

Temporal Variation of *Leucaena Leucocephala* Seedlings in Soil Conservation and Slope Protection

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Abstract—*Leucaena leucocephala* has been widely used in the ecological restoration and protection of engineering slopes in southwest hydropower projects. It is one of the key issues in slope ecological restoration that how to determine seeding age for transplantation. The erosion resistance, scour resistance, shear strength of soil-fibrous root systems and tensile strength of root systems were tested to evaluate the effects of *L. leucocephala* seedlings on soil conservation and slope protection and its temporal variation within 12 months after being planted. The results showed that the average height and root biomass of *L. leucocephala* seedlings reached 208.1cm and 46.6g. The erosion resistance, scour resistance and shear strength of its soil-root system were increased by 288.4 %, 198.6% and 226.4% contrast with that of the control, respectively. The effects of its soil-root system on soil conservation and slope stabilization increased with the prolonging of plant growth time constantly, and during six month to seven, it grow the fastest. Correlation analysis indicated that the performance of soil root systems had significant positive correlation with root system biomass. It suggested that the differences in root system biomass caused the changes of root systems in soil conservation and slope stabilization. *L. leucocephala* seedlings over seven month old had very obvious effects on soil conservation and slope stabilization with good ability to establish, can be used practically for the ecological restoration of engineering slopes.

Keywords-Soil conservation and slope stabilization; *Leucaena leucocephala* seeding; ecological restoration; soil root system; Biomass.

Plant root system can conserve soil and strengthen slope by improving the scour resistance, erosion resistance and shear strength of soil through root network [1]. *Leucaena leucocephala* is an evergreen small tree belonging to *Leucaena* genus of Fabaceae family. It has been largely used in the ecological restoration projects with developed root system, rigorous plant growth, strong fecundity and adaptation [2]. Previous studies showed that

the anchor ability of its fast-growing tap root system could significantly improve the shear strength of soil [3]. Since the performance of vegetation on soil conservation and slope protection was comprehensively implemented through root-soil system of plant communities. Plants in different ages with different root systems would really make great different effects [4]. This paper focused on root system's growth and development of *L. Leucocephala* seedlings, temporal variation of soil-root system on soil conservation and slope protection, and the correlation between the index of root system in soil conservation and slope protection and root biomass. All these research data were scientifically analyzed to evaluate the effects and the variation of *L. leucocephala* seedlings' soil-root system on soil conservation and slope stabilization, and determine whether or not it could be used for ecological recovery of engineering slopes.

I. MATERIAL AND METHODS

A. Field experimental design

The experimental plot included 12 standard quadrats (1.5 m in width, 3 m in length). 11 quadrats were used for planting experiment and one quadrat as the control. Holes in specification of 0.5m×0.5m were dug out at each planting quadrat Five seeds were planted in each hole. After germination, the strongest seedling in each hole was kept for experiment and the rests were cleared up. 15 plants were sampled randomly per month after planting three month to test the growth of above ground part, so did their soil root system using soil drill (Depth: 10 cm, Diameter: 8 cm) to test the erosion resistance, scour resistance, and shear strength. A control soil sample was collected and tested at the same time.

B. Determination of soil reinforcement and slope protection

1 Test of soil erosion resistance

Enhancement of soil erosion resistance of the soil-root system was measured using the method of the collapse resistant in static water and calculated as following [6]: $C_e = (V_1 - V_2)/V_2$ C_e is the enhancement of erosion resistance of soil-root system ranging from 0 to 1. V_1 and V_2 are the detachment rate of the soil-root system sample and control soil sample, respectively. 5 samples and 2 control samples were tested per month.

2 Test of Soil Scour Resistance

Enhancement of soil scour resistance of the soil-root system was measured using the method of scouring soil samples with hydraulic flume based on following calculation: $E_v = (C_1 - C_2)/C_2$. E_v is the enhancement of roots scour resistance of soil-root system. C_1 and C_2 are the scour resistance coefficients of soil-root system and control sample, respectively. The measurement unit of scour resistance coefficient is the amount of water (L) to flush out 1 g of saturated sample soil. 5 samples and 2 control samples were tested per month.

C. Test of Shear Strength

Soil shear strength of the soil-root system was measured based Mohr-Coulomb law: $\tau = \sigma \tan \phi + C$ [6]. C presents effective soil cohesion [kPa] including the cohesion among soil particles and the cohesion between soil particles and roots; σ is effective stress force that is normal to the slope [kPa]; ϕ is effective angle of shear resistance. Soil shearing stress (τ) was calculated by the formula: $\tau = KR$. Soil shear resistance indices (C , ϕ) are determined according to the τ - σ curve. Soil shearing stress was tested using the strain-controlled direct shear apparatus. 5 samples and 2 control samples were tested per month.

D. Test of tensile strength

The Diti method was used to test the tensile strength of roots [6]: $P = 4F/\pi D^2$. F and D represent the maximum tensile resistance and diameter of the section of root, respectively. Five plants were measured per month.

E. Test of root system structure

After finished all the above experiments, remove soil, collect and clean all the root, and use scanner to determine the root area, root length and root furcation number of the collected root on record. Then, plants were dried to a constant mass at 60 °C in an oven, and weighed to test their biomass.

F. Data analysis

One-way analysis of variance (ANOVA) was performed to determine the structure of roots and the effects of the soil-root system on soil conservation and slope protection. The relationship of spatial distribution between root structure and the performance of the soil-root system in soil conservation and slope protection was uncovered by linear analysis of root biomass with enhancement of soil erosion resistance, enhancement of soil scour resistance and shear strength, respectively. All analyses were conducted using SPSS software (13.0).

II. RESULTS AND ANALYSIS

A. The dynamic change of seedling growth and root structure

There are significant differences among seedlings with different growth time in root length, root area, furcation number and root biomass of root system ($P < 0.01$) (Table 1). The indices of *L. Leucocephala* seedlings increased with the increasing age. Plant height, root length, root area, root biomass and root furcation number of seven-month-old seedling was all increased most fast, which was higher than that of six-month-old plantation by 84.13%, 26.89%, 28.24%, 145.62% and 44.93%.

TABLE 1 THE DYNAMIC CHANGE OF SEEDLING GROWTH AND ROOT STRUCTURE FEATURE

Seeding age	Height (cm)	Root length (cm)	Root area (cm ²)	Root furcation number	Root biomass (g)
3 month	5.92±0.42a	10.58±0.63a	31.95±2.95a	0.84±0.40a	0.19±0.01a
4 month	17.61±1.21b	58.76±2.73b	186.63±5.13b	2.00±0.32b	0.24±0.02a
5 month	46.82±3.34b	64.08±1.17b	201.59±2.68b	3.42±0.81bc	6.51±0.33b
6 month	86.21±1.85c	81.31±3.79c	258.51±12.66bc	4.83±1.68bc	15.99±1.00b
7 month-old	126.60±3.02c	96.28±5.07c	278.71±14.96c	7.00±1.34bc	32.41±2.07c
8 month	135.81±2.13cd	106.22±1.99d	280.19±14.52c	7.40±2.49c	37.45±2.90cd
9 month	150.54±3.43d	108.83±0.60d	287.71±5.37c	9.83±2.70c	40.37±1.19d
10 month	166.00±2.07d	109.43±1.35d	291.60±5.66d	5.60±1.62d	44.14±0.30d
11 month	182.22±4.14d	111.01±0.93d	295.43±3.44d	7.80±1.53d	46.64±0.55d
F value;	25.22;	43.13;	36.87;	3.20	1
Significance	0.000**	0.000*	0.000**	0.00	2.07;
		*		7**	0.00**

B. Effects and spatial variation of soil reinforcement and slope protection

1) Erosion Resistance of Soil Root System

The existence of plant root system significantly decreased the soil detachment rate, and improved its erosion resistance. The detachment rate and erosion reinforcement of *L. leucocephala* soil-root systems ranged between 14.27-9.47 and 0.13-0.55 respectively. The detachment rate dramatically declined with the increase of the growth time, while the enhancement of erosion resistance significantly increased ($p=0.004$; $p=0.005$) (Fig. 1). The detachment rate of eleven-month-old *L. leucocephala* seedlings was lower than that of the control by 40.81%, and its enhancement of erosion resistance was higher than that of 3-month-old seedlings. It indicated that

7-month-old *L. leucocephala* seedlings had highest increase in erosion resistance.

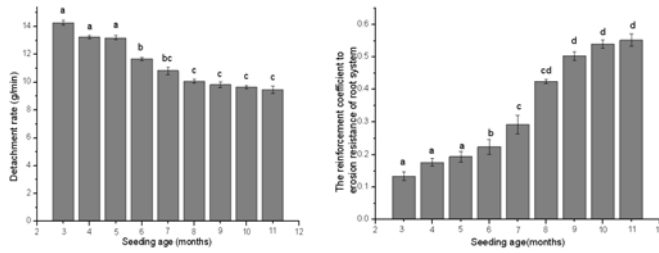


Figure 1. Effect and Variation of Erosion Resistance of Soil Root System

2) Scour Resistance of Soil Root System

Plant root system can also efficiently improve the effect of scour resistance on shallow soil layer. The scour resistance coefficient and reinforcement of *L. leucocephala* seedling's soil-root systems changed at the range of 0.03-0.066 and 0.033-0.731 respectively. The scour resistance rate and the reinforcement dramatically improved with the increase of the growth time ($p=0.007$; $p=0.008$) (Fig. 2). The detachment rate of eleven-month-old seedling was higher than that of the control by 90.59% and was also higher than that of 3-month-old seedling by 84.29%. The enhancement of scour resistance of 6-month-old seedling and 7-month-old seedlings was increased by 55.35% and 39.36% when compared with that of 7-month-old seedlings respectively.

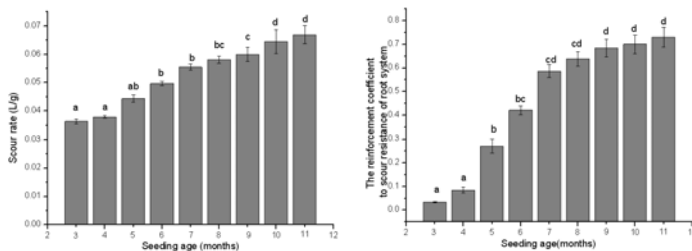


Figure 2. Effect and Variation of Scour Resistance of Soil Root System

3) Shear Strength and Tensile Strength of Soil-root System

Plant root system also efficiently improved the effect of shear strength on shallow soil layer. The tensile strength of *L. leucocephala* seedling's soil-root systems increased with the increase of age. Its shear strength and tensile strength were changing at the range of 12.35-33.3(kpa) and 8.59-38.53(N/mm²) respectively, and were improved with the increase of time ($p=0.017$; $p=0.03$) (Fig. 2). The shear strength of 11-month-old seedlings was higher than that of the control by 226.4 and was also higher than that of 3-month-old seedlings by 169.6. The maximum enhancement value occurred in seventh month seedlings, which was 21.6% higher than that of last month seedlings. In the experiment of tensile strength, 7-month-old seedling was 348.4% higher than that of 3-month-old seedlings. The most significant enhanced value occurred in 6-month-old seedlings, which was 38.2% higher than that of 11-month-old seedlings.

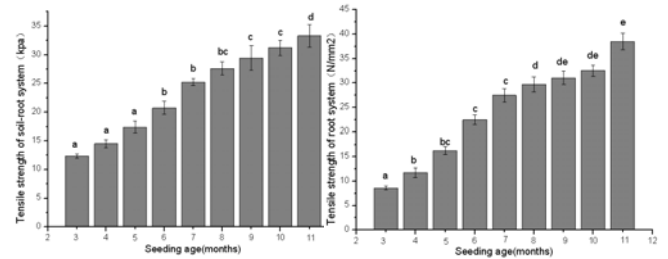


Figure 3. Effect and Variation of Shear and Tensile Strength of Soil Root System

C. The relationship of root Structure and soil reinforcement and slope protection

The enhancement of *L. leucocephala* seedling in soil erosion resistance, soil scour resistance and shear strength of soil-root system had a significant linear relationship with the average root biomass ($p=0.001$; $p=0.003$; $p=0.003$) (Fig. 4). All of them increased with the increase of root biomass. It suggested that there were significant differences between root system organization and structure of plants in different ages. These differences led to further differences in their performance of soil root systems on soil and slope protection in shallow soil layer.

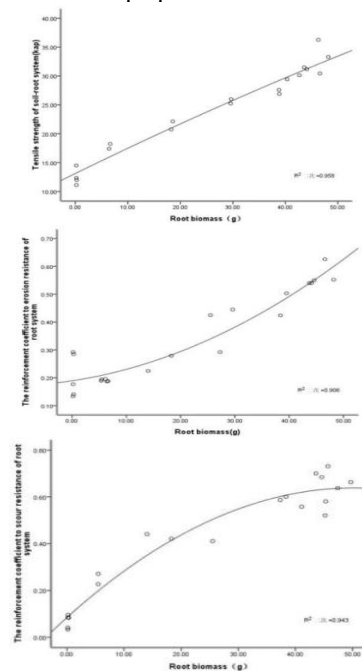


Figure 4. Relationship Between Root Biomass and Soil Reinforcement and Slope Protection

III. DISCUSSION

The function of soil-root system on soil conservation and slope protection is realized by the cohesion and reinforcement of roots on soil and coordinate regulation by above ground part and root system on slope surface hydrologic process [7]. This study showed that the enhancement of erosion resistance, scour resistance and

tensile strength of 11-month-old *L. leucocephala* seedlings was higher than that of 3-month-old seedling by 388.2%, 211.5% and 348.4% respectively. The shear strength was 226.4% higher than that of the control. It indicated that *L. leucocephala* seedling had significant effects on soil conservation and slope stabilization.

Many researches suggested that there was significant correlation between root-soil system's soil and slope protection performance and root system's biological and ecological characteristics, especially spatial-temporal structure. Plant species, ages, spatial structure and ecological conditions like soil types and moisture all influence root-soil systems' soil and slope protection performance [8]. Our research also indicated that the enforcement of soil root system had a significant positive correlation with biomass. The effects of soil root system on soil conservation and slope protection increased with the seedling growing time. It suggested that the growth and development of plant promote the performance of root-soil system in soil conservation and slope protection. Seedlings grew fast in the sixth (August) and seventh month (September) during the whole experimental period as the sunshine and temperature was favorite for seedlings growth. All the growth indicators were increased most obviously. The fast growth of *L. leucocephala* seedlings enriched the effects of root-soil systems on soil conservation and slope protection.

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