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The main influencing factors of soil mechanical characteristics of the gravity erosion environment in the dry-hot valley of Jinsha river

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Abstract: The dry-hot valley region counts as one of the most eco-sensitive zones in China, the issue of soil erosion is critical in regional ecological environment, soil mechanical property is one of the primary factors confining the occurrence of erosion, and it is attached crucial significance to in ascertaining the characteristics and principal factors of soil mechanics, and how to prevent and control soil erosion in arid red soil area of dry-hot valley. Through monitoring field location and directly shearing, the soil mechanical characteristics and the primary influencing factors of the mass erosion environment in the basin were ascertained. As the result indicates: (1) The soil moisture content, cohesion and internal friction angle are evidently correlated with each other abiding by power function, the relationship among soil cohesion, internal friction angle and volume moisture content goes as:

$$c = 80.107e^{-5.451\frac{\omega}{1.64+\omega}}, \varphi = 65.646e^{-3.325\frac{\omega}{1.64+\omega}};$$

(2) The soil being large in pore radius vary in number and distribution evidently with structure and destruction degree (*P*<0.05). Soil aggregation was also significantly different (P<0.05), with the increasing of structural failure rate, the shear strength of soil decreased, and the probability of damage was increased as the external load increaseing. (3) The disintegration of soil can be effectively decelerated, and anti-disintegration ability of soil can be enhanced by the root system. The impact exerted by plant root system on shear strength of soil decreased as soil got deeper, more than a certain depth can be ignored; the impact exerted by plant root system on small-scale gravitational erosion was particularly evident, whereas the impact exerted by large-scale mass erosion was comparatively small. The ability of plant roots to optimize soil resistance was primarily through the roots shorter than 2 mm, the effective fibrous roots in the soil of the *Leucaena* Benth and the *Dodonaea angustifolia* were comparatively small, and the root of the herbaceous plants was comparatively large.

Keywords: Dry-hot valley; Soil shear strength; Cohesion; Internal friction angle; Soil moisture content; Soil structure; Root system.

1 Introduction

Soil erosion refers to the process of soil and its parent material being destroyed, denuded, transported and deposited under the action of hydraulic, wind, freeze-thaw or gravity [1,2]. The soil erosion shall result in soil and water losses, posing a major threat to the environment and arousing the concern from the public currently [3-5]. The dry and hot valley region counts as one among the most eco-sensitive zones in China. It is characterized by high temperature, large evaporation, clear, dry and wet conditions, etc. Consequently, the surface vegetation grows scarcely in this area. Soil erosion is at the core of regional ecological environment construction [6,7]. At present, the research on soil erosion in dry-hot valley lays primary interest on soil erosion mechanism and soil erosion environment effect [7-9]. The research on soil erosion in dry-hot valley primarily fastens on gully erosion and mass erosion mechanism [2,7,8,10-13], and the gully erosion and mass erosion had been preliminarily analyzed; In terms of the environmental effects exerted by soil erosion, the focus is shifting from the impact exerted by soil quality and soil productivity to the soil

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mechanics mechanism of mass erosion [9,14,15]. The mechanical properties of the soil primarily restrict the gravitational erosion [16,17]. At present, the researches on soil mechanical properties with respect to soil erosion were basically conducted through anatomizing shear strength. The soil shear strength is perceived as a primary index of mechanical properties of soil, directly indicating the difficulty degree in soil deformation under the action of external force. Additionally, the magnitude of the value determines the degree of erosion [18].

When ascertaining the shear strength of soil, the soil shear strength determination method, distribution regularity and influence factors are primarily concentrated on. As the studies bespeak, the shear strength of undisturbed soil and disturbed remolded soil in different forest soils are evidently different by direct shear test [19]. The undisturbed soil in the Loess Plateau and the shear strength of compacted loess were ascertained by Jiang [20] from the macroscopic perspective, highlighting that the variation in level. As exhibited, soil cohesion progressively risen from north to south, the angle of internal friction from north to south, progressively reduced the trend of the longitudinal variation in the law and with the increasing of the soil depth, as the soil bulk density increasing, the shear strength was also optimized. The research about the impact factor were the loss of soil bulk density, and sand/clay/powder, moisture content, organic matter content, acidity and the soil of physical and chemical factors index, which had been reported in the leading factors of shear strength and soil in the process [18,21]. The degree of acid and alkaline affected the activity of soil microorganisms, the increasing of soil humic acid and the shear resistance of soil [22-24]. In addition, the effects exerted by plant roots on soil shear strength were also prominent, inclusive of: plant root biomass, root morphology, root length, root surface density etc. The mechanical properties of the root soil complex are optimized by plant root through soil anchoring, reinforcement and optimization of soil physical properties [25-29]. Although some achievements had been attained in the related studies, intensive research has been rarely conducted in the dry-hot valley areas, primarily in the climate areas inclusive of the Loess Plateau and subtropical woodlands [19,27,29,30].

The gravitational erosion of the gully slope is being severely gravitationally destructed in Yuanmou dry and hot valley, especially the collapse of the water and heat conditions, resulting in a large extent of soil erosion. The gully erosion and collapse are the primary source of sediment in the upper reaches of the Yangtze River [2,16,31]. Therefore, this study, in line with the characteristics of dry-hot valley mass erosion area erosion environment at Yuanmou in Jinsha River basin, ascertains the primary influence factor of soil mechanics and characteristics, to provide certain theoretical basis and technical support for the regional soil erosion control and sustainable development.

2 Materials and Methods

2.1 Overview of the study area

The study area locates in three small watersheds, viz. the Laocheng, Juna and Naneng, the typical mass erosional eruption area in the Jinshajiang dry-hot valley of Yunnan Province, and the Laocheng, Juna and Naneng three small watershed research area located in: N25°36′21”~ N25°37′53”, E101°52′12”~ E101°53′47”, with 1127~1397m in altitude (Figure 1), with the climate pertaining to subtropical dry monsoon climate, being mild in the region, and with less precipitation, evaporation, drought characteristics. The annual average temperature is 21.9 degrees celsius, extremely high temperature reached to 42 degrees celsius in May 1963 and extremely low temperature was recorded as 0.8°C in December 26, 1982). Light and heat resources were abundant; the average hours of sunshine was 2677, the sunshine rate was 60% or more; frost period was short, the average frost period was only for two days. The average annual precipitation is attained as 636.1mm, and the rainy season is concentrated in 6~10 months, taking up over 92.3% of the annual precipitation. The soil was dry red soil. The plantation was basically the savanna, herbs were dominant, whereas shrubs were few and sparse. The vegetation was dominated by *Leucaena* Benth, *Dodonaea angustifolia* and *Heteropogon cantortus*, etc.

The edge of the ditch on dry red soil gully slope system hereinafter (referred to as the channel or the valley), gully district between the edge of the ditch to ditch the sideline in dry-hot valley; The slope was steep with the maximum angle over 80 degrees; The ditch edge is basically the channel for flood and sediment transport, commonly referred to as ditch bed. Gully land is a region simultaneously encounters with hydraulic erosion and mass erosion (As exhibited in Table 1). The slope of the gully slope was steeper, and it was the place concentrated by mass erosion phenomenon inclusive of soil slide, slump and collapse: The smaller whereas frequent occurrence of mass erosion was also an important way to change the geomorphic of the tidal channel in the dry hot-valley of Yuanmou.

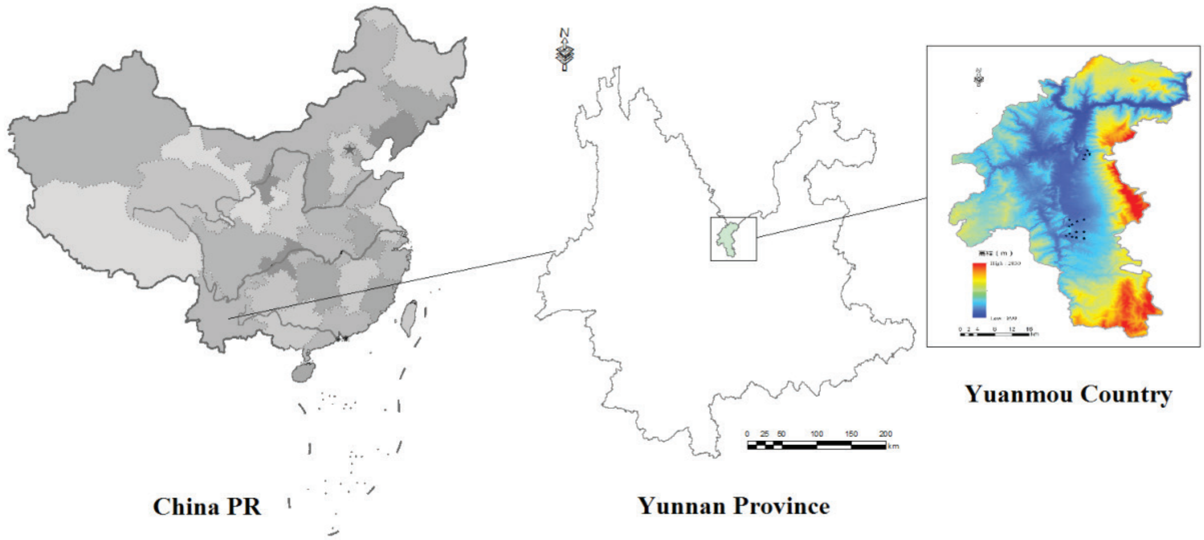

Figure 1: The location of the study area and the soil sampling point map(Yuanmou Country, Yunnan Province, China).

Table 1: The cross sectional survey area in the small watershed of the study area.

Geomorphic type		Geomorphic position	Soil types	Major erosion patterns	Geomorphic features	Land use types
Ditch ground	Shape of mountain ridge	Upper part	Dry red soil	Sheet erosion	0°~5°, topographic uniformity	Farmland, savanna
		Middle part		Rill	5°~20°, topographic uniformity	
		Lower part		Rill shallow furrow	20°~30°, uneven topography	
Gully land		Gully slope		Gully, collapse	30°~45°, fragmentation	Wasteland, grass

2.2 Research methods

2.2.1 Sample setting and soil collection

All the samples plots were set in the same altitude, slope and slope aspect with 20m× 20m areas, which were located in the Laocheng, Juna, Naneng three small watersheds at Yuanmou from February to March in 2016. The soil samples were collected directly from the middle part of the soil surface (0-20cm) through adopting 5 point method in each sample plot with a 100cm^3 ring knife. The collected soil samples were air dried, and thereupon dried after 2mm and 1mm and 0.25mm screening.

2.2.2 Soil determination

The soil density was ascertained through adopting the loop cutting method, and the soil moisture content was confirmed via drying method. The hydrometer method is adopted by the soil mechanical composition. German - mechanical sieving method is adopted by the soil agglomeration [32]. The characteristics of large pore structure in soil were attained through adopting Radulovich method [33]. The shear strength was ascertained in the light of the characteristics of dry red soil, the excess pore water pressure when the increasing shear stress can be dissipated quickly, so the use of straight fast shear method. The test was conducted on an electric strain controlled direct shear apparatus. The confining pressure was attained as 50kPa, 100kPa, 200kPa, 300kPa, the shear rate was attained as 0.5mm/s, and the soil sample moved at 5mm, which was confirmed to be the specimen shear failure. The soil moisture content of the sample was selected as 7%, 15%, 20% and 25% to ascertain the impact exerted by soil water content on shear strength index. Among them, the soil moisture content of 7% was equivalent to the soil in a dry state, 15%

Leucaena Benth root system | *Dodonaea angustifolia* root system | *Heteropogon cantortus* root system | *Enlariopsis binata* root system

Figure 2: The morphological distribution of roots of the primary plant.

of the soil in a semi-humid state, 20% of the soil in a wet, 25% of the soil in a saturated state. In the light of the field observation of small watersheds, the average mass water content of the slumped soil after the gravitational erosion was often at 19% -22%, Therefore, the water content of the soil was temporarily attained as 20%, bespeaking that the soil was prone to gravitational erosion.

Root soil composite disintegration determination was set in 8 selected field collection of intact 30cm ×12cm ×15cm earth (each plant type 2, with soil column without plant roots as control), to record the number of roots in less than 2 mm diameter of the six sections of each earthwork, to derive the number of roots in each earth, and thereupon to acquire the average value of the 6 root number in the soil earth. Prior to the test respectively to the 9 column watering, and the water content was almost the same when the water was infiltrated and maintained at approximately 10%. Three undisturbed soil samples were selected randomly in depth of 5 cm with a ring knife in each model, the immersion method was adopted to ascertain the time required for complete soil disintegration.

2.2.3 Samples of plant root

The selection of plants were basically the *Leucaena* Benth, *Dodonaea angustifolia*, *Heteropogon cantortus* and *Enlariopsis binate* having been extensively distributed in dry-hot valley of Yuanmou, and the selection of *Leucaena* Benth, tree height was small trees shorter than 2 m, which were perceived as the common plant species. The number of these plants in the horizontal root and vertical root were more, due to decrease the mutual influence between plants arising from growth to the maximum extent, the good growth condition sample was selected, where there were no other trees approximately showed this tree growth in the range of 30 cm. To decrease the growth difference of the selected plant species, the size of the tree and shrub at 0.5 ~ 2 cm in diameter were selected to evaluate the difference of soil fixation effect by different plant species. In the meantime, to prevent the damage to the root system when collecting samples, the artificial excavation method was adopted to ensure the whole structure of the root system. *Leucaena* Benth root acquisition excavation depth was 60cm, *Dodonaea angustifolia* and herb gathering excavation depth were 30~40cm, cut out part of the stem above the base part, brush the soil block that attached on the root, and loaded in plastic bags which were taken back to the laboratory for follow-up test. After measuring the shear strength of soil samples, the roots of plants in the excavated samples were weighed and the root contents of the samples were acquired. The morphological distribution of roots in several plants is exhibited in Figure 2, and the distribution of root diameter was exhibited in figure 3.

2.3 Data processing

2.3.1 The index of the shear strength of the soil [21]

If the viscosity is deliberated, the shear strength of the soil can be expressed as a Coulomb model is:

$$\tau_f = c + \sigma \tan\varphi \tag{1}$$

If the soil is sand, the viscosity is not considered, and the Coulomb model is:

$$\tau_f = \sigma \tan\varphi \tag{2}$$

Where τ_f is the soil shear strength; σ is the shear sliding surface normal stress; φ is the internal friction angle of soil; c is the cohesion of soil.

2.3.2 The index of the soil structure

Average weight diameter of the aggregate (MWD):

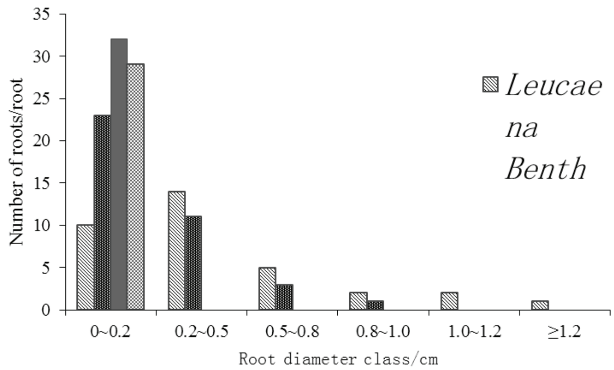

Figure 3: The distribution of root diameter.

$$MWD = \sum_{i=1}^{n} XiWi \quad (3)$$

$$\text{The rate of structural damage} = \frac{(> 0.25\text{mm Dry sieve aggregate} - > 0.25\text{mm Wet sieve aggregate}) \times 100\%}{> 0.25\text{mm Dry sieve aggregate}} \quad (4)$$

Where X_i is the average diameter of each particle size aggregate; W_i is the weight percentage of each particle size aggregate.

In this experiment, the effective root ratio, ρ was adopted to manifest the effective root density of the root soil complex, that is, the ratio of root mass that the root diameter of soil is less than or equal to 2 mm to the ratio of root mass in all soil types. That is:

$$\rho = \alpha / \beta \quad (5)$$

Where: ρ is the effective root ratio, dimensionless, adopted to illuminate the effective root density of the root complex; α is the total root amount in the earth, g; β is the effective root of the earth, g.(Table 2)

Ethical approval: The conducted research is not related to either human or animals use.

3 Results and discussion

3.1 Impact exerted by Moisture Content on Soil Shear Strength

Soil moisture content is perceived as the significant factor influencing the shear strength of the soil, when it was low, the molecular membrane approximately the soil particles was larger, while the number of water molecules was less, and the traction impact exerted by soil particles

Table 2: Basic properties of the tested soil.

Sampling locations	Soil types	Natural moisture content(%)	Wet density/ (g/cm3)	Total porosity/ (g/kg)	Capillary porosity(%)	Ventilation porosity(%)	Saturated water holding capacity(%)	Capillary water holding capacity(%)	Field water holding capacity(%)	Sand 2-0.2mm	Powder0.2-0.002mm	Clay < 0.002mm	Soil texture
Laocheng	Dry red soil	10.02±0.42	1.32±0.02	55.18±0.76	48.48±1.34	6.7±0.58	41.93±1.09	36.84±1.47	29.47±0.95	40.27±1.15	27.67 ±0.76	32.07 ±1.87	Loamy clay
Juna	Dry red soil	5.94±0.38	1.57±0.004	41.83±0.41	37.18±1.53	4.65±1.53	26.64±0.33	23.68±1.04	17.13±1.08	38.67±0.97	31.33±1.23	30.00±1.24	Loamy clay
Naneng	Dry red soil	9.08±1.18	1.53±0.07	46.63±0.68	38.75±2.77	7.88±1.45	30.44±1.87	25.25±0.63	19.59±1.65	45.33±1.45	29.33±1.09	25.33±0.87	Loamy clay
Average		8.35±1.99	1.47±0.13	47.88±6.07	41.47±5.69	6.41±1.2	33.01±7.19	28.59±6.49	22.06±5.92				

was lower; as the water molecules grew in number, the traction effect progressively was enhanced [32]. The direct shear test of undisturbed soil sample was conducted to test the shear strength of dry red soil under different water content. Results was indicated in Figure 4, the shear strength formula of undisturbed soil with different water content was exhibited in formula 6~9.

The formula of shear strength in undisturbed soil with different water content goes as:

$$\omega = 7\%: \ \tau_f = \sigma \tan 42.13° + 37.28 \tag{6}$$

$$\omega = 15\%: \ \tau_f = \sigma \tan 31.34° + 23.45 \tag{7}$$

$$\omega = 20\%: \ \tau_f = \sigma \tan 23.56° + 17.67 \tag{8}$$

$$\omega = 25\%: \ \tau_f = \sigma \tan 15.47° + 6.68 \tag{9}$$

Where ω is the water content of soil volume; τ_f is the shear strength of soil. σ is the normal stress of sliding surface.

As being evident from Figure 4, the soil moisture content exerted an evident impact on the shear strength of dry red soil, and the shear strength of soil increased progressively with the reduction of water content. Accordingly, as the soil moisture content rose, the internal friction angle φ and cohesive force c were evidently decreased. In the light of the theory of shear strength of unsaturated soil, the cohesion was encompassed by the original cohesion and curing cohesion, the original cohesion was comprised by the long-term pressure of the geological formation, comparatively stable; curing cohesion arose from the matrix suction and negative pore pressure. When the water content increased, the matrix suction reduced, and the curing cohesion slid accordingly. Therefore, the cohesion was basically keeping the pace with the increasing of water content, while the curing cohesion decreased and the total cohesion decreased accordingly. This was because when the soil moisture content increased to a certain extent, arising from the thickness of water film around soil particles increased, the bonding force of water film on soil particles decreased, moving between the soil particles more easily, and the friction force decreased, in the meantime, when the soil moisture content increased, the water shall exert a wedging effect on cementing material, resulting in easier between the soil particles sliding, the soil was more likely to damage. In addition, the soil moisture content easily led to the changement of soil microbial activity, which led to the changement of soil chemical properties, for example, the decreasing of organic matter and cation exchange capacity led to the decline of soil fertility, the soil consolidation and the reduction of soil shear strength[25-26,34-36].

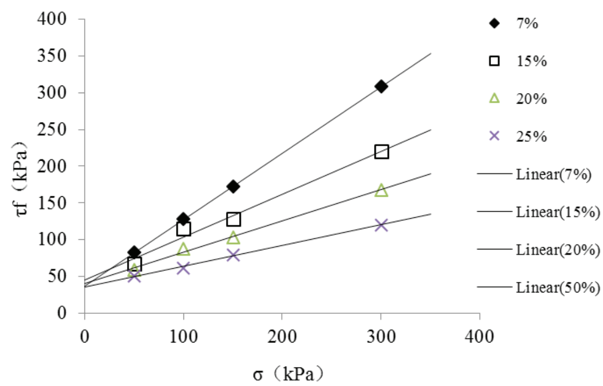

Figure 4: The shear strength line of different water content soil.

The internal friction angle was formed by the effective pressure, the frictional force was generated between the soil particles, and the internal friction angle was comprised by two parts, viz.

$$\varphi = \varphi_0 + \Delta\varphi \tag{10}$$

Where φ is the friction angle of the soil; φ_0 is the basic friction angle; Äφ is the difference between the actual internal friction angle and the basic internal friction angle. φ_0 is merely dependent on soil particle size and gradation, the value of a soil basically remains constant; Äφ changed with soil moisture changing, with the increasing of water content, combined with the water film between the soil particles thick, aqueous electrolyte concentration decreased, The change of redox potential in soil solution was obvious, and the chemical properties of soil changed [37], the distance between colloidal particles increasing, soil particle joint strength decreased, reducing the friction strength of soil particles, the internal friction angle decreased. Many researches indicated that the relationship between soil moisture content and cohesive force was power function [26, 38]. In the light of the experimental data, the change of cohesion at dry clay in different water content can be obtained (Figure 5).

Considering the dry density of undisturbed dry red soil was about 1.64g / m^3, we can establish the relationship between soil cohesion and volume moisture content:

$$c = 80.107 e^{-5.451 \frac{\omega}{1.64+\omega}} \tag{11}$$

Where c is the cohesive force; ω is the volume moisture content of soil.

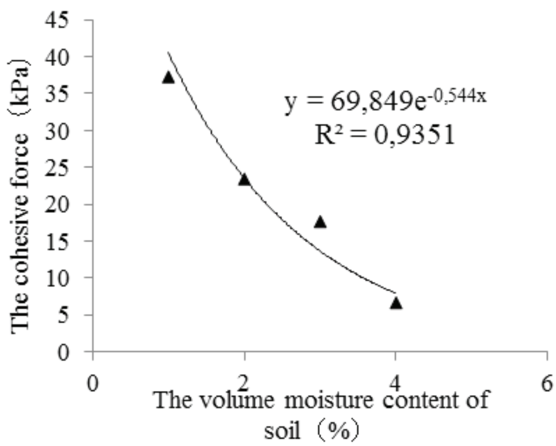

Figure 5: Relationship between cohesive force and moisture content of dry red soil.

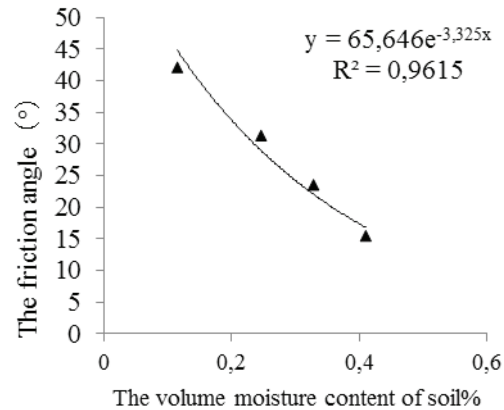

Figure 6: Relationship between friction angle and moisture content of dry red soil.

It can be seen that the cohesive force of dry red soil decreased evidently with the increasing of water content.

Similarly, the change in the friction angle of dry red soil under different water content conditions can be roughly obtained (Figure 6). The trend of linear fitting was exhibited. The quality of the soil water content into the volume of soil moisture content that can be:

$$\varphi = 65.646e^{-3.325\frac{\omega}{1.64+\omega}} \tag{12}$$

Where c is the friction angle; ω is the volume moisture content of soil.

It can be seen that the friction angle of dry red soil decreased evidently with the increasing of water content.

2.2 Effects exerted by soil structure on shear strength of soil

The unsaturated of dry red soil formed an overhead structure with coarse particles, as its primary framework during its development, the micro particles, humus colloids and soluble salts at the coarse particle contact point together to form a cement bond. The dry red soil has poor soil chemical properties, and soil fertility is generally low.The bond strength was the structural strength of unsaturated of dry red soil. When the soil's natural structure was destroyed, the bonding strength of the cemented material was progressively lost, and the shear strength of the soil decreased remarkably. Common property index of soil aggregate characteristics in damage of soil structure and soil macro pore index to evaluate the soil structural, the higher failure rate, large pore number, the higher the extent of damage, less small conversely, otherwise the smaller.

The occurrence of mass erosion was closely associated with the structural characteristics of the soil itself, through the study of Typical Valley gully slope, the shear strength of soil under the soil structure destruction in different parts of the mass erosion, destruction of soil structure and to ascertain the possible impact exerted by the mass erosion.

As being evident from Figure 7 and Table 3, due to the difference of land structure and its damage degree, the soil water penetration curve, the large pore radius number and distribution range of the Juna small watershed indicated evident difference ($P<0.05$). The steady flow rate of soil flow in Juna small watershed was higher than that of the other two watersheds, in which the large pores of Naneng small watershed were worse. The field observation also bespoke that the Naneng small watershed was compared by the other two basins, and the scale of mass erosion outstripped that of the other two watersheds in the same steep slope area.

As being evident from Tables 4 and 5, The dry-wet sieve aggregate content of dry red soil in the 3 watersheds was the highest in the Juna small watershed, and the lowest in the Naneng small watershed, bespeaking that the soil agglomeration in the Juna small watershed was better, while the soil agglomeration in the Naneng small watershed was comparatively poor. It is further illuminated from the structural damage rate that Juna (11.95%) < Laocheng (16.78%) < Naneng (27.45%). Soil cohesion was adopted to characterize the erosion resistance of soil.

From the analysis of Table 6, the same moisture content of different structural dry red soil, through the triaxial shear of the solidified drainage test bespoke, with the increasing of vertical pressure, compared to high damage rate of soil, the initial hole, altitude change, peak

Table 3: Range and quantity of large pore radius in watershed.

Watershed	Thickness of test soil sample (cm)	Radius range (mm)	Average radius (mm)	Median radius (mm)	Total density of large pore (ind·dm^{-2})
Juna	5	1.8 0.6	0.88	1.21	501.5
Laocheng	5	1.3 0.5	0.715	0.985	818.5
Naneng	5	1.4 0.9	1.075	1.34	235

Table 4: Characteristics of soil wet - dry agglomerate and its structural damage rate.

Watershed	Particle size fraction(%)						MWD	Rate of structural damage(%)
	10-5mm	5-2mm	2-1mm	1-0.5mm	0.5-0.25mm	0.25mm	(mm)	
Juna	67.41	10.485	3.23	6.145	4.945	7.78	5.45	11.95
Laocheng	61.42	18.8	3.885	3.685	1.53	10.68	5.195	16.78
Naneng	41.945	14.11	9.655	12.535	9.745	12.015	3.805	27.45

Table 5: Characteristics of soil wet sieve aggregates in watershed.

Watershed	Particle size fraction(%)						MWD(mm)
	10-5mm	5-2mm	2-1mm	1-0.5mm	0.5-0.25mm	0.25mm	
Juna	41.495	8.145	5.51	11.91	13.99	18.95	3.59
Laocheng	38.22	10.245	5.705	11.245	14.095	20.495	3.4
Naneng	32.685	10.82	8.58	15.24	11.86	20.825	3.06

shear stress, pore pressure peak of the good structure and low failure rate of soil were generally increased with the increasing of the vertical pressure, which indicated that with the increasing of the external load, the shear strength also decreased soil structure of poor soil, and the probability of destruction was bigger.

Soil moisture content had evident influence on the structure strength of dry red soil. In addition, the original density of soil on the soil shear strength also had a more evident impact, greater the density of soil, larger the soil particles between the surface friction and bite force and greater the internal friction angle. In the meantime, greater the density, smaller the soil gap, closer the contact, and greater the cohesion. There was a comparison by the shear strength of the original dry red soils with different structural and destructive rates in different study basins (Figure 8). The moisture content of the 3 areas was controlled by 15%, whereas the soil density was different. The dry density of undisturbed soil in the Naneng watershed was about 1.69g/cm^3, the dry density of the Juna small watershed was about 1.71g/cm^3, and the dry density of the Laocheng small watershed was about 1.64g/cm^3. We can see that the high rate shear

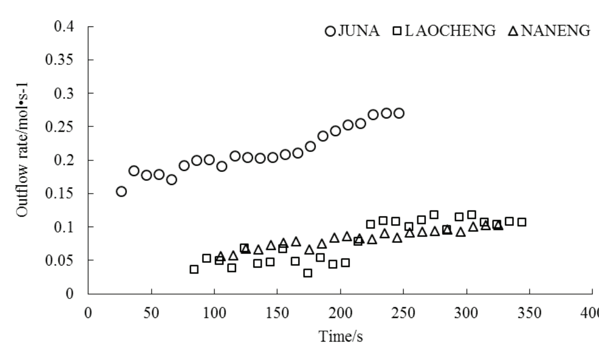

Figure 7: Water breakthrough curve of dry red soil with different structure in River Basin.

strength index was evidently higher than that of the other two comparatively good structure, low structural damage rate of dry red soil structure. The loss of shear strength after soil structure failure was primarily manifested in the decreasing of cohesion, and the change of internal friction angle was not great. In general, the poor structure of the dry red soil became loose, shear strength evidently reduced. Under the condition of precipitation, the gravity of the soil was increased and the shear strength index was

Table 6: Changes of soil mechanical properties in three axis tests of consolidated drainage in 3 watersheds.

Watershed	Vertical pressure(kPa)	initial hole pressrue(kPa)	Consolidated drainage	Elevation change(mm)	Shear peak(kPa)	Peak pore pressure(kPa)
Laocheng	50	3.2	0.91	0.025	341.7	2.6
	100	8.7	2	0.056	390.7	11.6
	200	14	2.65	0.074	576.2	16.5
	300	16.7	3.73	0.105	692.3	28.3
Juna	50	10.1	0.73	0.02	433	5.1
	100	14.3	1.3	0.036	458	6.5
	200	14.7	0.89	0.025	629.5	6.8
	300	22.5	1.38	0.038	835.8	12.4
Naneng	50	38.9	4.03	0.113	158.1	20.5
	100	91.2	6.13	0.174	198.4	46
	200	184.7	8.33	0.238	307.1	96.3
	300	289	9.73	0.28	472.5	157

decreased. It was easy to reduce the gravitational erosion inclusive of landslide and slump.

3.2 Impact exerted by plant root system on shear strength of soil

3.2.1 Shear strength of root soil complex

To analyze the value of root system on the shear strength of soil reinforcement, the experiment of plain soil without root system was added. The shear strength of the measured soil was 96.53 kPa. The maximum shear strength value of the root soil was subtracted from the shear strength value of the soil, that is, the shear strength of soil increased by root system. In the light of the graph of the shear strength of the straight shear test and the shear strength of the root soil complex, the trend line of shear strength were sketched to peak the shear strength. In all plants, *Leucaena* Benth root system had the largest increasing in shear strength, and its value was 40.67 kPa. Figure 9 is indicative of the relationship between the overall shear strength of the root system and the soil and the displacement of 16 plants in the four plants in this experiment, and the difference in the reinforcement impact exerted by the plant roots on the soil shear strength. The shear strength of the root-soil complex increased sharply at the beginning of the shear failure, and thereupon reached the maximum. The shear strength of the soil complex tended to be stable, and its shear strength value shall decreased progressively after being completely destroyed. The presence of cellulose and hemicellulose in plant roots determines the strength of the root system, and has an important influence on the anchorage of the root system.

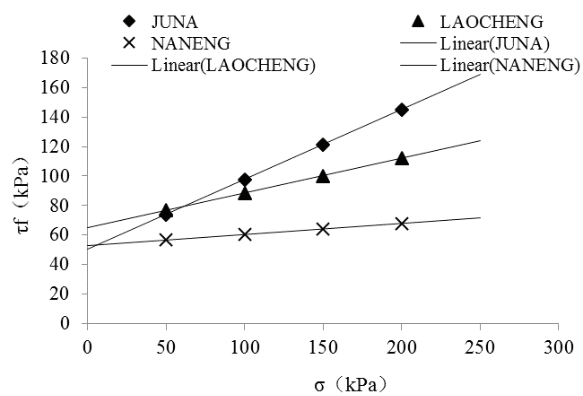

Figure 8: Comparison of shear strength of dry red soil with different structures.

When the root-soil complex was subjected to shear failure, the displacement of the different plant roots reaching the maximum shear strength was different, the area formed by the curve and the positive direction of the X axis were the energy consumed to destroy the root-soil complex. Take *Leucaena* Benth as an example, in the experiment, the curve about the shear strength of *Leucaena* Benth root system and the displacement of 6 *Leucaena* Benth plants collected were different, when the shear strength reached the maximum value, the shear displacement of 6 *Leucaena* Benth root-soil complex was different. It is accordingly denoted that although the same plant, due to root growth and distribution in the soil there was a certain difference, the anchoring impact exerted by the roots were different.

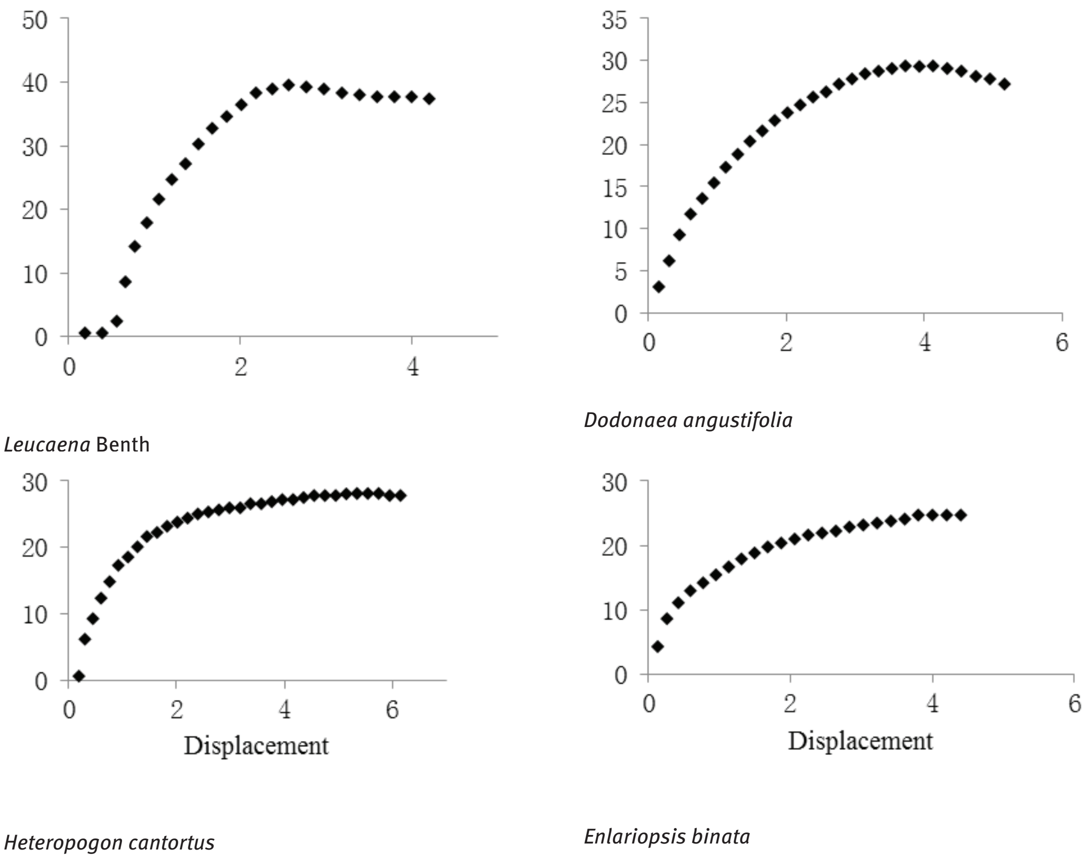

Figure 9: Relationship curve between shear strength increment and displacement.

3.2.2 Impact exerted by plant on disintegration resistance of soil

The effective root density data of 6 model bins were measured by experiment. The result was exhibited in Table 7. As being evident from Table 7, the ability of plant roots to optimize soil resistance was primarily through the roots of less than 2 mm root function, the effective root density of *Leucaena* Benth was the smallest, and after the disintegration experiment was conducted, the root of the whole product was removed by observing the distribution of the root system, the primary root was well developed, and the fibrous roots were comparatively few and had lateral growth, so the effective root in the soil was less; *Heteropogon cantortus* and *Enlariopsis binata* bark effective root volume were more, indicating that the herbaceous plants to be roots of fine root biomass, effective root was comparatively large. The presence of cellulose and other chemical components in root system has a direct effect on the effect of “reinforcement” [36].These ingredients accelerated the different chemical secretion substances by roots, such as: all kinds of organic acids and ketone acetate material etc, chemical complexation or reduction in the soil, which has the effects of improving the soil structure and enhancing the stability of soil strength [39,40].

The characteristics of soil structure for hydraulic infiltration and disintegration, or the degree of difficulty of dispersing and disintegration of soil can be manifested by the ability of soil disintegration. The impact exerted by root system on soil disintegration in dry-hot valley was ascertained, and the anti-disintegration ability of plain soil and different root ratio soil were compared, to ascertain the relevant law of influence. Under the same water condition, the soil structure of plain soil was prone to collapse, within 1hours had completely disintegrated, and the presence of roots can slow down the process, had a great influence on soil destruction time. It can be attained from the table that, the shortest disintegration time for root-soil complex was 3.3 hours and the longest time is 6 hours. It is accordingly indicated that the root system can effectively reduce the disintegration rate of soil and enhance its anti - disintegration ability. This was because of the fibrous roots in the soil interspersed and entangled, forming a similar soil “reinforced” effect, and promote

Table 7: The time of complete disintegration of soil under different effective root ratio conditions.

The number soil column	Plant types	Effective root ratio	The time of complete disintegration/min
1	nothing	0	43
2	*Leucaena* Benth	0.42±0.06	205
3	*Dodonaea angustifolia*	0.65±0.11	261
4	*Heteropogon cantortus*	0.76±0.17	362
5	*Enlariopsis binata*	0.72±0.09	324

the agglomeration of soil particles, thereby enhancing the ability of soil to resist dispersion and suspension.

Through the study on the results of field observations and Liu [41] of the basic agreement, the slope of herbaceous plants primarily distriwhereased in root surface soil within the depth of 40cm, the exponential distribution from the soil surface downwards, root density was close to zero beyond a certain depth in the soil (Figure 10). Therefore, the impact exerted by plant roots on the shear strength of soil was weakened with the increasing of soil depth, and the depth of the plant roots was negligible. The impact exerted by plant roots on small-scale mass erosion was evident, and the role of large-scale mass erosion impact was comparatively small.

Vegetation coverage index was usually used to estimate vegetation and reduce water erosion. There is a certain relationship between vegetation coverage and soil root number and its distribution. In the light of field sampling and dig section observation, arising from underlying surface texture was comparatively uniform in the study area and there is a correlation between vegetation coverage and biomass of roots. That is, the root content was more in the vegetation cover large ditch slope soil.

For loose soils with vegetation development were usually formed by water transport. In the light of the different plant root content by controlling the moisture content of 20% of the undisturbed soil samples using the direct shear test, as exhibited in Figure 11.

The shear strength of soil under different plant root content were:

Plant root system content was 3.23%;

$$\tau_f = \sigma \tan 24.24° + 19.87 \quad (13)$$

Plant root system content was 1.16%;

$$\tau_f = \sigma \tan 21.76° + 14.75 \quad (14)$$

Plant root system content was 0;

$$\tau_f = \sigma \tan 19.69° + 11.85 \quad (15)$$

In the formula, τ_f is the shear strength; σ is the normal stress.

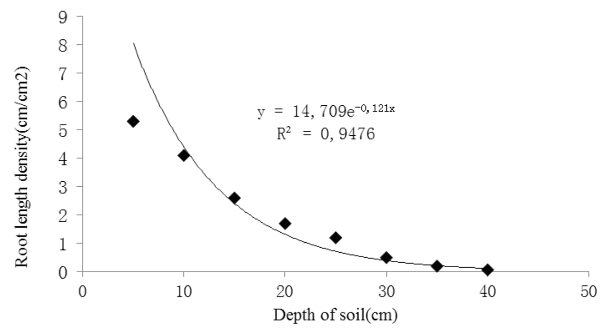

Figure 10: Density distribution of root system with soil depth.

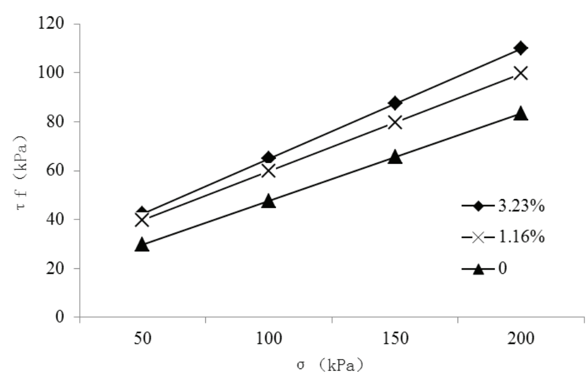

Figure 11: Trend of shear strength of dry red soil with different plant root contents.

Compared with the soil without plant roots, the shear strength of the soil with a certain plant root system increased evidently. Among them, the plant root system primarily increased the cohesion of the soil, whereas had little effect on the internal friction angle of the soil. It can basically ignore the impact exerted by the plant root system on the internal friction angle of the soil. In the light of the experiment, we can get the relationship between the root system content of soil and the cohesion of soil (Figure 11). The relationship between cohesion and content of soil root can be expressed as:

$$c = 248.19x + 11.858 \quad (16)$$

In the formula, X is the root content (mass percentage).

To sum up, it can be stated that the chemical composition of plant roots contributes to the strengthening soil. The plant root system can increase the shear strength of the soil by anchoring and reinforcing the soil, so as to optimize the erosion resistance of the soil. In addition, the vegetation increased the permeability of the slope soil and slope roughness, the amount of rainwater infiltration was increased, and the slope flow was reduced. In the light of the observation of the Laocheng small watershed, in the area where vegetation coverage was better, the precipitation below 25mm can hardly produce overland flow arising from the function of vegetation. Even for more than 25mm of precipitation, the resulting flow was much less than the area without vegetation cover. The overland flow often caused a great deal of mass erosion at the gully head and the steep slope, so the decreasing of overland flow had a evident deterrent effect on mass erosion. In addition, through field observation, it was attained that the tension distribution on the slope tended to produce dense cracks under the impact exerted by weathering, precipitation and temperature changed, and mass erosion often occurred in these places. Vegetation formed a soft humus layer on the slope, which can slow down the fluctuation of temperature and humidity of the lower soil mass, reduce the generation of soil cracks, and thereupon the frequency of mass erosion.

4 Conclusion

Through the study of the primary influencing factors of soil mechanical characteristics under the mass erosion environment in the dry-hot valley of Jinsha River, Yuanmou, the following conclusions were obtained in this study:

(1) Soil moisture content had a evident influence on the shear strength of dry red soil, and the shear strength of soil increased progressively with the decreasing of water content. Among them, with the increasing of soil moisture content, the internal friction angle φ and cohesive force c are evidently decreased. The relationship between soil moisture content, cohesion and internal friction angle is an evident power function relationship, in which the relationship between soil cohesion, internal friction angle and the water content is given respectively as below:

$$c = 80.107e^{-5.451\frac{\omega}{1.64+\omega}}, \quad \varphi = 65.646e^{-3.325\frac{\omega}{1.64+\omega}}.$$

(2) There were evident differences between different structure, damage radius of soil large pores quantity and distribution range ($P<0.05$), soil aggregation also increased evidently, the structure of the body structure difference damage rate was larger, the structure damage rate increased, the shear strength decreased with the increasing of soil, and the external load increased probability damage. The dry red soil with poor structure became loose and the shear strength decreased remarkably. Under precipitation conditions, soil moisture content increased, soil gravity increased, shear strength decreased, and mass erosion was prone to occur.

(3)Arising from the “reinforced” impact exerted by plant root system, the agglomeration of soil particles was promoted, and the anti-dispersion and suspension ability of soil were enhanced. The root system can effectively reduce the disintegration rate of soil and enhance its anti-disintegration ability. The impact exerted by plant roots on the shear strength of soil was weakened with the increasing of soil depth, and the depth of the plant roots was negligible. The impact exerted by plant roots on small-scale mass erosion was evident, and for large-scale mass erosion. The impact exerted by the role was comparatively small. The same kind of plant due to root growth and distribution in the soil there was a certain difference, the root of the anchoring effect was different. The ability of plant roots to optimize soil resistance was primarily through the roots of less than 2 mm root function, there were less effective roots in trees and shrubs of *Leucaena* Benth and *Dodonaea angustifolia*; the herbaceous plants to be roots of fine root biomass, effective root was comparatively large.

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References

[1] Zhang H.J., Cheng J.H., Principle of soil erosion, 3rd ed., China Forestry Publishing House, 2014.
[2] Liu G.C., Deng W., Wen A.B., Sha Y.C., Ji Z.H., Xiong D.H., et al., A review on the essentiality and subject orientation of establishing gully erosion and collapse experimental station in Jinsha River Valley, Journal of Mountain Science, 2010, 28(3), 333-340.
[3] Zhang X.M., Zhao W.W., Liu Y.X., Application of remote sensing technology in research of soil erosion: A review, Bulletin of soil and water conservation, 2017, 37(2), 228-238.
[4] Hu Y.F., Tian G.H., Audrey L.M., He R.Z., Risk assessment of soil erosion by application of remote sensing and GIS in Yanshan Reservoir catchment, China., Natural Hazards, 2015, 79(1), 277-289.
[5] Krishna Bahadur K.C., Mapping soil erosion susceptibility using remote sensing and GIS, A case of the Upper Nam Wa Watershed, Nan Province, Thailand., Environmental Geology, 2009, 57(3), 695-705.
[6] Jiang J., Zhang C.B., Zhang X.B., Yang Q.H., Review on the effects of soil moisture on mechanical properties of soil reinforcement by plant roots., Chinese Agricultural Science Bulletin, 2015, 31(11), 253-261.
[7] Xiong D.H., Yang D., Zhai J., Li J.J., Su Z.A., Dong Y.F., et al., Preliminary study on hydrodynamic characteristics of overland flow and sediment yields of gully heads in Yuanmou hot-dry valley, Journal of Soil and Water Conservation, 2012, 26(6), 52-62.
[8] Zhou H.Y., Li H.X., Fan J.R., Yang Z., Sensitivity evaluation of soil erosion in Yuanmou dry hot valley, Soil and Water Conservation in China, 2009, 4, 39-41.
[9] Zhen Z.C., Zhan X.Z., Li T.X., Jin W., Lin C.W., Change characteristics and influencing factors of soil shear strength during maize growing period, Transactions of the Chinese Society for Agricultural Machinery, 2014, 45(5), 125-130, 172.
[10] Chai Z.X., Preliminary analysis of soil and water loss in Panxi Area, Geography of Sichuan, 1985, 7, 75-78.
[11] Yang Z.Y., Su J.R., Luo D., Li Z.H., Chen X.M., Progress and perspectives on vegetation restoration in the dry-hot valley, Forest Research, 2007, 20(4), 563-568.
[12] Yang D., Xiong D.H., Zhai J., Li J.J., Su Z.A., Dong Y.F., Morphological characteristics and causes of gullies in Yuanmou Dry-hot valley region, Science of Soil and Water Conservation, 2012, 10(1), 38-45.
[13] Giadrossich F., Schwarz M., Cohen D., Mechanical interactions between neighboring roots during pullout rests, Plant Soil, 2013, 367, 391-406.
[14] Pu Y.L., Xie D.T., Ni J.P., Wei C.F., Lin C.W., Effects of hedgerow patterns on soil shear strength and anti-scouribility on slope farmland in purple soil area, Scientia Agricultura Sinica, 2014, 47(5), 934-945.
[15] Stokes A., Norris J.E., van Beek L.P.H., How vegetation reinforces soil on slopes. In: Slope stability and erosion control: Eco technological solutions, Norris J.E. (Eds.), Springer Netherlands, 2008.
[16] Chen A.Q., Zhang D., Xiong D.H., Liu G.C., Effects of mechanical properties of surface soil on soil anti-scour ability in Yuanmou dry-hot valley, Transactions of the Chinese Society of Agricultural Engineering, 2012, 28(5), 108-113.
[17] Zhang X.M., Wang Y.J., Xia Y.P., Wu Y., Grey relational analysis and evaluation anti shear strength of the undisturbed soil vegetation's in Jinyun Mountain in Chongqing city, Research of Soil and Water Conservation, 2007, 14(2), 145-147, 151.
[18] Zhang A.G., Li R., Yang Q.K., Study on soil anti-shearing intensity of water erosion in China, Bulletin of Soil and Water Conservation, 2001, 21(3), 5-9.
[19] Zhang X.M., Ding S.W., Cai C.F., Elfects of drying and wetting on nonlinear decay of soil shear strength in slope disintegration erosion area, Transactions of the CSAE, 2012, 28(5), 241-245.
[20] Jiang D.S., Soil and water loss and control pattern in the Loess Plateau, China Water Conservancy and Hydropower Press, 1997.
[21] Chen H.X., Li F.H., Hao S.L., Zhang X.P., Effects of soil water content and soil sodality on soil shearing strength, Transactions of the CSAE, 2007, 23(2), 21-25.
[22] Xu J.M., Jiang X., Liu F., Dou S., Zhou L.X., Xu R.K., et al.. Soil chemistry science in China and its perspective, Acta Pedologica Sinica, 2008, 45(5), 817-829.
[23] Yao L.D., Cheng G.H., Wang L.X., Chen H.Y. Lou L.P., Effects of biochar application to microorganisms in soil, .Environmental Chemistry, 2015, 34(4), 697-704.
[24] Han L.F., Sun K., Kang M.J., Wu F.C., Xing B.S., Influence of functional groups and pore characteristics of organic matter on the sorption of hydrophobic organic pollutants, Environmental Chemistry, 2014, 33(11), 1811-1820.
[25] Zhu J.Q., Wang Y.Q., Wang Y.J., Zhang H.L., Li Y.P., Liu Y., Analysis of root system enhancing shear strength based on experiment and model, Rock and Soil Mechanics, 2014, 35(2), 449-457.
[26] Zhang C.B., Chen L.H., Jiang J., Vertical root distribution cohesion of typical trees on the Loess Plateau, China, Journal of Arid Land, 2014, 6(5), 601-611.
[27] Li J.X., He B.H., Chen Y., Huang R., Tao J., Tian T.Q., Root distribution features of typical herb plants for slope protection and their effects on soil shear strength, Transactions of the CSAE, 2013, 29(10), 144-152.
[28] Comino E., Marengo P., Rolli V., Root reinforcement effect of different grass species: a comparison between experimental and models results, Soil&Tillage Research, 2010, 110(1), 60-68.
[29] Zhang C.B., Chen L.H., Liu X.P., Triaxial compression test of loess root composites to evaluate mechanical effect of roots on reinforcing soil, Journal of Soil and Water Conservation, 2009, 23(2), 57-60.
[30] Hu P., Song X.G., Wu D.G., Experimental research on reinforcement mechanism of express way slope protection with greensward, Rock and Soil Mechanic, 2008, 29(2), 442-444.
[31] Tiwari R.C., Bhandary N.P., YaRabe R., New numerical scheme finite-ement method for evaluating the root-reinforcement effect on soil slope stability, Geotechnique, 2013, 63(2), 129-139.
[32] Shao M.G., Wang Q.J., Huang M.B., Soil physics, Higher Education Press, 2006.
[33] Radulovich R., Solorzano E., Sollins P., Soil macrospore size distribution from water breakthrough curves, Soil Science Society of America Journal, 1989, 53, 556-559.

[34] Jiang J., Yang Z., Ren Q., Sun G.X., Distribution of soil humic acids redox potentials and corresponding electron transfer amounts, Environmental Chemistry, 2015, 34(2), 219-224.
[35] Jiang J., Kappler A., Kinetics of microbial and chemical reduction of humic substances: implications for electron shuttling, Environmental Science &'Technology, 2008, 42(10), 3563-3569.
[36] Wang M.M., Zhou Q.X., Environmental effects and their mechanisms of biochar applied to soils, Environmental Chemistry, 2013, 32(5), 768-780.
[37] Huang T.L., Zhou R.Y., Xia C., Xu J.L., Effects of oxidation-reduction potential and microorganism on the release of phosphorus from sediments, Environmental Chemistry, 2014, 33(6), 930-936.
[38] Dang J.Q., Li J., Effect of water content on the strength of unsaturated loess, Acta Univ. Agric., Boreali-occidentalis., 1996, 24(1), 57-60.
[39] Wu L.K., Lin X.M., Lin W.X., Advances and perspective in research on plant-soil-microbe interactions mediated by root exudates, Chinese Journal of Plant Ecology, 2014, 38(3), 298-310.
[40] Liu G.N. Liu X.H., A review on the impact of soil colloids on heavy metal transport, Environmental Chemistry, 2013, 32(7), 1308-1317.
[41] Liu X.P., Chen L.H., Song W.F., Study on the shear strength of forest root-loses composite, Journal of Beijing Forestry University, 2006, 28(5), 67-72.