Freezing - thawing cycles characteristics of soft rock and sand compound soil in Mu Us sandy land

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Abstract. Freeze-thaw is an important climatic phenomenon in middle and high latitudes and high altitudes. The effect of freeze-thaw on soil structure will be different from that without freeze-thaw. In order to study the structural stability of the compound soil of soft rock and sand in the Mu Us Sandy Land under the influence of seasonal freeze-thaw environment, this study adopted the method of combining indoor freeze-thaw simulation and field investigation to analyze the influence of freeze-thaw cycle on the structural stability of the compound soil. The results showed that after 10 cycles of freezing and thawing, the content of large aggregate structure (>1 mm) in 1:0, 1:1, 1:2, and 1:5 compound soils all decreased, and the decrease rate of 1:1 compound soil was the smallest. The content of small aggregate structure (<1 mm) increased, and the composition of each particle size was mostly concentrated between 0.5 and 0.25 mm. Therefore, the low freeze-thaw cycle can break large soft rock rocks, promote the full mixing of soft rock and sand, and improve the structure of the surface compound soil, instead of being dominant.

1. Introduction

Freeze-thaw is an important climatic phenomenon in mid-high latitudes and high-altitude areas. Under freezing and thawing conditions, soil physical and chemical properties change to varying degrees, and its impact on soil structure will also be different from that of unfreezing and thawing conditions. The effects of freeze-thaw alternation on soil structure and properties mainly depend on soil texture, initial soil water content, freeze-thaw temperature and cycle frequency, etc.[1-3], and also vary due to differences in organic matter content, chemical composition and root development in soil[4-5]. In order to systematically study the stability of soft rock and sand compound soil structure, this study took the different proportions of soft rock and sand compound soil after land consolidation in the Mu Us sandy land as the research object, using indoor simulation freeze-thaw combined with field investigations.
Methods, analyze the formation characteristics of the frozen layer of aeolian sandy soil and the compound soil, explore the impact of environmental changes—freezing and thawing on the structure of the compound soil in different proportions, and judge the adaptability potential of the compound soil in different proportions to extreme environments. It is of great significance to improve the soil structure in the Mu Us sandy land.

2. Materials and methods

2.1. Overview of the experimental area

The experimental samples were taken from Dajihan Village, Xiaojihan Township, Yuyang District, Yulin City, and Mu Us Sandy Land. Yuyang District (E109°28′58″-109°30′10″, N38°27′53″-38°28′23″) is located in the northern part of Shaanxi, with an altitude between 1206-1215m, and the southern edge of the Mu Us Desert and the middle reaches of Wuding River. Yuyang District is a typical mid-temperate semi-arid continental monsoon climate zone, with uneven distribution of precipitation in time and space, dry climate, long winters and short summers. The annual average frost-free period is 154 days, the annual average temperature is 6.0-8.5℃, and the average January temperature is -9.5-12℃. The temperature drops below 0℃ in November every year, and gradually returns to above 0℃ in March of the next year, the freezing period lasts for 4-5 months. The soil is frozen and thawed in the late autumn and early spring seasons. The average annual precipitation in northern Shaanxi is 413.9 mm, and 60.9% of the rainfall is concentrated in the three months from July to September, the same period of rain and heat. The annual average sunshine hours are 2879 h, the sunshine percentage is 65%, and the annual total radiation is 145.2 kcal /cm². Soft rock and sand are alternately distributed in the project area, the main soil type is eolian sand soil, and the organic matter content is low (0.03%).

2.2. Sample Collection

Collect local purple-red soft rock and aeolian sand in Xiaojihan Township, Yuyang District, Yulin City, Shaanxi, in the Mu Us Sandy Land. After the collected soft rock and aeolian sand are removed from the grass roots and other debris, they are naturally dried. Soft rock (P) and aeolian sand soil (S) are fully mixed by manual shovel mixing according to four different mass ratios (m (P): m (S) =1:0, 1:1, 1:2, 1:5) and then ready for use. According to long-term field test observations and related research results of the compound soil combination scheme of soft rock and sand [6-8], these four ratios are suitable for planting corn and potatoes in the study area. In the four mass ratios of soft rock and aeolian sandy soil, the particle size distribution of the compound soil is that coarse sand (>1 mm) has the most content, followed by fine sand (0.5~1 mm) and coarse silty (<0.5 mm) more content. Collect local irrigation water and perform moisture correction on the experimental samples. Table 1 shows the physical and chemical properties of the experimental samples.

| m(P): m(S) | Particle composition /% | Texture   | Organic matter (g kg⁻¹) |
|------------|--------------------------|-----------|------------------------|
| 1:0        | 24.52                    | 64.98     | 10.50                  | silt loam | 0.53 |
| 1:1        | 53.82                    | 38.12     | 8.06                   | loam     | 0.42 |
| 1:2        | 68.86                    | 26.01     | 5.13                   | sandy loam | 0.77 |
| 1:5        | 79.03                    | 17.35     | 3.62                   | sandy loam | 1.05 |

2.3. Experimental design

With four proportion distribution of compound soil as culture medium, each proportion distribution of compound soil sample preparation for five copies, 500g each, and respectively put them into 20 round aluminum boxes. In order to make the indoor freezing and thawing conditions closer to the natural state, that is, temperature fluctuations start from the surface soil as much as possible, and asbestos nets are placed outside the aluminum box to achieve a better insulation effect. Scale 1 soil samples are marked
as M0, M1, M2, M5, M10, scale 2 soil samples are marked as A0, A1, A2, A5, A10, scale 3 soil samples
are marked as S0, S1, S2, S5, S10, scale 4 Soil samples H0, H1, H2, H5, H10. M0, A0, S0 and H0 are
control samples, which are not subject to freeze-thaw treatment. In order to simulate the actual situation
of soil freezing and thawing, the samples were corrected for moisture according to the soil moisture
content during the spring snow-melting period. According to the investigation and analysis, the soil
moisture content of proportion 1, proportion 2, proportion 3, and proportion 4 in the spring snowmelt
period are 17.32%, 11.72%, 9.92% and 7.65% respectively. During the experiment, the water lost is
constantly replenished and the experimental soil samples are kept corresponding moisture conditions.
Completely freeze the soil at -10°C for 1 d, and then place it at room temperature for 1 d, this is a freeze-
thaw cycle. Five samples of each ratio were set to be repeated three times to determine the soil aggregate
structure content before freezing and thawing, one cycle, two cycles, five cycles, and ten cycles.

The soil aggregate structure is separated by a dry sieve method to separate 2 particle size group
aggregates >1mm and <0.5mm, and each group of particle size aggregates is weighed, and the content
of different particle size aggregates of the soil can be calculated.

3. Results and analysis

3.1. Analysis of formation characteristics of aeolian sandy soil and composite soil frozen layer
In the winter and spring of Mu Us Sandy Land, the soil is often in two physical processes: freezing and
thawing. In winter, when the external environment temperature decreases, the cultivated layer soil
mainly uses its own heat release to reduce the temperature of the soil surface. When the external
temperature drops to the freezing point of the soil, the soil moisture appears to freeze, and the frozen
soil gradually occurs. At the beginning of the spring next year, the temperature of the external
environment continued to rise, and the soil of the cultivated layer melted from the ground surface
downwards and the freezing depth upwards, and began to thaw [9]. Related research pointed out [10]
that when the external environment temperature is lower than the freezing point of the soil, but the soil
water content is lower than the freezing critical water content (1%), the soil will still not freeze. In
autumn and winter, the Mu Us sandy land is dry and less rainy. The local aeolian sandy soil is basically
in a state of weak water loss. The water content of the surface soil is low, and the freezing layer is
difficult to form. While aeolian sandy soil is at a distance below the ground surface, the soil moisture
content is higher and can reach the freezing critical moisture content, the soil begins to freeze, and the
freezing depth gradually increases as the temperature decreases and time passes. Therefore, in the winter
land fallow period of the Mu Us Sandy Land, due to the existence of the dry sand layer, the wind erosion
and desertification of the land are more serious.

Compared with aeolian sandy soil, the combined soil of soft rock and sand has better water retention.
Therefore, the surface water content of the compound soil is significantly higher than that of the sandy
soil. The surface of the compound soil is more likely to freeze and form a frozen layer, which makes the
Mu Us sandy land, in the winter land fallow period, it has the ability to prevent wind and sand. The
compound soil freezing front gradually develops from the surface soil to the lower layer, and the higher
the soil moisture content, the greater the freezing depth. The formation of the frozen layer enhances the
ability of the Mu Us Sandy Land to resist wind erosion, showing the remarkable wind-proof and sand-
fixing effect of the compound soil. On the one hand, the formation of a frozen layer on the surface of
the compound soil creates a protective shell on the local sandy soil, preventing the surface of the loose
sandy soil from directly contacting the outside airflow, effectively preventing local wind erosion hazards;
In addition, the freezing of soil water can produce soil cohesion, which makes frozen soil have tensile
strength, unconfined compressive strength and shear strength, and enhances soil anti-corrosion
properties [11].

3.2. Effects of freeze-thaw alternation on the structure of compound soil aggregates
The interaction between the frequency of freeze-thaw cycles and the mixing ratio of arsenic sandstone
and sand affects the formation of soil aggregates. As can be seen from Fig. 1, before freezing-
thawing, >1mm particle content in the compound soil gradually decreased with the increase of sand proportion, and the changes of large aggregate structure content (>1m) and clay content in the compound soil were basically the same. After freezing-thawing alternation, the content of compound soil large aggregates decreased first and then increased, and the overall content decreased compared with that before freezing-thawing. The higher the sand content, the lower the content of large aggregate structure. The rate of decrease of large aggregate structure of 1:1 compound soil is the smallest. After 10 cycles of freeze-thaw alternation, the average content of large aggregate structure (> 1mm) decreased by about 34%, and the average content of small aggregate structure (< 0.5mm) increased by about 50%. This is because freezing and thawing have a two-way effect on the stability of soil aggregates. Even if the freezing and thawing effect increases the stability of loose sand, the density increases and the void ratio decreases. It also reduces the stability of the compact soft rock, decreases the density, and increases the void ratio. The higher the clay content of the compound soil, the smaller the damage to the large aggregate structure after the freeze-thaw alternation. On the contrary, the lower the compound soil clay content, the greater the damage to the large aggregate structure after the freeze-thaw alternation; After the freeze-thaw cycle, the structure of smaller particles (<0.5mm) in the compound soil increased with the increase of the sand content, and the increase rate first decreased and then increased.

![Figure 1. The effects of mixing ratio and freeze-thaw cycle on the aggregate structure content of compound soil.](image)

4. Conclusion
The compound soil has the characteristics of water retention and water retention. The frozen cap layer is formed from the surface layer, which improves the mechanical stability of the soil surface and enhances the resistance to wind erosion. The alternation of freezing and thawing can reduce the stability of the compound soil aggregate structure, change the composition of the soil aggregate structure particles, disintegrate the large aggregate structure into small aggregate structure, and significantly reduce the proportion of the larger particle size aggregate structure (>1mm), improve the proportion of other small and medium-sized aggregate structures. The higher the clay content of the compound soil, the less the destructive effect of the freeze-thaw alternation on the stability of the aggregate structure. The 1:1 composite soil has the smallest reduction rate of the large aggregate structure after the freeze-thaw alternation. And the composition of each particle size is mostly concentrated between 0.5~0.25 mm.

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