Postprint of Soil Particle Size Distribution Characteristics in Pinus sylvestris var. mongolica Plantations in the Horqin Sandy Land

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Abstract

To reveal the effects of Mongolian pine plantations of different ages on the particle size distribution characteristics of aeolian sandy soil in the Horqin Sandy Land, soils from middle-aged, near-mature, and mature Mongolian pine plantations were studied, with aeolian sandy soil from bare sandy land as the experimental control. Laser diffraction technique was used to determine the particle size composition of soil samples, calculate and analyze soil particle size parameters, and plot soil particle size distribution curves. The results showed: (1) The aeolian sandy soil under Mongolian pine plantations in the Horqin Sandy Land was dominated by sand, followed by silt, with clay content being the lowest. With increasing stand age, the contents of soil clay and silt showed an increasing trend, while sand content showed a decreasing trend. The sand content in bare sandy land was generally higher than that in the same soil layer of forest land. (2) The aeolian sandy soil under Mongolian pine plantations in the Horqin Sandy Land had relatively coarse texture, poor sorting, mostly positive skewness values, and mostly sharp and narrow kurtosis values. The fractal dimensions of 0-10 cm and 10-20 cm aeolian sandy soils were 2.18-2.43 and 1.98-2.17, respectively. The aeolian sandy soil in bare sandy land had coarser texture, better sorting, and smaller fractal dimensions. (3) The particle size frequency distribution curves of aeolian sandy soil under Mongolian pine plantations in the Horqin Sandy Land were all bimodal. With increasing stand age, the refinement of soil particles in 10-20 cm depth lagged behind that in 0-10 cm depth. The content of suspension components in forest land was higher than that in bare sandy land, while the sorting of saltation components in bare sandy land was higher than that in forest land. There were significant differences in the particle size distribution characteristics of aeolian sandy soil under different Mongolian pine plantations in the Horqin Sandy Land, and the results of this

study can provide a theoretical basis for desertification control and ecological restoration in the Horqin Sandy Land.

Full Text

Soil Particle Size Distribution Characteristics of Pinus sylvestris var. mongolica Plantations in the Horqin Sandy Land

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Abstract

To reveal the effects of different stand ages of *Pinus sylvestris* var. *mongolica* plantations on the particle size distribution characteristics of aeolian soils in the Horqin Sandy Land, we collected aeolian soil samples from mid-age, near-mature, and mature plantations, using bare sandy land as an experimental control. Soil particle size composition was determined using laser diffraction technology, and soil particle size parameters were calculated and analyzed to plot soil grading curves. The results showed that: (1) The aeolian soils under *P. sylvestris* var. *mongolica* plantations in the Horqin Sandy Land were dominated by sand particles, followed by silt, with clay content being the lowest. With increasing stand age, soil clay and silt contents showed an increasing trend, while sand content showed a decreasing trend. The sand content of bare sandy land was generally higher than that of plantation soils at the same depth. (2) The aeolian soils under *P. sylvestris* var. *mongolica* plantations had relatively coarse texture and poor sorting, with predominantly positive skewness values and sharp, narrow kurtosis values. The fractal dimensions of 0–10 cm and 10–20 cm depth soils were 2.18–2.43 and 1.98–2.17, respectively. Compared with plantation soils, bare sandy land had coarser texture, better sorting, and smaller fractal dimensions, though skewness values showed no significant differences. (3) The particle size frequency distribution curves of aeolian soils under *P. sylvestris* var. *mongolica* plantations were all bimodal. With increasing stand age, the refinement of soil particles in the 0–10 cm layer lagged behind that in the 10–20 cm layer. The content of suspended components in plantation soils was higher than in bare sandy land, while the sorting of saltation components in bare sandy land was better than in plantation soils. Significant differences in particle size distribution characteristics existed among different *P. sylvestris* var. *mongolica* plantations in the Horqin Sandy Land. These results provide a theoretical basis for desertification control and ecological restoration in this region.

Keywords: Horqin Sandy Land; *Pinus sylvestris* var. *mongolica*; particle size distribution; particle size parameters; grading curve

1 Study Area and Methods

1.1 Study Area

The study area is located in Zhanggutai Sandy Forest Park (42°23 N, 122°22 E) in the southeastern Horqin Sandy Land, with an elevation of 226 m. The region has a mid-temperate sub-humid continental monsoon climate, with an average annual temperature of 5.9 °C and average annual precipitation of 526.5 mm concentrated in June–August. The average annual evaporation is 2,615.2 mm, relative humidity is 62%, average annual wind speed is 5.0 $\mathrm{m \cdot s^{-1}}$, and the average number of days with strong winds (>17 $\mathrm{m \cdot s^{-1}}$) is 150 d, mainly occurring in spring. The soil type is primarily mobile aeolian sandy soil and grassy aeolian sandy soil, with uniform sand particles and a sand layer thickness exceeding 100 m, representing typical aeolian landforms. Soil nutrient elements such as N, P, and K are relatively low. The vegetation is dominated by psammophytes, with major tree species including *Pinus sylvestris* var. *mongolica*, *Pinus sylvestris*, and *Acer mono*, and major shrub species including *Lespedeza bicolor*, *Rhamnus parvifolia*, and *Caragana microphylla*.

1.2 Sample Collection and Analysis

In October 2017, we established three 20 m × 20 m experimental plots in mid-age (33 years), near-mature (42 years), and mature (48 years) *P. sylvestris* var. *mongolica* plantations in Zhanggutai Sandy Forest Park, with distances >100 m between plots. All *P. sylvestris* var. *mongolica* trees with DBH >5 cm were measured to record stand age, tree height, DBH, and canopy density. Basic plot information is shown in . Within each plot, three standard trees were selected as sampling targets. After removing the litter layer below the canopy projection, surface soil samples (0–10 cm) were collected using a five-point sampling method, mixed, and placed in ziplock bags. Bare sandy land was selected as the experimental control, with a total of 12 sampling points. Soil samples were air-dried in the laboratory, and roots and gravel were removed before particle size composition was determined using a Malvern MS 2000 laser particle size analyzer. Each sample was measured three times, with results based on the USDA soil particle size classification standard. The soil particle volume fraction at 50% was output as the median particle diameter.

1.3 Calculation of Soil Particle Size Parameters

Based on the Udden-Wentworth scale and Krumbein' s logarithmic transformation method, particle size values were converted to Φ values using the formula $\Phi = -\log_2 d$, where d is the particle diameter (mm). The Folk-Ward graphical method was used to calculate soil particle size parameters including mean particle size, standard deviation, skewness, and kurtosis to characterize the average degree, dispersion degree, and distribution symmetry of soil particle size distribution. The parameter calculation formulas are as follows:

Mean particle size:

$$d_0 = \frac{\Phi_{16} + \Phi_{50} + \Phi_{84}}{3}$$

Standard deviation:

$$\sigma_0 = \frac{\Phi_{84} - \Phi_{16}}{4} + \frac{\Phi_{95} - \Phi_5}{6.6}$$

Skewness:

$$S_0 = \frac{\Phi_{16} + \Phi_{84} - 2\Phi_{50}}{2(\Phi_{84} - \Phi_{16})} + \frac{\Phi_5 + \Phi_{95} - 2\Phi_{50}}{2(\Phi_{95} - \Phi_5)}$$

Kurtosis:

$$K_0 = \frac{\Phi_{95} - \Phi_5}{2.44(\Phi_{75} - \Phi_{25})}$$

Soil particle size fractal dimension can further compare particle distribution characteristics and texture uniformity among different soils, and reflect other soil features such as soil genesis, fertility, land use impacts, and degradation degree. The calculation formula is:

$$D = 3 - \frac{\lg \frac{v(r<R_i)}{V_T}}{\lg \frac{R_i}{R_{\max}}}$$

where D is the soil volume fractal dimension; r is soil particle size (mm); R is the soil particle size of grade i (mm); R is the maximum soil particle size (mm); v(r<R) is the soil volume with particle size less than R (mm^3); and V_T is the sum of volume fractions for all particle size grades (mm^3).

1.4 Statistical Analysis Methods

Excel 2010 and SPSS Statistics 21 software were used for statistical analysis. One-way ANOVA and the least significant difference (LSD) test were used to examine significant differences in soil particle size composition and parameters among different plot types, with a confidence interval of 95%.

2 Results and Analysis

2.1 Soil Particle Size Composition

The aeolian soils under *P. sylvestris* var. *mongolica* plantations in the Horqin Sandy Land were dominated by sand particles, with an average content of 69.29-87.04% in the 0-10 cm layer, among which fine sand and medium sand were relatively high while very coarse sand was relatively low. Silt content was second, averaging 13.30-25.05%, while clay content was the lowest at less than 1.82%. With increasing stand age, the clay and silt contents of near-mature and mature stands were significantly higher than those of mid-age stands ($P<0.05$), while medium sand content was significantly lower ($P<0.05$). Fine sand content in near-mature and mature stands was significantly lower than in mid-age stands ($P<0.05$), while very fine sand content in near-mature stands was significantly higher than in mid-age and mature stands ($P<0.05$). Coarse sand and very coarse sand contents showed no significant changes ($P>0.05$). The clay and silt contents of bare sandy land were significantly lower than those of plantation soils at the same layer ($P<0.05$), while medium sand content was significantly higher ($P<0.05$). There were no significant differences in coarse sand and very coarse sand contents between bare sandy land and plantation soils ($P>0.05$).

In the 10-20 cm layer, plantation soils were also dominated by sand particles, with an average content of 82.57-94.23%. Silt content reached 5.68-17.15%, while clay content was less than 0.28%. With increasing stand age, soil clay and silt contents increased significantly ($P<0.05$). Very fine sand content in mature stands was significantly higher than in mid-age stands ($P<0.05$), while fine sand content in near-mature and mature stands was significantly lower than in mid-age stands ($P<0.05$). Medium sand content in mature stands was significantly lower than in mid-age and near-mature stands ($P<0.05$). Coarse sand and very coarse sand contents showed no significant changes ($P>0.05$). The clay and silt contents of bare sandy land were significantly lower than those of near-mature and mature plantation soils at the same layer ($P<0.05$), while medium sand content was significantly higher than in mature stands ($P<0.05$). Fine sand content was significantly lower than in mature stands ($P<0.05$), while coarse sand and very coarse sand contents showed no significant differences from plantation soils ($P>0.05$).

2.2 Soil Particle Size Parameters

As shown in , the mean particle sizes of 0-10 cm aeolian soils in mid-age, near-mature, and mature *P. sylvestris* var. *mongolica* plantations were 1.51-2.18 Φ, indicating relatively coarse soil texture. Standard deviations were 0.84-1.12 Φ, indicating poor sorting. Skewness values were 0.32-0.47, showing extremely positive skewness, while kurtosis values were 1.04-1.78, indicating sharp, narrow distributions with uneven particle distribution. Fractal dimensions were 2.36-2.77. With increasing stand age, the mean particle size, standard deviation, and fractal dimension of near-mature and mature stands were significantly higher than those of mid-age stands ($P<0.05$). The skewness value of mature stands was significantly higher than that of near-mature stands ($P<0.05$), while kurtosis values of near-mature and mature stands were significantly lower than those of mid-age stands ($P<0.05$). The mean particle size and standard deviation of 0–10 cm bare sandy land soils were significantly lower than those of plantation soils at the same layer ($P<0.05$), while kurtosis showed no significant difference ($P>0.05$). The fractal dimension was significantly lower than those of near-mature and mature stands ($P<0.05$), but showed no significant difference with mid-age stands ($P>0.05$).

The mean particle sizes of 10–20 cm aeolian soils in mid-age, near-mature, and mature stands were 1.91–2.43 Φ, also indicating relatively coarse texture. Standard deviations were 0.88–1.44 Φ, with mid-age stands showing moderate sorting while near-mature and mature stands showed poor sorting. Skewness values were 0.25–0.46, with mid-age stands showing positive skewness and near-mature and mature stands showing extremely positive skewness. Kurtosis values were 1.16–1.51, with mid-age and near-mature stands showing sharp, narrow distributions. Fractal dimensions were 2.15–2.42. With increasing stand age, the mean particle size, standard deviation, and fractal dimension of near-mature and mature stands were significantly higher than those of mid-age stands ($P<0.05$). Kurtosis values were significantly lower than those of mid-age stands ($P<0.05$), while skewness showed no significant change ($P>0.05$). The mean particle size, standard deviation, and fractal dimension of 10–20 cm bare sandy land soils were significantly lower than those of near-mature and mature stands ($P<0.05$), but showed no significant difference with mid-age stands ($P>0.05$). Skewness values showed no significant differences from plantation soils ($P>0.05$), while kurtosis was significantly lower than that of mid-age stands ($P<0.05$).

2.3 Soil Particle Size Distribution Curves

2.3.1 Soil Particle Size Frequency Distribution Curves As shown in [Figure 1: see original paper], the particle size frequency distribution curves of 0–10 cm aeolian soils in different *P. sylvestris* var. *mongolica* plantations in the Horqin Sandy Land were all bimodal, with peaks near 3 Φ and troughs near 2 Φ. The left side of the trough represented fine components (clay and silt), while the right side represented coarse components (sand). The fine component peaks decreased in the order: mature stand > near-mature stand > mid-age stand, while coarse component peaks decreased in the order: mid-age stand > near-mature stand > mature stand. With increasing stand age, the fine component content of 0–10 cm soils gradually increased while the coarse component content gradually decreased. The particle size frequency distribution curve of bare sandy land was unimodal, with a peak near 2 Φ. The fine component content of bare sandy land was lower than that of plantation soils, while the coarse component content was higher.

As shown in [Figure 1: see original paper], the particle size frequency distribution curves of 10–20 cm aeolian soils were also bimodal, with peaks near 3 Φ and troughs near 2 Φ. The fine component peaks decreased in the order: mature stand > near-mature stand > mid-age stand, while coarse component peaks decreased in the order: mid-age stand > near-mature stand > mature stand. With increasing stand age, the fine component content gradually increased while the coarse component content gradually decreased. The particle size frequency distribution curve of bare sandy land was unimodal with a peak near 2 Φ. The fine component content was lower than that of plantation soils, while the coarse component content was higher than that of near-mature and mature stands but showed no significant difference with mid-age stands.

2.3.2 Soil Particle Size Cumulative Frequency Distribution Curves As shown in [Figure 2: see original paper], the cumulative frequency distribution curves of 0–10 cm soils in plantations and bare sandy land could be divided into three components: suspended (fine fraction), saltation (medium fraction), and creep (coarse fraction), with size intervals of <3 Φ, 3–1 Φ, and >1 Φ, respectively. The saltation component size intervals for mature, near-mature, mid-age stands, and bare sandy land were 2.5–1.5 Φ, 2.8–1.2 Φ, 3.2–1.0 Φ, and 2.4–1.4 Φ, respectively. Suspended component content decreased in the order: mature stand > near-mature stand > mid-age stand > bare sandy land. The steeper the slope of the cumulative frequency distribution curve, the better the sorting of soil particles, indicating that saltation components had the best sorting among all components. The sorting of saltation components decreased in the order: bare sandy land > mid-age stand > near-mature stand > mature stand.

The cumulative frequency distribution curves of 10–20 cm soils could also be divided into suspended, saltation, and creep components. The saltation component size intervals for mature, near-mature, mid-age stands, and bare sandy land were 2.6–1.4 Φ, 2.9–1.1 Φ, 3.0–1.0 Φ, and 2.3–1.5 Φ, respectively. Suspended component content decreased in the order: mature stand > near-mature stand > mid-age stand > bare sandy land. Saltation component particles were well sorted, with sorting decreasing in the order: bare sandy land > mid-age stand > near-mature stand > mature stand. The sorting of saltation components in 0–10 cm bare sandy land soils was better than in 10–20 cm soils.

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3 Discussion

The high sand content and low clay and silt contents in aeolian soils of the Horqin Sandy Land are attributed to intense wind erosion in the region. Clay and silt particles, being smaller than sand, have lower threshold wind velocities and are more susceptible to near-surface wind erosion and transport. With increasing stand age, soil clay and silt contents showed an increasing trend while sand content decreased, because mature plantation ecosystems are more stable and can more effectively influence the occurrence and development of soil wind erosion. On one hand, forest canopy can effectively reduce wind speed and suppress wind erosion forces. On the other hand, surface litter not only increases surface roughness and raises the threshold wind velocity for soil particle entrainment, but also increases soil organic matter content, promotes soil aggregate formation, and enhances soil system stability, thereby effectively inhibiting wind erosion. The clay and silt contents of 0–10 cm bare sandy land soils were significantly lower than those of plantation soils at the same layer ($P<0.05$), while the 10–20 cm layer showed no significant difference with mid-age stands, because the surface layer of bare sandy land lacks vegetation cover, and strong wind erosion continuously removes fine particles.

The mean particle size of aeolian soils under *P. sylvestris* var. *mongolica* plantations was relatively coarse, but showed an increasing trend with stand age, indicating that soil particle composition was becoming finer. Plantation soils were mostly poorly sorted, and sorting became progressively worse with stand age because the more stable ecosystems of near-mature and mature stands had higher clay and silt contents, resulting in finer soil texture and wider particle size distribution ranges. Plantation soils showed extremely positive skewness and sharp, narrow kurtosis because fine and medium sand contents were very high while clay and silt contents were extremely low, causing highly asymmetric and relatively concentrated particle size distributions. With increasing stand age, soil kurtosis values decreased, indicating that the growth of *P. sylvestris* var. *mongolica* plantations promoted fine root turnover, increased soil nutrients, and improved soil structure, gradually optimizing the symmetry of particle size distribution. The clay and silt contents of 0–10 cm bare sandy land soils were significantly lower than those of plantation soils ($P<0.05$), and the 10–20 cm layer was significantly lower than that of near-mature and mature stands ($P<0.05$), indicating that soil wind erosion has more severe impacts on bare sandy land.

The fractal dimensions of 0–10 cm and 10–20 cm plantation soils ranged from 2.18–2.43 and 1.98–2.17, respectively. Soil volume fractal dimension directly reflects the content of fine particles (clay and silt). In areas with higher wind erosion intensity and longer erosion duration, soil becomes coarser as fine particles are removed, resulting in smaller fractal dimensions. The increasing trend of soil fractal dimension with stand age further demonstrates the increasing fine particle content. The mean particle size and standard deviation of bare sandy land soils were significantly lower than those of plantation soils ($P<0.05$), and fractal dimensions were significantly lower than those of near-mature and mature stands ($P<0.05$), confirming more severe wind erosion impacts.

The particle size frequency distribution curves of plantation soils were all bimodal. The fine component content of bare sandy land was lower than that of plantation soils, while the coarse component content was higher in the 0–10 cm layer and higher than that of near-mature and mature stands in the 10–20 cm layer, demonstrating the lag in soil particle refinement with depth. The canopy of *P. sylvestris* var. *mongolica* plantations can effectively intercept wind-sand movement, causing fine particles in wind-sand flow to settle upon encountering obstacles, combined with the direct effects of plant litter on surface soils. This results in faster structural refinement of surface soils than deeper soils, making the improvement of aeolian soils by *P. sylvestris* var. *mongolica* plantations a top-down vertical process with lagged refinement in deeper layers.

The aeolian soils in the study area showed clear divisions of suspended, saltation, and creep components. The suspended component content of plantation soils was higher than that of bare sandy land due to the wind-sand flow interception by *P. sylvestris* var. *mongolica* plantations. The saltation components of both plantation and bare sandy land soils were better sorted than the other two components, resulting from frequent collisions and high-speed rotational abrasion of saltation particles. However, the saltation component of bare sandy land soils showed the best sorting, indicating more intense wind-sand movement on bare sandy land surfaces.

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4 Conclusions

(1) The aeolian soils under *Pinus sylvestris* var. *mongolica* plantations in the Horqin Sandy Land were dominated by sand particles, followed by silt, with clay content being the lowest. With increasing stand age, soil clay and silt contents showed an increasing trend while sand content decreased. The sand content of 0-10 cm bare sandy land soils was significantly higher than that of plantation soils at the same layer ($P<0.05$), while the sand content of 10-20 cm bare sandy land soils was significantly higher than that of near-mature and mature stands ($P<0.05$).

(2) The aeolian soils under *P. sylvestris* var. *mongolica* plantations had relatively coarse texture. The 0-10 cm soils were poorly sorted with extremely positive skewness and sharp, narrow kurtosis, with fractal dimensions of 2.18-2.43. With increasing stand age, the 10-20 cm soils changed from moderately to poorly sorted, skewness changed from positive to extremely positive, kurtosis changed from sharp and narrow to moderate, and fractal dimensions were 1.98-2.17. Compared with plantation soils, bare sandy land had coarser texture, better sorting, and smaller fractal dimensions, though skewness values showed no significant differences ($P>0.05$).

(3) The particle size frequency distribution curves of aeolian soils under *P. sylvestris* var. *mongolica* plantations were all bimodal. With increasing stand age, the refinement of soil particles in the 0-10 cm layer lagged behind that in the 10-20 cm layer. The suspended component content of plantation soils was higher than that of bare sandy land, while the sorting of saltation components in bare sandy land was better than in plantation soils.

References

[1] MOHAMMADI M H, MESKINI-VISHIKAEE F. Predicting soil moisture characteristic curves from continuous particle-size distribution data[J]. Pedosphere, 2013, 23(1): 70–80.

[2] HU H C, TIAN F Q, HU H P. Soil particle size distribution and its relationship with soil water and salt under mulched drip irrigation in Xinjiang of China[J]. Science China Technology Sciences, 2011, 54(6): 1568–1574.

[3] ZHANG Junhua, LI Guodong, NAN Zhongren, et al. Research on soil particle size distribution and its relationship with soil organic carbon under the effects of tillage in Heihe oasis[J]. Geographical Research, 2012, 31(4): 608–618.

[4] XU G C, LI Z B, LI P. Fractal features of soil particle-size distribution and total soil nitrogen distribution in a typical watershed in the source area of the middle Dan River, China[J]. Catena, 2013, 101: 17–23.

[5] MÉ J C, MILTON C C C, DENILTON C G, et al. Fractal analysis in the description of soil particle-size distribution under different land-use patterns in Southern Amazonas State, Brazil[J]. African Journal of Agricultural Research, 2016, 11(23): 2032–2042.

[6] WANG D, FU B J, ZHAO W W. Multifractal characteristics of soil particle size distribution under different land-use types on the Loess Plateau, China[J]. Catena, 2008, 72(1): 29–36.

[7] GUI Dongwei, LEI Jiaqiang, ZENG Fanjiang, et al. Analysis on soil PSD and its affecting factors at different depths in oasis farmland: A case study in the Qira Oasis[J]. Arid Zone Research, 2011, 28(4): 622–629.

[8] DU Haiyan, ZHOU Zhibin, LIU Fengshan, et al. Variation of fractal dimension of soil particle size distribution in the aral reclamation area in oasis development[J]. Arid Zone Research, 2013, 30(4): 615–622.

[9] NADEU E, VENTE J D, MARTINEZ-MENA M, et al. Exploring particle-size distribution and organic carbon pools mobilized by different erosion processes at the catchment scale[J]. Journal of Soils and Sediments, 2011, 11(4): 667–678.

[10] 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.

[11] 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): 15379–15389.

[12] REN Yue, GAO Guanglei, DING Guodong, et al. Characteristics of organic carbon content of leaf-litter-soil system in *Pinus sylvestris* var. *mongolica*

plantations[J]. Journal of Beijing Forestry University, 2019, 30(3): 743-750.

[13] CHEN Fusheng, ZENG Dehui, SINGH Anand Narain, et al. Effects of soil moisture and soil depth on nitrogen mineralization process under Mongolian pine plantations in Zhanggutai sandy land, P R China[J]. Journal of Forestry Research, 2005, 16(2): 101-104.

[14] BAO Yongzhi, LIU Yanxi, DUAN Limin, et al. Photosynthetic traits of *Caragana microphylla* and *Populus* spp. and their responses to climate in the Horqin Sandy Land[J]. Arid Zone Research, 2019, 36(2): 420-429.

[15] LIU Xinping, HE Yuhui, WEI Shuilian, et al. Growth response of *Pinus sylvestris* var. *mongolica* to precipitation and air temperature in the Horqin Sandy Land[J]. Journal of Desert Research, 2016, 36(1): 57-63.

[16] MENG Xiangnan, ZHAO Yusen, ZHENG Lei, et al. Population structure and understory species diversity of different aged *Pinus sylvestris* var. *mongolica* plantations in Neijiang Sandy Land of northeast China[J]. Chinese Journal of Applied Ecology, 2012, 23(9): 2332-2338.

[17] ZHANG Jiyi, ZHAO Halin, CUI Jianheng, et al. Community structure, soil water dynamics and community stability of *Pinus sylvestris* var. *mongolica* plantation in Horqin Sandy Land[J]. Scientia Silvae Sinicae, 2005, 41(3): 1-6.

[18] CHEN Fusheng, ZENG Dehui, FAN Zhiping, et al. Available nitrogen in forest soil of *Pinus sylvestris* var. *mongolica* plantations in Zhanggutai sandy lands[J]. Journal of Beijing Forestry University, 2005, 27(3): 6-11.

[19] GAO Guanglei, DING Guodong, ZHAO Yuanyuan, et al. Effects of soil particle size classification system on calculating volume-based fractal dimension[J]. Journal of Basic Science and Engineering, 2014, 22(6): 1060-1068.

[20] YANG Jinling, LI Decheng, ZHANG Ganlin, et al. Comparison of mass and volume fractal dimensions of soil particle size distribution[J]. Acta Pedologica Sinica, 2008, 45(3): 413-419.

[21] DONG Zhi, WANG Liqin, YANG Wenbin, et al. Grain size characteristics of gobi sediment in Ejina Basin[J]. Science of Soil and Water Conservation, 2013, 11(1): 32-38.

[22] GAO G L, DING G D, ZHAO Y Y, et al. Characterization of soil particle size distribution with a fractal model in the desertified regions of northern China[J]. Acta Geophysica, 2016, 64(1): 1-14.

[23] JIA Xiaohong, LI Xinrong, LI Yuanshou. Fractal dimension of soil particle size distribution during the process of vegetation restoration in arid sand dune area[J]. Geographical Research, 2007, 26(3): 518-525.

[24] YU K Y, YAO X, DENG Y B, et al. Effects of stand age on soil respiration in *Pinus massoniana* plantations in the hilly red soil region of southern China[J]. Catena, 2019, 178(7): 313-321.

[25] HUPY J P. Influence of vegetation cover and crust type on wind-blown sediment in a semi-arid climate[J]. Journal of Arid Environments, 2004, 58(2): 167-179.

[26] DING Guodong. Aeolian physics[M]. Beijing: China Forestry Publishing House, 2010: 138-139.

[27] LIU Yundong, GAO Guanglei, DING Guodong, et al. Soil quality in wind erosion desertified regions: A review[J]. Journal of Nanjing Forestry University (Natural Sciences Edition), 2017, 41(5): 161-168.

[28] HU Yunfeng, LIU Jiyuan, ZHUANG Dafang, et al. Fractal dimension of soil particle size distribution under different land use/land coverage[J]. Acta Pedologica Sinica, 2005, 42(2): 336-339.

[29] HAN Guang, ZHANG Guifang, YANG Wenbin. A quantitative analysis for the provenance of dune sand in the Hulun Buir Sandy Land: Application of stepwise discriminant analysis to the granulometric data[J]. Acta Geographica Sinica, 2004, 59(2): 189-196.

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