Effects of Different Plantation Forests on Soil Aggregates in the Naiman Sandy Area: Postprint

Authors: Wu Ji

Date: 2023-01-17T00:00:00+00:00

Abstract

To analyze the composition and stability variation of soil aggregates under different artificial forests in the Naiman Sandy Area and to identify the optimal forest type for soil and water conservation as well as windbreak and sand fixation, soils beneath poplar, Chinese pine, and Mongolian pine pure plantations were investigated. Through dry and wet sieving methods, the composition of soil aggregates in the 0~20 cm, 20~40 cm, and 40~60 cm soil layers was examined, and soil conditions were evaluated using soil stability indicators. The results demonstrated: (1) The macroaggregate content in soils under the three artificial forests showed considerable divergence between dry and wet sieving outcomes, with the percentage of aggregate destruction (PAD) values further confirming that water-stable aggregates more representatively reflect the stability of soil aggregates under artificial forests in the Naiman Sandy Area. Moreover, under both sieving conditions, the content of >0.25 mm aggregates (R>0.25) in the 0~20 cm soil layer was significantly higher than that in the 40~60 cm layer. (2) Considering the performance of different artificial forests on soil aggregate R>0.25, mean weight diameter (MWD), geometric mean diameter (GMD), and fractal dimension (D) values, Mongolian pine exhibited the most favorable soil structure, the highest water stability, and relatively lower D values. (3) Soil aggregate diameter values and fractal dimension D values displayed significant linear relationships with the contents of various particle sizes, though the positive-negative critical points of correlation coefficients differed. The 2 mm and 0.25 mm particle size fractions constitute boundaries in the soil aggregation process and can serve as intuitive parameters for characterizing soil mechanical stability and water stability, respectively. Comprehensive experimental results indicate that planting Mongolian pine in the ecologically fragile Naiman Sandy Area can effectively ameliorate soil structure and is suitable for promotion in sand fixation efforts in this region.

Full Text

Arid Zone Research, ChinaXiv Partner Journal, Vol. 39 No. 6, Nov. 2022

Effects of Different Plantations on Soil Aggregates in the Nayman Sand Region

Wu Ji[1], Yang Guang[1], Han Xueying[1], Wen Yaqin[2], Yang Yiwen[3], Li Wenlong[4], Liu Yi[5]

[1]College of Desert Management, Inner Mongolia Agricultural University, Hohhot 010018, Inner Mongolia, China
[2]Hohhot Water Resources and River-Lake Protection Center, Hohhot 010020, Inner Mongolia, China
[3]Grassland Research Institute, Inner Mongolia Academy of Forestry Sciences, Hohhot 010020, Inner Mongolia, China
[4]Institute of Grassland Research, Chinese Academy of Agricultural Sciences, Hohhot 010010, Inner Mongolia, China
[5]Hulunbuir Water Conservancy Development Center, Hulunbuir 021100, Inner Mongolia, China

Abstract

To analyze the composition and stability variation of soil aggregates under different artificial forests in the Nayman sand region and identify the optimal forest type for soil and water conservation and wind-sand fixation, this study examined the soils beneath pure stands of poplar (*Populus*), oil pine (*Pinus tabuliformis*), and Mongolian pine (*Pinus sylvestris* var. *mongolica*) in the Nayman sand region. Using dry and wet sieving methods, we investigated the composition of soil aggregates in the 0–20 cm, 20–40 cm, and 40–60 cm soil layers, evaluating soil conditions through stability indicators. The results showed that: (1) The content of large aggregates showed significant differences between dry and wet sieving results, particularly in the 40–60 cm layer. The soil aggregate destruction rate (PAD) values further demonstrated that water-stable aggregates are more representative for reflecting aggregate stability in plantation forests in the Nayman sand region. Under both sieving conditions, the content of >0.25 mm aggregates (R>0.25) in the 0–20 cm layer was significantly higher than in the 40–60 cm layer. (2) Integrating the performance of different plantations on soil aggregate stability parameters (R>0.25, mean weight diameter (MWD), geometric mean diameter (GMD), and fractal dimension (D)) revealed that Mongolian pine soils exhibited the best structural properties with the highest water stability and relatively low D values. (3) The soil aggregate diameter indices and fractal dimension D showed clear linear relationships with the content of each particle size fraction, though the positive-negative critical points of correlation coefficients differed. The 2 mm and 0.25 mm particle size classes serve as important boundaries in the soil aggregation process and can be used as intuitive parameters to characterize soil mechanical stability and water stability, respectively. Overall, the experimental results indicate that planting Mongolian pine

can effectively improve soil structure in the ecologically fragile Nayman sand region and is suitable for promotion in sand fixation efforts.

Keywords: Nayman sand region; artificial forest; soil aggregate; aggregate stability

Introduction

Soil aggregates are the basic structural units of soil [?]. Their formation process is highly complex, primarily influenced by the quantity and properties of cementing substances. The quantity and quality of soil aggregates affect soil water retention, fertility, and aeration capacity. Good soil aggregates can enhance soil productivity, improve soil erosion resistance, and reduce the risk of soil and water loss [?]. Therefore, soil aggregate stability is typically used as a key indicator for evaluating soil quality [?]. Soil aggregate stability refers to the ability of aggregates to resist external forces or environmental changes and maintain their original form [?], mainly including mechanical stability and water stability. Currently, the main indicators for evaluating aggregate stability include the content of >0.25 mm aggregates (R>0.25) [?], mean weight diameter (MWD) [?], geometric mean diameter (GMD) [?], soil aggregate destruction rate (PAD) [?], and fractal dimension (D) [?].

In recent years, the impact of artificial vegetation restoration on soil aggregate stability has gradually become a research hotspot [?]. Poor sandy soil, through artificial vegetation planting and management measures, sees increased aboveground biomass, enhanced root fixation, and improved soil conditions [?]. The Horqin Sandy Land is the largest sandy land in China, with low soil water content, poor nutrients, and harsh ecological conditions [?]. Due to natural and human factors, land regulation capacity is low, and the balance of soil water-stable aggregates is disrupted, leading to severe deficiencies in soil water storage and moisture retention capacity.

Naiman Banner is the core area of the Horqin Sandy Land and one of the most typical regions for desertification occurrence and development in the Horqin Sandy Land, representative in both desertification speed and reversal speed [?]. The desertified land area accounts for more than half of the total land area, with varying degrees of desertified land distributed throughout the region [?]. Therefore, this paper takes the entire Naiman Banner as the desertification research area, referred to as the Nayman sand region. Land desertification and vegetation degradation have been the main factors restricting development in sandy areas. Strong wind erosion removes large amounts of fine particles from the soil, causing nutrient loss and stability destruction. Artificial vegetation construction is one of the most common and effective methods for controlling land desertification and soil erosion in sandy areas, not only reducing wind erosion and fixing mobile sand but also promoting the formation of large aggregates through organic matter cementation, thereby increasing soil stability.

Research shows that different tree species cause significant differences in soil properties due to root effects, litter properties, and understory vegetation conditions, with soil aggregate characteristics centrally reflecting these comprehensive effects [?]. Therefore, studying the composition and stability of soil aggregates under different plantations is important for revealing the relationship between soil and vegetation development during vegetation restoration in the Nayman sand region and understanding the formation and transformation patterns of stable aggregates. The poplar, oil pine, and Mongolian pine plantations selected in this study have been widely planted in the Nayman sand region since the 1950s as main windbreak and sand-fixation tree species due to their good cold and drought tolerance, achieving good results and becoming the most suitable afforestation tree species for sandy land [?].

1. Study Area Overview

The study area is located in Naiman Banner on the southern edge of the Horqin Sandy Land [Figure 1: see original paper]. The geographical location is 42°14 17.5 -43°32 14 N, 120°20 35 -121°36 00 E. The climate is a north temperate continental monsoon arid climate, with an average annual temperature of 6.0–6.5°C, average annual evaporation of 1935 mm, average annual precipitation of approximately 350 mm, and aridity index of 1.4–1.8. Northwest winds prevail in winter and spring, with strong wind erosion activities in spring, and the annual average wind speed can reach 3.5–4.3 $m \cdot s^{-1}$. The zonal soil is chestnut soil. Due to abundant and loose surface sandy deposits from geological historical periods, sandy land has formed under wind action. Affected by wind erosion, some areas have become fixed aeolian sandy soil and chestnut-type aeolian sandy soil, characterized by low nutrient content and poor water and fertilizer retention capacity. The sandy texture makes soils susceptible to wind erosion, with poor capacity for storing rainwater and nutrients. Soil organic matter content ranges from 5.6 to 9.86 $g \cdot kg^{-1}$.

2. Experimental Design

2.1 Experimental Design

After comprehensive investigation of the sandy area, understanding the historical background of afforestation periods, policies, and timber prices, and comparing multiple forest farms, three state-owned forest farms with large-scale artificial forest planting, high survival rates, and available for experimental research were selected as sampling points: Xinzhen Forest Farm, Qinglongshan Forest Farm, and Xinglongzhao Forest Farm. Pure stands of poplar, oil pine, and Mongolian pine that were relatively concentrated and mature in age were selected as research objects. The initial site conditions were all relatively consistent mobile sandy land. The common management specifications were tree spacing of 2–3 m and row spacing of 5–7 m, with inter-row land in a natural vegetation recovery state without cultivation, and the sandy land was completely fixed. The soil type is chestnut-type aeolian sandy soil. The experiment set up

3 treatments, with 3 replications for each treatment. Soil aggregates were analyzed through dry and wet sieving to compare and analyze soil stability under different vegetation restoration plantations, providing a basis for selecting the optimal sand-fixation plantation.

2.2 Soil Sampling

In May 2021, a 30 m × 30 m tree sample plot was established in each forest stand. Along the diagonal of each sample plot, 3 representative sampling points (i.e., replications) were selected. At each sampling point, soil profiles were excavated, and undisturbed soil samples were collected from the 0-20 cm, 20-40 cm, and 40-60 cm soil layers from bottom to top. The undisturbed soil was placed in plastic boxes, avoiding compression and inversion during collection and transport to prevent aggregate destruction. The soil samples were air-dried at room temperature in the laboratory, and plant roots and gravel were removed. After air-drying, large soil clods were broken along natural cracks and passed through a 10 mm sieve before aggregate determination.

2.3 Aggregate Processing

Dry sieving: According to the quartering principle, 100 g of air-dried soil sample was taken and placed on a set of sieves with apertures of 5 mm, 2 mm, 0.25 mm, and 0.053 mm from top to bottom. The sieve shaker operated at a fixed frequency for 5 minutes to obtain aggregates of >5 mm, 2-5 mm, 0.25-2 mm, 0.053-0.25 mm, and <0.053 mm size fractions, and their percentages were calculated.

Wet sieving: Fifty grams of air-dried soil sample was soaked in pure water for 5 minutes, then placed in a set of sieves with different apertures (2 mm, 0.25 mm, and 0.053 mm) from top to bottom. Using a soil aggregate analyzer with amplitude of 3 cm and frequency of 30 cycles$\cdot$min^{-1}, wet sieving was performed in a pure water environment for 5 minutes to obtain aggregates of >2 mm, 0.25-2 mm, 0.053-0.25 mm, and <0.053 mm size fractions. The obtained aggregates of different size fractions were dried at 65°C and weighed [**?**].

2.4 Data Processing and Statistical Analysis

The following indices were calculated: content of >0.25 mm aggregates (R>0.25), mean weight diameter (MWD), geometric mean diameter (GMD), fractal dimension (D), and soil aggregate destruction rate (PAD). The formulas are as follows [**?**]:

$$R_{>0.25} = \frac{M_{>0.25}}{M_T} \times 100\%$$

where M_T is the total weight of aggregates, and $M_{>0.25}$ is the weight of aggregates >0.25 mm.

$$MWD = \sum_{i=1}^{n} \omega_i x_i$$

$$GMD = \exp\left(\sum_{i=1}^{n} \omega_i \ln x_i\right)$$

$$D = 3 - \frac{\lg(\omega_i / x_i^3)}{\lg(x_i / x_{\max})}$$

$$PAD = \frac{R_{>0.25}(\text{dry}) - R_{>0.25}(\text{wet})}{R_{>0.25}(\text{dry})} \times 100\%$$

where n is the number of aggregate size classes, x_i is the mean diameter of the ith size class, ω_i is the mass percentage of the ith size class, and $x_{\max}$ is the maximum aggregate diameter.

Data processing used Excel 2016 to calculate means and standard deviations, expressed as mean ± SD. SPSS software was used for one-way ANOVA analysis of different data groups and trend testing. Pearson correlation analysis was performed, and analysis charts were created using Excel 2016.

3. Results and Analysis

3.1 Composition of Soil Aggregates

Mechanical stability aggregates: The changing trends of particle size content in different soil layers were consistent across the three plantations [Figure 2: see original paper]. For poplar plantations, aggregate content showed a decreasing then increasing trend with decreasing particle size, with the 0.25-0.053 mm fraction being the most abundant, significantly higher than other fractions. For oil pine plantations, aggregate content decreased with decreasing particle size, with the >2 mm fraction being significantly higher than other fractions. For Mongolian pine plantations, aggregate content first increased then decreased with decreasing particle size, with the smallest fraction being the least abundant and the 0.25-0.053 mm fraction being the most abundant. Overall, the >2 mm fraction showed the pattern: oil pine > Mongolian pine > poplar, while the 2-0.25 mm fraction showed: Mongolian pine > oil pine > poplar. This indicates that under dry sieving conditions, the formation and maintenance capacity of mechanically stable large aggregates followed the order: oil pine > Mongolian pine > poplar.

Water stability aggregates: Compared with dry sieving, the content of >2 mm aggregates changed significantly [Figure 3: see original paper]. The <0.053 mm fraction content decreased significantly with soil depth, while the >2 mm fraction content was highest in the 0-20 cm layer. Overall, the >2 mm fraction content showed: Mongolian pine > oil pine > poplar, while the 2–0.25 mm fraction showed: Mongolian pine > poplar > oil pine. The formation and maintenance capacity of water-stable large aggregates followed the order: Mongolian pine > oil pine > poplar.

3.2 Stability of Soil Aggregates

Mechanical stability: Analysis of mechanical stability indicators (Table 1) showed that R>0.25 values in the 0–20 cm layer of poplar plantations were significantly higher than other layers, while oil pine showed significantly higher values in the 20–40 cm layer. Mongolian pine showed no significant differences across layers, indicating it was not affected by soil depth. Regression analysis of fractal dimension (D) values showed no significant differences among forest types or soil layers. The R>0.25 index is an important parameter for quantitatively evaluating soil aggregate structure stability, with higher values indicating better erosion resistance. Under dry sieving, its trend across soil layers was consistent with MWD and GMD. R>0.25 values followed: oil pine > Mongolian pine > poplar. Oil pine showed the highest R>0.25 values, while no significant differences existed between Mongolian pine and poplar. PAD values were lowest in the 0–20 cm layer of Mongolian pine, showing significant differences from the other two species, indicating better soil structure stability .

Water stability: Analysis of water stability indicators (Table 2) showed that Mongolian pine had the highest R>0.25 values across all soil layers, followed by poplar and oil pine. In the 0–20 cm layer, Mongolian pine R>0.25 values were significantly higher than the other two species. PAD values, representing the proportion of aggregates broken after wet sieving, were lowest for Mongolian pine, indicating the most stable aggregate structure .

3.3 Correlations Between Aggregate Composition and Stability Parameters

Correlation analysis (Tables 3 and 4) showed that for mechanical stability aggregates, the correlation coefficients between diameter indices (MWD, GMD) and fractal dimension D ranged from -0.33 to -0.32 and -0.97 to -0.80, respectively. The <0.053 mm and 0.25–0.053 mm fractions showed negative correlations with diameter indices, while the 2–0.25 mm fraction showed positive correlations, all reaching significant levels except for the >2 mm fraction. For water-stable aggregates, correlation coefficients between diameter indices and D ranged from -0.94 to -0.80. The <0.053 mm fraction showed extremely significant negative correlations with diameter indices, while the 0.25–0.053 mm and 2–0.25 mm fractions showed significant positive correlations. The positive-negative correlation boundary was the 0.25 mm particle class [TABLE:3, TABLE:4].

These results indicate that for mechanical stability aggregates, the percentage content of >2 mm aggregates can exceed 60%, following the order: oil pine > Mongolian pine > poplar. After wet sieving, large >2 mm aggregates disintegrate upon contact with water, causing water-stable aggregates to concentrate in the 0.25–2 mm range, with water-stable large aggregates following: Mongolian pine > poplar > oil pine. Overall, poplar plantations showed the poorest aggregate stability. Poplar is a light-loving and moisture-loving species that cannot meet its water and fertilizer requirements in the arid sandy environment, resulting in poor understory soil quality. Under dry sieving, oil pine plantations contained the most large aggregates, but these large aggregates had low stability and high destruction rates when wet, indicating poor water and fertilizer retention.

4. Discussion

Good soil structure requires high-quality soil aggregates with appropriate particle size distribution, particularly the quantity and stability of water-stable aggregates [?]. This study used dry and wet sieving to analyze soil aggregates under different plantations in the Nayman sand region of the Horqin Sandy Land. The two sieving methods have different advantages and disadvantages, yielding different aggregate composition and stability measurements. Dry sieving reflects the overall condition of both non-water-stable and water-stable aggregates in undisturbed soil, representing the ability of aggregates to resist mechanical destruction. Wet sieving reflects the distribution of water-stable aggregates, as non-water-stable aggregates easily break into smaller fractions under water pressure. Therefore, water-stable aggregates are more representative for evaluating aggregate stability in plantation forests in the Horqin Sandy Land.

The results show that under dry sieving, oil pine plantations contained mostly >2 mm aggregates with the highest MWD values. However, these large aggregates had low stability, as evidenced by high destruction rates after wet sieving and high fractal dimension values ($D > 2.88$), indicating poor water and fertilizer retention and susceptibility to compaction when wet [?]. In contrast, Mongolian pine plantations showed the best soil structure stability, primarily due to their strong, well-developed root systems that improve and consolidate soil. The root exudates provide excellent cementation. While water is an important factor for large aggregate formation in arid regions, the natural conditions of low rainfall in the Nayman sand region do not affect Mongolian pine growth and survival, and the annual precipitation can meet the water and nutrient needs for subsequent growth [?].

Numerous studies indicate that larger aggregate diameter indices (MWD, GMD) and smaller fractal dimension D values represent better aggregate stability [?]. This study found that under dry sieving, oil pine had the highest $R>0.25$ values, but under wet sieving, Mongolian pine had the highest values, indicating that the large aggregates in oil pine plantations were not truly stable. The correlation results show that diameter indices and D values have clear linear relationships with aggregate content, with positive-negative boundaries at the 2 mm and 0.25 mm particle classes. These boundaries are crucial dividing lines in the soil aggregation process and can serve as intuitive parameters for characterizing mechanical and water stability. The 0.25 mm particle class is particularly sensitive in affecting fractal dimension and structural characteristics during soil aggregation [?].

Overall, the study demonstrates that for the ecologically fragile Nayman sand region, planting Mongolian pine can effectively improve soil structure and is recommended for sand fixation efforts.

5. Conclusions

(1) The content of large aggregates in the three plantation types differed significantly between dry and wet sieving results. PAD values further demonstrated that water-stable aggregates are more representative for reflecting aggregate stability in plantation forests in the Nayman sand region. Under both sieving conditions, the content of >0.25 mm aggregates (R>0.25) in the 0–20 cm layer was significantly higher than in the 40–60 cm layer.

(2) Integrating the performance of different plantations on soil aggregate stability parameters (R>0.25, MWD, GMD, D) showed that Mongolian pine soils had the best structural properties with the highest water stability and relatively low D values.

(3) Soil aggregate diameter indices and fractal dimension D showed clear linear relationships with the content of each particle size fraction, with positive-negative critical points differing. The 2 mm and 0.25 mm particle classes serve as important boundaries in the soil aggregation process and can be used as intuitive parameters to characterize soil mechanical stability and water stability, respectively.

Overall, the experimental results indicate that planting Mongolian pine in the ecologically fragile Nayman sand region can effectively improve soil structure and is suitable for promotion in sand fixation efforts in this area.

References

[?] He Shaolang, Huang Shangshu, Zhong Yijun, et al. Effect of tillage depth on the characteristics of soil water stable aggregates in slopeing farmland of red soil[J]. *Research of Soil and Water Conservation*, 2019, 26(6): 127-132.

[?] Cui Xinrui, Zhang Jialiang, Wang Yunqi, et al. Effect of different forests on the soil aggregate stability in Xiaolongshan forest region of Gansu Province[J]. *Journal of Soil and Water Conservation*, 2021, 35(4): 275-281.

[?] Luo Xiaohong, Wang Zifang, Lu Chang, et al. Effects of land use type on the content and stability of organic carbon in soil aggregates[J]. *Environmental Science*, 2019, 40(8): 3816-3824.

[?] Li Yue, Li Hang. The stability of soil aggregates: An overview[J]. *Journal of Anhui Agricultural Sciences*, 2014, 42(11): 3245-3247.

[?] Qi Yingchun, Wang Yiquan, Liu Jun, et al. Comparative study on composition of soil aggregates with different land use patterns and several kinds of soil aggregate stability index[J]. *Transactions of the Chinese Society of Agricultural Engineering*, 2011, 27(1): 340-347.

[?] Sun Tiancong, Li Shiqing, Shao Ming' an. Effects of long term fertilization on distribution of organic matters and nitrogen in cinnamon soil aggregates[J]. *Scientia Agricultura Sinica*, 2005, 46(9): 1841-1848.

[?] Li Xiaogang. The characteristics of soil aggregate in Jingtai electricirrigating area of Gansu[J]. *Acta Pedologica Sinica*, 2000, 53(2): 263-270.

[?] Yu Fazhan, Zhang Qian, Zhang Zhongqi, et al. Effects of different type of forest vegetation on the soil distribution of soil aggregate and its organic carbon in Lushan Mountain[J]. *Research of Soil and Water Conservation*, 2016, 23(6): 15-19.

[?] Gao Liang, Gao Yong, Wang Jing, et al. Impact of land cover change on soil carbon storage in the southern Horqin Sandy Land, Inner Mongolia[J]. *Journal of Desert Research*, 2016, 36(5): 1357-1364.

[?] Liu Licheng. Reflections on the development strategy of plantation forests in Tongliao City[J]. *Inner Mongolia Forestry Investigation and Design*, 2012, 35(2): 48-52.

[?] Zhao Yue, Li Aiguo, Yang Xingmin, et al. Afforestation technology and economic benefit analysis of sassafras pine commercial timber forest in Horqin Sandy Land[J]. *Inner Mongolia Forestry Investigation and Design*, 2015, 38(3): 59-61, 140.

[?] Sun Fengkui. The selection of tree species for the purpose of sand fixation afforestation: Discussion on the utilization of indigenous tree species[J]. *Inner Mongolia Forestry*, 1991, 36(2): 25-26.

[?] Cao Liyue. Effects of Cultivation Period on Soil Aggregate and Organic Carbon in Horqin Sandy Land[D]. Gansu: Northwestern Normal University, 2021.

[?] Lian Jie, Zhao Xueyong, Wang Shaokun, et al. Impacts of wind erosion on the distribution patterns of soil organic carbon and total nitrogen in Horqin Sandy Land, China[J]. *Chinese Journal of Ecology*, 2013, 32(3): 529-535.

[?] Mei Rong, Ulantuya. Research on land use change in County Region by remote sensing and GIS: A case study in Naiman in Inner Mongolia[J]. *Journal of Arid Land Resources and Environment*, 2004, 18(6): 81-84.

[?] Bao Huijuan. Study on the Sustainable Development in the Sand Desertification Region[D]. Changchun: Graduate School of Chinese Academy of Sciences (Northeast Institute of Geography and Agricultural Ecology), 2004.

[?] Cao Liyue, Li Yulin, Zhan Jin, et al. Effects of tillage on distribution and stability of soil aggregates in Horqin Sandy Land[J]. *Journal of Desert Research*, 2021, 41(2): 212-220.

[?] Fan Ruqin, Liang Aizhen, Yang Xueming, et al. Effects of tillage on soil aggregates in black soils in northeast China[J]. *Scientia Agricultura Sinica*, 2010, 43(18): 3767-3775.

[?] Duan Erjun, Yu Qing. Comparison of soil aggregate characteristics in different tree species forests in semi mid hilly region, central Loess Plateau[J]. *Journal of Anhui Agricultural Sciences*, 2010, 38(21): 11355-11358, 11383.

[?] Dong Lili, Zhang Fenli, Qin Ruijie. Study on effects of different vegetation types on soil aggregate water stability based on LB method[J]. *Agricultural Research in the Arid Areas*, 2010, 28(2): 191-196.

[?] Fang Wei. Effects of Vegetation Restoration on Soil Aggregate Stability in Karst Slope Land in Eastern Yunnan[D]. Kunming: Yunnan Normal University, 2021.

[?] Wang Kai, Na Enhang, Zhang Liang, et al. Soil aggregates stability and fractal features on dump slopes of opencast coal mine in Funxin, China[J]. *Arid Zone Research*, 2021, 38(2): 402-410.

[?] Li Songsong. Review on effect of drought on soil aggregates stability and its biological regulation mechanism[J]. *Grassland and Prataculture*, 2022, 32(3): 12-14, 33.

[?] Zhao Youpeng, Meng Miaojing, Zhang Jinchi, et al. Relationship between soil aggregate stability and different forms of Fe and Al oxides in different forest types[J]. *Bulletin of Soil and Water Conservation*, 2018, 38(4): 75-81, 86.

[?] Fang Wei, Fan Tao. Differences in soil aggregate stability of different species of *Pinus yunnannesis* in karst mountain area of eastern Yunnan Province[J]. *Bulletin of Soil and Water Conservation*, 2020, 40(3): 95-102, 132.

[?] Leffelaar P A. Water movement, oxygen supply and biological processes on the aggregate scale[J]. *Geoderma*, 1993, 57: 143-165.

[?] Liu Wenli, Wu Jinggui, Fu Minjie, et al. Effect of different cultivation years on composition and stability of soil aggregates fractions in orchards[J]. *Journal of Soil and Water Conservation*, 2014, 28(1): 129-135.

[?] Song Lining, Zhu Jiaojun, Li Mingcai, et al. Needles stable carbon isotope composition and traits of *Pinus sylvestris* var. *mongolica* in sparse wood grassland in south edge of Keerqin Sandy Land under the conditions of different precipitation[J]. *Chinese Journal of Applied Ecology*, 2012, 23(6): 1435-1440.

[?] Hu Xukai, Chen Yutian, Zhu Lixia, et al. Effect of dry wet alternation on characteristics of soil aggregates[J]. *Journal of Agricultural Science and Technology*, 2021, 23(2): 141-149.

[?] Zheng Zicheng, Li Tingxuan, Zhang Xizhou, et al. Study on the composition and stability of soil aggregates under different land use[J]. *Journal of Soil and*

Water Conservation, 2009, 23(5): 228-231, 236.

[?] Zhao Wenzhi, Liu Zhimin, Cheng Guodong. Fractal dimension of soil particle for sand desertification[J]. *Acta Pedologica Sinica*, 2002, 55(6): 877-881.

[?] Liu Yi, Li Shiqing, Li Shengxiu. Fractal dimensions of soil aggregates under different environments in the Loess Plateau[J]. *Journal of Northwest A & F University (Natural Science Edition)*, 2008, 73(1): 86-92, 100.

[?] Su Yongzhong, Wang Fang, Zhang Zhihui, et al. Soil properties and soil aggregate characteristics in marginal farmlands of oasis in middle Hexi Corridor region[J]. *Scientia Agricultura Sinica*, 2007, 48(4): 741-748.

[?] Six J, Elliott E T, Paustian K. Soil structure and soil organic matter: II. A normalized stability index and the effect of mineralogy[J]. *Soil Science Society of America Journal*, 2000, 64(3): 1042-1049.

[?] Liu Xinping, He Yuhui, Wei Shuilian, et al. Growth response of *Pinus sylvestris* var. *mongolica* to precipitation and air temperature in the Horqin Sand Land[J]. *Journal of Desert Research*, 2016, 36(1): 57-63.

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