Postprint of a Study on the Morphological Characteristics of Caragana Nebkhas in the Hunshandake Sandy Land

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Abstract

Shrub sand dunes play a crucial role in maintaining grassland ecological functions and in the process of land desertification. The Otindag Sandy Land hosts numerous shrub sand dunes, among which Caragana shrub sand dunes are the most typical. Caragana shrub sand dunes on lands with different desertification degrees (slight, moderate, severe, and very severe desertification) were selected for field investigation and morphometric measurements to compare the morphological characteristics of Caragana shrub sand dunes across different desertification levels and to analyze the relationships between shrub and sand dune morphological parameters and their influencing factors. The results indicate that: (1) The sizes of shrub sand dunes vary among lands with different desertification degrees, generally exhibiting a pattern where the scale of shrub sand dunes gradually decreases from very severe, severe, and moderate to slight desertification; the vertical projection on the horizontal plane of shrub sand dune morphology on slightly and moderately desertified lands resembles an ellipse, with a shape similar to a semi-ellipsoid, whereas that on severely and very severely desertified lands resembles an irregular rhombus, with a shape similar to a quadrangular pyramid; the primary influencing factor of sand dune morphology may be related to sand source abundance. (2) Various morphological parameters of Caragana shrubs on lands with different desertification degrees are significantly correlated, with correlation coefficients between morphological parameters of Caragana shrub sand dunes on severely and very severely desertified lands being higher than those on moderately and slightly desertified lands; overall, the long axis, short axis, and height of shrub sand dunes develop synergistically. (3) The relationships between the long axis, short axis, and height of Caragana shrub sand dunes on slightly and moderately desertified lands follow a power function, indicating that shrub sand dunes still have considerable development potential; the relationships between the long axis, short axis, and height of shrub sand dunes on severely and very severely desertified lands follow

a quadratic function, indicating that shrub sand dunes have reached maturity and are prone to developing toward decline due to factors such as insufficient water supply to the root system.

Full Text

Morphological Characteristics of Caragana Shrub-Coppice Dunes in the Otindag Sandy Land

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Abstract: Shrub-coppice dunes play a crucial role in maintaining grassland ecological functions and influencing land desertification processes. The Otindag Sandy Land hosts numerous shrub-coppice dunes, among which Caragana shrub-coppice dunes are the most typical. This study selected Caragana shrubs on sandy lands with varying desertification degrees (mild, moderate, severe, and serious) for field investigation and morphological measurement. We compared the morphological characteristics of Caragana shrub-coppice dunes across different desertification levels and analyzed the relationships between shrub and dune morphological parameters and their influencing factors. The results revealed three key findings. First, dune size varied significantly with desertification degree, generally decreasing from serious to severe, moderate, and mild desertification. The horizontal projections of dunes on mild and moderate desertification lands resembled ellipses, with shapes similar to semi-ellipsoids, whereas those on severe and serious desertification lands appeared as irregular rhombuses in projection, with shapes resembling quadrangular pyramids. These morphological differences likely relate to sand source abundance. Second, all morphological parameters of Caragana shrub-coppice dunes showed significant correlations across different desertification degrees, with correlation coefficients being higher on severe and serious desertification lands than on moderate and mild lands. Overall, the long axis, short axis, and dune height developed synergistically. Third, power function relationships existed between the long axis, short axis, and height on mild and moderate desertification lands, indicating substantial development potential. In contrast, quadratic function relationships characterized these parameters on severe and serious desertification lands, suggesting that the dunes have reached maturity and may decline due to insufficient root water supply.

Keywords: Caragana; shrub-coppice dunes; morphological characteristics; Otindag Sandy Land

1.1 Study Area Overview

The Otindag Sandy Land is located in the southeastern part of the Inner Mongolian Plateau in China, at the intersection of the northern Inner Mongolian dry denudation plateau, the northeast-trending Greater Khingan Mountains, and the southeast-trending Yinshan Mountains. Administratively, it primarily covers the central and western parts of Xilingol League and the western part of Chifeng City in Inner Mongolia. The region belongs to the semi-arid steppe zone with distinct temperate continental climate characteristics. The annual average temperature ranges from 0–3°C, with large annual and daily temperature variations that facilitate material formation and accumulation. Annual sunshine duration reaches 2700–3200 hours, and the accumulated temperature $ 10°*Cis*2000–2600°*C*, *providingabundantheatandlightforsummercropsandforage.Influencedbythesoutheas*
s^{-1}$ and 50–80 windy days per year, making it one of the windiest regions in China' s sandy areas. The zonal soils are primarily chestnut soil, followed by brown calcic soil, with aeolian sandy soil as the main azonal soil type. The vegetation is dominated by steppe communities, with fixed and semi-fixed dunes in the western part of the sandy land characterized by Caragana microphylla, Caragana pygnaea, Artemisia desertorum, and Phyllostachys propinqua associations, mixed with Artemisia frigida, Caryopteris mongholica, Echinops gmelini, Asparagus gobicus, Cleistogenes squarrosa, and Stipa capillata.

1.2.1 Sample Site Selection

We selected sample sites with Caragana shrub-coppice dunes across different desertification degrees in the western Otindag Sandy Land. The basic information for each site is presented in Table 1. Field investigations of Caragana shrub-coppice dune morphology were conducted on sandy lands with varying desertification degrees. More than 30 typical, undisturbed, and independent Caragana shrub-coppice dunes were randomly measured at each sampling point, totaling 120 dunes across all sites.

1.2.2 Measurement Indicators and Data Processing

Measurement indicators included both shrub and dune parameters. Shrub parameters comprised canopy length (L), canopy width (W), and shrub height (H). Dune parameters included dune long axis (L_d), dune short axis (W_d), dune height (H_d), dune base area (S_d), and dune volume (V_d). Due to morphological differences among Caragana shrub-coppice dunes under varying desertification degrees, different calculation methods were employed for base area and volume:

(1) On mild and moderate desertification lands, dunes exhibited elliptical vertical projections in the horizontal plane, resembling semi-ellipsoids:

[Mathematical formulas would appear here as in original]

(2) On severe and serious desertification lands, dunes accumulated sand at both the top and tail sections, with longer tails, and the base area resembled a rhombus, forming a quadrangular pyramid shape:

[Mathematical formulas would appear here as in original]

All data were statistically analyzed using Excel, with Pearson correlation and regression analyses performed.

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2 Results and Analysis

Statistical analysis of Caragana shrub-coppice dunes across the four sampling sites revealed significant differences in both shrub and dune morphological characteristics under different desertification degrees (Table 2).

2.1 Morphological Characteristics of Caragana Shrub-Coppice Dunes

On mild desertification lands, Caragana shrubs averaged 129.6 cm in length, 140.6 cm in width, and 55.9 cm in height, with relatively uniform development. Dune long axis averaged 255.2 cm, short axis 133.6 cm, and height 17.8 cm, with a long-to-short axis ratio of 1.91:1. Most dunes exhibited semi-ellipsoid shapes with low height, and shrubs largely covered the dunes, which were essentially stabilized and protected the shrub base from wind erosion.

On moderate desertification lands, Caragana shrubs averaged 194.0 cm in length, 196.5 cm in width, and 67.6 cm in height, showing slightly larger and better development than those on mild desertification lands. Dune long axis averaged 383.9 cm, short axis 187.6 cm, and height 34.8 cm, with a long-to-short axis ratio of 2.05:1. The dunes were largely enveloped by shrubs, forming larger semi-ellipsoid shrub-coppice dunes.

On severe desertification lands, Caragana shrubs averaged 243.9 cm in length, 247.0 cm in width, and 83.7 cm in height, developing larger than those on mild and moderate lands due to stronger aeolian activity and richer sand sources. Dune long axis averaged 475.1 cm, short axis 237.2 cm, and height 44.9 cm, with a long-to-short axis ratio of 2.00:1. Abundant herbaceous vegetation nearby intercepted wind-blown sand, limiting sand supply and restricting dune development. The dune long axis averaged 1.95 times the shrub length due to sand accumulation on the leeward slope under wind erosion, with slight sand accumulation on the windward slope. The base area resembled an irregular rhombus, forming a quadrangular pyramid shape.

On serious desertification lands, Caragana shrubs averaged 215.5 cm in length, 221.1 cm in width, and 85.3 cm in height—slightly smaller than those on severe desertification lands but larger than those on mild and moderate lands. Dune

long axis averaged 452.3 cm, short axis 215.1 cm, and height 51.0 cm, with a long-to-short axis ratio of 2.10:1. Severe sand mobilization caused strong erosion of shrub-coppice dunes, exposing some shrub roots, yet abundant sand supply promoted shrub growth, resulting in larger dunes than those on mild and moderate desertification lands.

The average volumes of Caragana shrub-coppice dunes on mild, moderate, severe, and serious desertification lands were 0.494$×10^{3}$ cm^3, 1.753$×10^{3}$ cm^3, 1.865$×10^{3}$ cm^3, and 2.849$×10^{3}$ cm^3, respectively, demonstrating that dune size generally decreases with decreasing desertification degree.

2.2 Correlation Analysis of Morphological Parameters

Significant correlations existed among all morphological parameters of Caragana shrub-coppice dunes across different desertification degrees (Table 3). On mild desertification lands, correlations between shrub length (L) and shrub width (W), shrub length (L) and shrub height (H), and shrub width (W) and shrub height (H) were 0.633, 0.601, and 0.648, respectively. On moderate desertification lands, the corresponding correlation coefficients were 0.523, 0.493, and 0.481, with moderate desertification showing the weakest correlations. On severe desertification lands, correlation coefficients were 0.729, 0.708, and 0.741, respectively. On serious desertification lands, they reached 0.798, 0.784, and 0.813, indicating the strongest correlations among shrub parameters.

Correlations among dune parameters also varied by desertification degree. On mild desertification lands, correlation coefficients between dune long axis (L_d) and short axis (W_d), L_d and height (H_d), and W_d and H_d were 0.791, 0.327, and 0.354, respectively. On severe and serious desertification lands, corresponding coefficients were 0.901 and 0.896 (L_d-W_d), 0.628 and 0.699 (L_d-H_d), and 0.645 and 0.637 (W_d-H_d), respectively. Dune parameter correlations were weakest on mild desertification lands and similar between severe and serious desertification lands.

Strong correlations existed between shrub and dune parameters. On mild desertification lands, shrub width (W) and dune short axis (W_d) showed the highest correlation coefficient of 0.798. On moderate desertification lands, shrub length (L) and dune long axis (L_d), and shrub width (W) and dune short axis (W_d) were extremely significantly correlated with coefficients of 0.750 and 0.759, respectively. On severe desertification lands, shrub width (W) and dune short axis (W_d), shrub length (L) and dune short axis (W_d), and shrub length (L) and dune long axis (L_d) showed the highest correlations at 0.901, 0.896, and 0.891, respectively. On serious desertification lands, shrub width (W) and dune short axis (W_d) maintained the highest correlation across all desertification degrees at 0.913, all showing extremely significant correlations.

2.3 Regression Statistical Analysis of Morphological Parameters

Given the significant correlations among dune long axis (L_d), short axis (W_d), and height (H_d), regression analysis was performed to explore relationships between horizontal scale and height, revealing developmental characteristics across desertification degrees.

On mild desertification lands, the fitted function between dune long axis and height was: H_d = 0.202 L_d^0.791 (R^2 = 0.327). The fitted function between short axis and height was: H_d = 0.354 W_d^0.798 (R^2 = 0.354). The relatively low R^2 values indicate unstable development when dune scale is small. The larger power exponent for short axis versus height suggests height increases faster with short axis growth.

On moderate desertification lands, the fitted function between long axis and height was: H_d = 0.391 L_d^0.750 (R^2 = 0.473). The fitted function between short axis and height was: H_d = 0.759 W_d^0.727 (R^2 = 0.473). These R^2 values exceed those for mild desertification lands, indicating better development. The larger power exponent for long axis versus height shows that on moderate desertification lands, height increases faster with long axis growth.

On severe desertification lands, the relationship between long axis and height followed a quadratic function: H_d = -1.215 × 10^{-5} L_d^2 + 0.103 L_d - 0.601 (R^2 = 0.628). The relationship between short axis and height was: H_d = 0.0001 W_d^2 + 0.246 W_d - 4.138 (R^2 = 0.645). The optimal quadratic models indicate that dune height initially increases with long and short axes but eventually decreases, suggesting dunes have reached maturity and begun to decline.

On serious desertification lands, the fitted function between long axis and height was: H_d = -1.803 × 10^{-5} L_d^2 + 0.166 L_d - 18.678 (R^2 = 0.699). The fitted function between short axis and height was: H_d = -3.331 × 10^{-5} W_d^2 + 0.29 W_d - 9.103 (R^2 = 0.637). The fitting effect for long axis and height on serious desertification lands was superior to that on mild, moderate, and severe lands, with the highest correlation coefficient (R^2 = 0.699). The largest power exponent in the quadratic function indicates that on serious desertification lands, dune height increases with horizontal scale at a greater rate.

Regression analysis of horizontal scale versus height across all desertification degrees showed that serious desertification lands had the highest R^2 value. Except for severe desertification lands where the quadratic function provided the best fit, power functions were optimal for other degrees. This clearly demonstrates that on severe desertification lands, Caragana shrub-coppice dune height begins to decline after reaching a certain horizontal scale. Compared with mild and moderate desertification lands, the power exponent was largest on serious desertification lands, indicating faster height increase with horizontal scale growth.

3.1 Influences on Caragana Shrub-Coppice Dunes Across Desertification Degrees

Caragana shrub-coppice dunes on mild, moderate, severe, and serious desertification lands showed significant morphological differences. Our findings indicate that dune size decreases with decreasing desertification degree, with sand source abundance being the primary factor influencing dune morphology and size. Vegetation cover, sand source availability, and wind regime are the main factors causing these differences. The optimal shrub density is generally considered to be 20–35%. Caragana shrub-coppice dunes on serious and some severe desertification lands have vegetation cover below this threshold. Field observations confirm that severe and serious desertification lands are typically located at wind gaps or near erosion zones with abundant sand sources and strong sand mobilization. Sparse surface vegetation provides little sand interception, while shrub presence effectively traps wind-blown sand, causing particle deposition and dune formation. Dunes on serious and severe desertification lands are generally in developmental or stable stages. Sand burial promotes Caragana growth, which in turn enhances sand-trapping capacity. This mutual reinforcement gradually expands dune size, and few dunes in these areas show degradation or decline, likely because aging shrubs are easily buried by mobile sand. In contrast, mild and moderate desertification lands experience weaker sand activity and relatively limited sand sources. Moderate wind-blown sand benefits shrub development but rarely forms large, stable dunes. With surface vegetation cover basically exceeding 40%, wind-blown sand is intercepted and sand accumulation decreases significantly, allowing shrubs to persist even after senescence. Wind significantly shapes dune morphology by interfering with surface sand flow and eroding shrubs. Under strong winds, shrubs experience greater erosion, and sand typically accumulates on the leeward side, forming long tails. This produces the quadrangular pyramid morphology observed on severe and serious desertification lands. Under weak winds, sand erosion is minimal and accumulation occurs within shrub canopies, creating the rounded or ellipsoidal shapes characteristic of mild and moderate desertification lands.

3.2 Development of Caragana Shrub-Coppice Dunes Across Desertification Degrees

Shrub morphology significantly influences dune development. Our results confirm significant correlations between shrub and dune parameters, with relationships becoming more pronounced as dune size increases. During growth and development, dune morphological parameters exhibit strong functional relationships. Generally, dunes in growth and stable stages show significant linear relationships among parameters, whereas declining dunes appear irregular with unclear parameter relationships. Our results show that regression models for Caragana shrub-coppice dunes across desertification degrees follow power and quadratic functions. Although optimal models differ, they clearly demonstrate that dune height increases with long and short axes, indicating synergistic

growth. When the fitted function is a power function, the long axis grows faster than the short axis for a given height increase, suggesting dunes develop both vertically and rapidly along the long axis. When the fitted function is quadratic with a negative quadratic coefficient, height increases with axis length at a decreasing rate, indicating dunes cease growth and begin to decline after reaching a certain stage. Previous studies have demonstrated good functional relationships between dune height and width/length, which our research confirms. Therefore, regional environmental changes can be reflected through relationships among dune morphological parameters, and conversely, dune morphology indicates desertification trends.

The quadratic function for severe desertification lands suggests dunes have reached their peak and begun declining, while on serious desertification lands, dunes have not yet reached the function' s maximum but have limited growth potential. Dunes on mild and moderate desertification lands show greater development potential. This indicates that shrub-coppice dunes develop rapidly under favorable conditions of abundant sand sources, sufficient water, and good vegetation. In China' s arid and semi-arid regions, rainfall also affects shrub growth, but once thresholds are exceeded, shrubs readily decline. Conversely, lacking certain developmental conditions such as insufficient sand supply prevents dunes from reaching large sizes.

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4 Conclusions

This study investigated Caragana shrub-coppice dunes on mild, moderate, severe, and serious desertification lands in the Otindag Sandy Land through field surveys of morphological characteristics. By linking dune developmental status and growth differences to desertification degrees, we provide a reliable basis for interpreting desertification severity and revealing regional land desertification processes. The main conclusions are:

(1) Dune size in the Otindag Sandy Land generally decreases from serious to severe, moderate, and mild desertification. Sand source abundance significantly influences dune scale. On severe and serious desertification lands with rich sand sources, dunes typically exhibit quadrangular pyramid shapes with sand tails in space, whereas on mild and moderate desertification lands, dunes mostly appear as semi-ellipsoids.

(2) All morphological parameters of Caragana shrub-coppice dunes are significantly correlated across different desertification degrees, with the long axis, short axis, and height developing synergistically. Shrub health directly affects dune scale. Correlations among morphological parameters are stronger on severe and serious desertification lands than on mild and moderate lands, indicating that larger, more mature and stable dunes exhibit better parameter relationships.

(3) Functional relationships exist among dune parameters across desertification degrees. Power functions describe the relationships between long axis, short axis, and height on mild and moderate desertification lands, indicating ongoing development. Quadratic functions characterize these relationships on severe and serious desertification lands, suggesting dunes have reached maturity and may trend toward decline.

References

[1] Tengberg A, Chen D L. A comparative analysis of nebkhas in central Tunisia and northern Burkina Faso[J]. Geomorphology, 1998, 22(2): 181-192.

[2] Nicking W G, Wolfe S A. The morphology and origin of nabkhas, region of Mopti, Mali, west Africa[J]. Journal of Arid Environments, 1994, 28(1): 13-30.

[3] Wu Shengli. Study on development mechanism of nebkha in the basin of Hetian River, Xinjiang[D]. Shanghai: East China Normal University, 2007.

[4] Al Awadhi J M, Al Dousari A M. Morphological characteristics and development of coastal nabkhas, north east Kuwait[J]. International Journal of Earth Sciences, 2013, 102(3): 949-958.

[5] Yan N, Baas A C W. Environmental controls, morphodynamic processes, and ecogeomorphic interactions of barchan to parabolic dune transformations[J]. Geomorphology, 2017, 278: 209-237.

[6] Wei Yajuan, Wang Ji, Dang Xiaohong, et al. Morphological features of Nitraria tangutorum nebkhas in different habitats[J]. Arid Zone Research, 2019, 36(1): 253-261.

[7] Gillies J A, Nield J M, Nickling W G. Wind speed and sediment transport recovery in the lee of a vegetated and denuded nebkha within a nebkha dune field[J]. Aeolian Research, 2014, 12: 135-141.

[8] Wang Yixuan, Chen Tianyuan, Wu Chan, et al. Formation and evolution of the Xitaijinair Salt Lake in Qaidam Basin revealed by chronology[J]. Arid Land Geography, 2019, 42(4): 876-884.

[9] Liu Minxia, Xia Sujuan, Nan Xiaoning, et al. Distribution pattern of Caragana roborovskyi population based on Ripley K function[J]. Arid Zone Research, 2019, 36(3): 606-613.

[10] Chen Dong, Zhang Yuqing, Wu Bin, et al. The morphological characteristics of nebkhas at different evolvement stages in southern margin of Mu Us Desert[J]. Journal of Desert Research, 2015, 35(3): 565-572.

[11] Du Jianhui, Yan Ping, Dong Yuxiang. The progress and prospects of nebkhas in arid areas[J]. Acta Geographica Sinica, 2010, 65(3): 339-350.

[12] Zhang Ping, Ha Si, Yue Xingling, et al. Morphology and sedimentary characteristics of Nitraria tangutorum nebkhas[J]. Arid Land Geography, 2008, 31(6): 926-932.

[13] Zhang Yuanyuan, Ma Chengcang, Han Lei, et al. Nabkha morphology and sand fixing capability of four dominant Caragana species in the desert region of the Inner Mongolia Plateau[J]. Journal of Ecology, 2012, 32(11): 3343-3351.

[14] Zuo Hejun, Yang Yang, Zhang Hongfei, et al. Morphological characters of Nitraria dune in Gobi of Alxa[J]. Research of Soil and Water Conservation, 2018, 25(1): 263-269.

[15] Wang Tao. Desert and desertification in China[M]. Shijiazhuang: Hebei Science and Technology Press, 2003: 137-140.

[16] Zhan Kejie. Researching of the coherence relationship between surface sand flow characteristic and shaping of nebkhas[D]. Lanzhou: Lanzhou University, 2016.

[17] Chang Zhaofeng, Zhu Shujuan, Du Juan, et al. Environmental factors causing the formation of sand accumulation belt along the oasis fringe in Minqin[J]. Arid Land Geography, 2019, 42(6): 1330-1336.

[18] Xie Guoxun, Luo Weicheng, Zhao Wenzhi. Effect of sand source and shrub features on nebkha morphological characteristics in desert steppe[J]. Journal of Desert Research, 2015, 35(3): 573-581.

[19] Gao Yong, Dang Xiaohong, Yu Yi, et al. Nabkha morphological characteristics and sand fixing capacity of Artemisia sphaerocphala in the south edge of the Ulan Buh Desert[J]. Journal of Desert Research, 2015, 35(1): 1-7.

[20] Kong Fangfang, Tan Lihua, Wu Yongqiu, et al. Morphology and sediments of nebkha in Qaidam Basin[J]. Journal of Beijing Normal University (Natural Science Edition), 2016, 52(1): 56-62.

[21] El Bana M I, Nijs I, Khedr A H A. The importance of phytogenic mounds (nebkhas) for restoration of arid degraded rangelands in northern Sinai[J]. Restoration Ecology, 2003, 11(3): 317-324.

[22] Lü Ping, Dong Zhibao, Zhao Aiguo, et al. Effect of shrub density on grain sizes and threshold wind velocity[J]. Journal of Sediment Research, 2011(3): 63-66.

[23] Tan Fengzhu, Wang Xueqin, Wang Haifeng, et al. Wind tunnel simulation of the three-dimensional airflow patterns around Tamarix ramosissima nebkhas under the change of background vegetation coverage[J]. Journal of Desert Research, 2018, 38(1): 48-57.

[24] Zhang Ping, Eerdun Hasi, Yang Yi, et al. Responses of nebkhas morphology to the mode and richness of sand supply[J]. Journal of Desert Research, 2015, 35(6): 1453-1460.

[25] Liu Fei, Chen Peiyuan, Yu Haichao, et al. Spatial distribution characteristics of soil water and salt under different land use types in Minqin[J]. Arid Land Geography, 2020, 43(2): 406-414.

[26] Hu X X, Mitsuru H, Wu Y N, et al. Responses in gross primary production of Stipa krylovii and Allium polyrhizum to a temporal rainfall in a temperate grassland of Inner Mongolia, China[J]. Journal of Arid Land, 2019, 11(6): 824-836.

[27] 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.

[28] Langford R P. Nabkha (coppice dune) fields of south central New Mexico, USA[J]. Journal of Arid Environments, 2000, 46(1): 25-41.

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