Study on Friction Characteristics of Root-soil Interface of two Types of Soil

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Abstract. Through quick direct shearing test, friction characteristics of root-soil interface between Caragana root and two types of soil, sandy soil and silt soil, is studied. The results show that: shear properties and residual shear properties of root-soil interface between Caragana root and two types of soil are both in the line with the Mohr-coulomb theory. The root-soil interface had significant differences in friction coefficient, cohesion, and residual cohesion between sandy soil and silt soil under the same dry density and same saturation of soil. Silt soil root-soil interface friction coefficient, residual friction coefficient, cohesion and residual cohesion were 11.94%, 6.69%, 100.98%, 46.37% more than that of silt soil. Silt root-soil interface residual friction coefficient and residual cohesion were lower than friction coefficient and cohesion, sandy root-soil interface was opposite.

1. Introduction
In the central and western parts of Inner Mongolia, the soil and water loss is serious and has the characteristic of interaction of typical wind erosion and water erosion. Among the soil and water conservation measures, biological measures are the most effective measures, they can not only reduce soil and water loss, but also improve the environment and regulate the local microclimate, whose engineering measures don’t have these advantages. Plant roots constantly absorb water and nutrients from the soil to meet growth and development of plant. The root-soil composites which are similar to a reinforced concrete form by the interaction of soil and penetration of plant roots, which can improve the shear strength of soil. Since the deformation modulus of plant root system is generally higher than soil, when there is a tendency of slippage or generate the interface slippage on root-soil interface, the friction resistance of root-soil interface can transfer the force which is producing relative sliding to the tensile properties of root system, which reduce the deformation of soil and increase the ductility of soil. The deeper the root system roots, the greater the load of the root-soil interface, and the greater the friction resistance of the root-soil interface. At the same time, during the growth process of plant root system, the surrounding soil will be squeezed, the load on the root-soil interface and the contact area
between the root and soil continually increase, and the effect of the improvement of the root-soil stability by the friction resistance of root-soil interface is obvious. According to scholars' research on soil-fixation mechanism of roots, friction characteristics of root-soil interface directly affect the stability of soil. Therefore, in order to further study the soil-fixation mechanism of roots, it is imperative to study the friction resistance characteristics of root-soil interface.

With different soil types, the mechanical properties of the root-soil interface are different, and then the effect of the improvement on strength of the root-soil composites by root system is also different. At present, studies of friction resistance characteristics of root-soil interface mostly take plants as the main subject to study the difference of soil-fixation effect when the same soil grows with different plants. There are few researches regards soil type as the main subject, that is, there are few studies on the same plant grows in different types of soil and the difference of friction resistance characteristics of the contact surface between different soil and root. This paper applied soil mechanics principle and used the direct shear test to study the friction resistance characteristics of root-soil interface, which is among two types of soil -- sandy soil and silty soil of the central Inner Mongolia and Caragana microphylla Lam, which is typical soil and water conservation shrub. This paper can provide basic data for improving the mechanical mechanism of soil fixation by shrub root system, and theoretical support for the adaptation between plants and soil in the vegetation construction of soil and water conservation and the improvement of the soil and water conservation effect.

2. Materials and Methods

2.1. Collection of test soil samples

The sandy soil used in the test was taken from sample plot of the Caragana microphylla Lam. and the silty soil was taken from the current chart of TuZuo Banner in Hohhot. In the study area, a section without man-made damage was selected as the soil sample plot, which avoided farmland, roadside, ditch and other special topographic parts. The section with a depth of 80cm was dug at the selected sampling point, with one layer per 20cm. On the section wall, by using triangular arrangement, three pieces of undisturbed soil were taken with a cutting ring which diameter is 50.46mm, and height is 50mm. In order to expediently collect the soil, a thin layer of vaseline applied on the inner side of the cutting ring before collecting the soil. And then vertically press the cutting ring into the soil until there is soil rising from the end of the cutting ring. Finally, the soil samples of both ends of the cutting ring is levelled, and then it is taken back to the lab after packed in a plastic bag. If the cutting ring sway or tilt in the process of soil sampling, it will resample. After the undisturbed soil is taken, a certain amount of about 2kg of soil which is taken from each layer is brought back to the laboratory for soil tests.

The determination of soil physical properties is carried out with the requirements of Code of Soil Test: the particle size composition of soil was analyzed by sieve method, the specific gravity of soil particles determined by the pycnometer method. The basic physical properties of the two types of soil are shown in table 1:

| Table 1. Physical properties of sandy soil and silty soil |
|----------------------------------------------------------|
| coarse fraction content (d>0.075) | coarse fraction content (d£0.075) | specific gravity of soil particle | soil porosity | dry density of soil |
|----------------------------------|----------------------------------|---------------------------------|---------------|-------------------|
| Sandy soil                       | 69.51%                           | 30.49%                          | 25.85         | 0.41              | 1.57              |
| Silty soil                       | 24.53%                           | 75.47%                          | 26.52         | 0.36              | 1.74              |

2.2. The collection of sample roots of Caragana microphylla Lam.

The root system of Caragana microphylla Lam. which was a seedling artificially transplanted in 2012 was taken from the shangwan mining area of Ejin Horo Banner, Inner Mongolia. In the shangwan mining area, 20 Caragana microphylla Lam. trees were randomly selected as a sample from a forest land which is with a complete condition and the Caragana microphylla Lam. in a good growth. The
ground diameter, plant height and crown breadth were measured, and then calculate its mean and standard deviation. A number of plants that closest to the mean value were selected as standard plants from 20 samples for root collection.

Table 2. plant height, crown breadth, ground diameter and mean values of Caragana microphylla Lam.

| sample plant | plant height (cm) | crown breadth (cm) | ground diameter (mm) | sample plant | plant height (cm) | crown breadth (cm) | ground diameter (mm) |
|--------------|-------------------|--------------------|----------------------|--------------|-------------------|--------------------|----------------------|
| 1            | 56                | 157                | 7.94                 | 11           | 67                | 124                | 6.43                 |
| 2            | 66                | 156                | 9.02                 | 12           | 64                | 168                | 5.67                 |
| 3            | 72                | 117                | 8.54                 | 13           | 58                | 139                | 9.32                 |
| 4*           | 70                | 138                | 8.21                 | 14           | 76                | 150                | 8.85                 |
| 5            | 68                | 145                | 6.94                 | 15           | 81                | 147                | 8.38                 |
| 6            | 69                | 166                | 9.03                 | 16           | 62                | 172                | 7.91                 |
| 7*           | 74                | 152                | 8.05                 | 17*          | 68                | 161                | 8.21                 |
| 8            | 81                | 161                | 7.68                 | 18*          | 72                | 140                | 8.54                 |
| 9            | 57                | 144                | 8.12                 | 19           | 56                | 166                | 7.48                 |
| 10           | 62                | 128                | 8.43                 | 20           | 73                | 171                | 7.95                 |

mean value 67.05±8.14  150.1±15.85  8.04±0.89

Note: * represents the selected standard strain.

The Caragana microphylla Lam. root system was collected three times in July, August and October 2018. When excavating root system, the root system was excavated from 1.5m to 2m on one side of the standard plant, and the root system was slowly excavated from the outside to the inside by contraction method. The root system within the required diameter range was collected, and then the roots were put into black plastic bags, covered with the wet sand in the pit, brought back to the laboratory for treatment.

2.3. Preparation of direct shear friction resistance specimens
Preparation of direct shear friction resistance specimens: the Caragana microphylla Lam. taproot epidermis with diameter of 3 ~ 5mm was adhered to wood block of the same size as the lower shear box, the upper box is the soil sample and the lower box is the root sample. When the shear, the direction of root axis is the same as the direction of shear. The remoulded sample of the two types of soil had a same saturability of 40%, and the soil dry density was the mean of natural dry density of two types of soil, namely 1.66g/cm3.

2.4. Method of direct shear friction resistance test
According to the quick shear test method, ZJ type quadruple strain controlled direct shear apparatus was used to simulate soil displacement or dislocation under the position of pore water bearing pressure. According to the stipulation of the Code of Soil Test, when the displacement reaches about 4mm, it is deemed that shear fracture occurs. The shear strength at this time is regarded as the friction resistance strength of the root-soil interface, and the corresponding cohesive strength and friction coefficient are respectively defined as the interfacial cohesive strength and the interfacial friction coefficient. When the displacement reaches about 10mm, the shear stress tends to be stable. The shear strength with this displacement is regarded as the residual shear strength of the root-soil interface, and the corresponding cohesive strength and friction coefficient are respectively defined as the interfacial residual cohesive strength and the interfacial residual friction coefficient. The vertical loads select four levels which is 12.5kPa (burial depth 0.8m), 25kPa(burial depth 1.5m), 50kPa and 100kPa, and the shear rate was...
0.8mm/min, as the root system of Caragana microphylla Lam. is mainly distributed in the range of soil burial depth of 1.5m, and dense distribution layer of the root system was about 0.8m underground. Each study repeats 3 times.

2.5. Data processing methods
Excel2010 and SAS9.0 software are used for regression analysis and variance analysis of the experimental data.

3. Results and Analysis

3.1. Relationship between shearing strength and vertical load on soil-root interface of Caragana microphylla Lam. roots and two types of soil.
Figure 1 shows the relationship between shear strength and residual shear strength and vertical load on soil-root interface of Caragana microphylla Lam. roots and two types of soil. It can be seen that there was a positive linear correlation between shear strength and residual shear strength of soil-root interface of two types of soil and vertical load, and the linear multiple correlation coefficient reached 99.78%. The results show that the shear properties and residual shear properties of soil-root interface of Caragana microphylla Lam. roots and two types of soil obey the Mohr-Coulomb theory, and the cohesion strength, friction coefficient, residual cohesive strength and residual friction coefficient of soil-root interface can be calculated by using the Mohr-Coulomb theory.

3.2. The friction characteristics on soil-root interface of Caragana microphylla Lam. roots and two types of soil
The friction coefficient on soil-root interface of Caragana microphylla Lam. roots and silty soil was 0.572, and that of sandy soil was 0.511 which obtained by direct shear friction resistance test and Mohr-Coulomb theory. According to the results of variance analysis, at the significance level of 0.05, the friction coefficient on soil-root interface of Caragana microphylla Lam. roots and silty soil is significantly higher than that of sandy soil (As shown in figure 2), residual friction coefficient on soil-root interface of silty soil is higher than that of sandy soil, but it is non-significant. The results showed that the root system of Caragana microphylla Lam. in the silty soil showed stronger friction characteristics than that in the sandy soil when the root system of Caragana microphylla Lam. has a displacement or tendency of displacement with soil which affected by the external force. The residual friction coefficient on soil-root interface of Caragana microphylla Lam. roots and silty soil was 0.558, which decreased by 2.45% compared with the friction coefficient, it indicated that the friction effect
between the Caragana microphylla Lam. root and soil is weakened after the shear failure occurs in root-soil interface of silty soil and a displacement is produced. The residual friction coefficient on the root-soil interface of sandy soil was 0.523, which was 2.35% higher than the interfacial friction coefficient, it indicated that the friction effect on the root-soil interface of Caragana microphylla Lam. roots and sandy soil not weakened even if root-soil interface already had shear failure. To maintain this slip or displacement still requires overcoming strong friction.

Figure 2. The friction coefficient and residual friction coefficient on the root-soil interface of Caragana microphylla Lam. roots and two types of soil

Figure 3. The cohesion strength and the residual cohesion strength on the root-soil interface of Caragana microphylla Lam. roots and two types of soil

Note: the figure with the same lowercase indicates insignificant difference, while the figure with different lowercase indicates significant difference, and the significance level is 0.05.

3.3. Cohesion properties on root-soil interface between Caragana microphylla Lam. roots and two types of soil

Figure 3 show the cohesion strength and residual cohesive strength of root-soil interface of Caragana microphylla Lam. roots and silty soil were significantly higher than that of silty soil (α = 0.05). The results showed that the root system of Caragana microphylla Lam. in the silty soil showed stronger cohesion properties than that in the sandy soil when the root system of Caragana microphylla Lam. has a shear failure or displacement with soil contact surface which affected by the external force.

According to the results of variance analysis, at the significance level of 0.05, the values of cohesion strength and its residual cohesion strength of root-soil interface of two types of soil were significant difference. Among them, the cohesive strength value of the root-soil interface of sandy soil is 3.15kpa, and the residual cohesive strength value is 4.04kpa which compared with cohesive strength increased by 28.14%; While the cohesive strength value of the root-soil interface of silty soil is 6.34kpa, and the residual cohesion strength value is 5.91kpa which compared with cohesive strength decreased by 6.68%. The results showed that the cohesive effect between the root system of Caragana microphylla Lam. and sandy soil was significantly enhanced, while that between Caragana microphylla Lam. and silty soil decreased obviously after occurs shear failure and produces a displacement on the root-soil interface of Caragana microphylla Lam. and two types of soil. Therefore, the cohesion strength of root-soil interface of silty soil is 2.01 times higher than that of sandy soil, and the residual cohesion strength is 1.46 times higher than that of root-soil interface of silty soil.
4. Conclusion and Discussion
(1) Studies of many scholars have shown that the root internal structure and biomechanical characteristics are different with different plant species, and the friction resistance characteristics on the root-soil interface are also different. In this paper, the friction coefficient, cohesion strength and residual cohesive strength of the root-soil interface of two types of soil are significantly different, it indicating that the friction effect on the contact surface between root system and soil depends not only on the characteristic of the root system of the plant species, but also on characteristic of the soil.

(2) The cohesion strength and residual cohesion strength of the root-soil interface of silty soil are higher than that of sandy soil, this may be due to the high content of fine particle group in silty soil, and then a large number of effective soil particles accumulated on the root-soil interface to improve the cohesive strength, the adsorption between water and root surface was stronger, the cohesive strength and residual cohesive strength of the root-soil interface are relatively high. The friction coefficient and residual friction coefficient of the root-soil interface of silty soil are higher than that of sandy soil, this may be caused by that the silty soil is easier to form soil block and occur sliding due to the high bonding degree of silty soil, while there are a lot of residual rolling frictions of soil particles on the root - soil interface of the sandy soil as the cohesion function of soil is weak and content of coarse grain is high, thus the friction effect on the root-soil interface of Caragana microphylla Lam. and sandy soil is small.

(3) In the two types of soils, the residual friction coefficient and residual cohesion strength are smaller than friction coefficient and cohesion strength on the root-soil interface of silty soil, while the residual friction coefficient and residual cohesion strength are larger than friction coefficient and cohesion strength on the root-soil interface of sandy soil. The results showed that friction and cohesion effect on the root-soil interface of Caragana microphylla Lam. and silty soil are decreasing, while that of sandy soil are increasing after the shear failure occurs on root-soil interface and a displacement is produced, this may be caused by that the directional alignment of soil particles under condition of high displacement shear. Due to soil porosity of silty soil is smaller and content of fine-grained soil is higher, some clay particles and silt particles in the process of shear squeezed into larger soil particles or break away from original position, dilatancy occurs on the root-soil interface, as a result, the dry density of root-soil interface decreases and soil porosity increases, the effective contact area between soil particles and root surface on the root-soil interface decreases, the residual friction coefficient and residual cohesion strength are smaller than the friction coefficient and cohesion strength on the root-soil interface of silty soil. While sandy soil contains more coarse grain and soil porosity is large, coarse grain constantly cut into fine particles in the process of shear, it is easy for the crushed fine particles to be embedded into the interspace on the root-soil interface, and even occurs shear shrinkage. On the root-soil interface, porosity decreases and compactness increases, as a result, the residual friction coefficient and residual cohesive strength on root-soil interface are improved.

Acknowledgement
The funding: The National Key Research and Development Program of China (2016YFC0500507) ; Inner Mongolia Natural Science Fund (2017MS0378) ; National Natural Science Foun-dation of China (51579157，51779156) ; the Basic Scientific Research Foundation Special Project of the Institute of Water Resources and Hydropower Research (MK2018J03)

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