
- [6] Ding Aiqiang, Xu Xianying, Zhang Wen, et al. Soil physicochemical and biological characteristics of *Tamarix ramosissima* nebkhas in different degradation degree[J]. Acta Prataculturae Sinica, 2019, 28(2): 1-11.
- [7] Lou Boyuan, Wang Yongdong, Yan Jinsheng, et al. Characteristics of soil ecological stoichiometry of different tree species in frigid desert steppe[J]. Arid Zone Research, 2021, 38(5): 1385-1392.
- [8] Chang Shuai, Yu Hongbo, Cao Congming, et al. Distribution characteristics of soil organic carbon in Xilin Gol steppe and its influencing factors[J]. Arid Zone Research, 2021, 38(5): 1355-1366.
- [9] Wei Cheng, Zhao Wenzhi, Ren Heng, et al. Nebkha morphological characteristics and soil nutrition content in three regions with different climates in North China[J]. Journal of Desert Research, 2021, 41(2): 191-199.
- [10] Li Xiaole, Wei Yajuan, Dang Xiaohong, et al. Soil mechanical composition and soil nutrient content of *Reaumuria soongorica* nebkhas[J]. Arid Zone Research, 2022, 39(3): 933-942.
- [11] Sun Caili, Liu Guobin, Xue Sha. Natural succession of grassland on the Loess Plateau of China affects multifractal characteristics of soil particle size distribution and soil nutrients[J]. Ecological Research, 2016, 31(6): 891-902.
- [12] Jiang Jiayu, Liu Rentao, Zhang Anning. Comparative analysis of soil fractal dimension and soil physical and chemical properties between *Caragana korshinskii* Shrub plantations in arid and semi arid desert steppe[J]. Research of Soil and Water Conservation, 2021, 28(4): 54-61, 69.
- [13] Ge Rileqiqige. On site protection technology of endangered plants in Hangjinqi: A case study of *Ammopiptanthus mongolicus* and almond[J]. Inner Mongolia Forestry, 2017, 62(1): 16-17.
- [14] Yang Jinling, Li Decheng, Zhang Ganlin, et al. Comparison of mass and volume fractal dimensions of soil particle size distributions[J]. Acta Pedologica Sinica, 2008, 45(3): 413-419.
- [15] Bao Shidan. Soil and Agricultural Chemistry Analysis[M]. Beijing: China Agriculture Press, 2005: 30-107.
- [16] Gao Guanglei, Ding Guodong, Zhao Yuanyuan, et al. Effects of biological soil crusts on soil particle size characteristics in Mu Us Sand Land[J]. Transactions of the Chinese Society for Agricultural Machinery, 2014, 45(1): 115-120.
- [17] Ding Guodong. Blown Sand Physics[M]. Beijing: China Forestry Publishing House, 2010.

- [18] Folk R L, Word W C. Brazos River bar; a study in the significance of grain size parameters[J]. *Journal of Sedimentary Research*, 1957, 27(1): 3-26.
- [19] Armas Cristina, Ordiales Ramón, Pugnaire Francisco I. Measuring plant interaction: A new comparative index[J]. *Ecology*, 2004, 85(10): 2682-2686.
- [20] Su Yongzhong, Zhao Halin. Fractal features of soil particle size distribution in the desertification process of the farmland in Horqin Sandy Land[J]. *Acta Ecologica Sinica*, 2004, 24(1): 71-74.
- [21] Xiang N, Peng G, Bing W, et al. Fractal characteristics of soil retention curve and particle size distribution with different vegetation types in mountain areas of northern China[J]. *International Journal of Environmental Research and Public Health*, 2015, 12(12): 15379-15391.
- [22] Yan Xin, An Hui. Fractal features of soil particle size in the process of desertification in desert grassland of Ningxia China[J]. *Chinese Journal of Applied Ecology*, 2017, 28(10): 3243-3250.
- [23] Sun Yuechao, Ma Shuoshi, Chen Zhi. Wind tunnels test on wind erosion effect of conservation tillage farmland and *Cara* collocated with grassland in strip[J]. *Transactions of the Chinese Society of Agricultural Engineering*, 2017, 33(11): 140-146.
- [24] Gao Yong, Ding Yanlong, Wang Ji, et al. Sediments particle size changes and its sand fixation ability for different shrub dunes[J]. *Transactions of the Chinese Society of Agricultural Engineering*, 2017, 33(22): 135-142.
- [25] Shi Shiling, Ren Xiaomeng, Zhang Xiaowei, et al. Soil nutrients and stoichiometric characteristics of the *Elaeagnus angustifolia* shelterbelt in the Hobq Desert[J]. *Arid Zone Research*, 2022, 39(2): 469-476.
- [26] Dean W R J, Milton S J, Jeltsch F. Large trees, fertile islands, and birds in arid savanna[J]. *Journal of Arid Environments*, 1999, 41(1): 61-78.
- [27] Luo W C, Zhao W Z. Adventitious roots are key to the development of nebkhas in extremely arid regions[J]. *Plant and Soil*, 2019, 442: 471-482.
- [28] Chen Yang, Qi Yanbing, Wang Yinyin, et al. Spatial variability and factors affecting soil available potassium in the central Qinling-Daba Mountain area[J]. *Research of Environmental Sciences*, 2017, 30(2): 257-266.
- [29] Li Xuebin, Zhang Yifan, Chen Lin, et al. Relationship between soil particle size distribution and soil nutrient distribution characteristics in typical communities of desert grassland[J]. *Acta Botanica Boreali Occidentalia Sinica*, 2017, 37(8): 1635-1644.
- [30] Tang Zhuangsheng, An Hui, Deng Lei, et al. Changes in the plant community and soil physical properties during grassland desertification of steppes[J]. *Acta Ecologica Sinica*, 2016, 36(4): 991-1000.

[31] Han Fugui, Man Duoqing, Zheng Qingzhong, et al. Species diversity and soil nutrient changes of a *Nitraria tangutorum* shrub community in Qingtu Lake wetland[J]. Acta Prataculturae Sinica, 2021, 30(1): 36-45.

[32] Ding Yanlong, Gao Yong, Meng Zhongju, et al. Particle size characteristics of wind erosion surface soil in the desert steppe[J]. Soils, 2016, 48(4): 803-812.

[33] Huang Lei, Zhang Yonge, Shao Fangli, et al. Soil ecological stoichiometry and its influencing factors in natural secondary forest, North Mountain of Hebei Province[J]. Acta Ecologica Sinica, 2021, 41(15): 6267-6279.

Note: Figure translations are in progress. See original paper for figures.

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