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Relative contribution of root physical enlacing and biochemistrical exudates to soil erosion resistance in the Loess soil

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ABSTRACT

Plant roots significantly affect soil erosion, while few works have pursued why root-penetrated soil obtained higher soil erosion resistance as compared with plain soil. For the purpose to investigate the relative contribution of root physical enlacing (root net-link and root-soil bond functions) and root biochemistrical exudates to soil erosion resistance. This study selected *Purple alfalfa* root- and designed root-penetrated Loess soil as study object, and subjected to flow scouring. The results showed that roots could significantly ameliorate soil properties, especially for soil enzymes. Root physical enlacing is the main reason, accounting for 77.7–82.0% of the root total effect in strengthening soil erosion resistance. And of this total, the relative contribution ratio of net-link and soil-root bond functions to soil erosion resistance was 0.71:0.29, averagely. Root surface area density could effectively reflect root physical enlacing effect. This kind of study may provide theoretical explanations for the root reinforcement in the flow-induced erosion regions.

1. Introduction

Soil erosion is a process, in which soil and other ground substance were destroyed, denudation, transport and deposition induced by water, wind, freeze-thaw and gravity acts in the land surface. In semiarid areas, soil erosion is a serious threat to land productivity and sustainability for natural and human-managed ecosystems (Su et al., 2010; Fu et al., 2011). Traditional vegetation techniques are recognized as effectively in reducing soil erosion, whereas the most evident vegetation source that protects soil against erosion is root wedging, which is an important mechanism where roots can bind soil together and tie weak surface soil layers into strong and stable subsurface layers (Zhang et al., 2011; Reinhart et al., 2012; Adili et al., 2012). Specifically, root-permeated soils are generally more capable of withstanding soil erosion than plain soils mainly because of the physical enlacing (root length, root surface area density, etc.) and root biochemistrical effect of roots (Liu, 1998; Li et al., 2015a, 2015b). For example, Gyssels and Poesen (2003) and Gyssels et al. (2005) pointed out that plant (Beet, Maize and Endive) roots could reduce sediment loss by 20%, averagely, in silt loam soils, Zhou and Shangguan (2005) found that soil loss could be cut as much as 96% in the Ryegrass root-penetrated soils, and such effect can be well explained by the root features like root biomass, root surface area density, etc. (Li et al., 2015a, 2015b). Even though, the relative contribution of root physical enlacing and biochemistry effect to soil reinforcement is still not clear recently, which hinders constructing a database to test newly developed erosion models, especially in the flow-induced erosion regions.

This study was performed to investigate the relative contribution of root physical enlacing and biochemistry effect to soil erosion resistance. In general, root total effect includes root net-link and soil-root bond functions, and root biochemistry effect (Liu, 1998; Li et al., 2015a, 2015b, 2016). As such, four treatments were designed: 1) root-penetrated soil samples, represents root total effect on soil erosion resistance, 2) Loess parent material, represents soil samples without root effect, 3) tillage soil, represents soil samples with only root biochemistrical effect, and 4) designed root-penetrated soil, represents soil samples with root net-link function alone. Such kind of study could strengthen the mechanism of roots to soil erosion resistance in the root-penetrated soil.

2. Materials and methods

2.1. Experiment design

This experiment was conducted at Ansai Field Experiment Station (36°51′ 22″ N, 109° 18′ 52″ E) of the Chinese Academy of Sciences in the northwest of China. The experimental treatments examined in the present study are: 1) *Purple alfalfa* root-penetrated soil, 2) Loess parent material, which came from soil material layer without root effect, 3) Sieved tillage soil without root available, and 4) root-texture cotton

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thread-penetrated soil, represents soil samples with root net-link function alone. Loess soil samples were collected from a potato-planted slope land, with aspect of N33 and slope gradient of 17°, lying in the Ansai Field Experiment Station. The soil samples were collected in two ways, one part (CK1, about 500 kg) is Loess parent material, sampled from 2.5–3 m-depth. In the sampling process, the surface contour-tillage soil was removed on one side, and then a pit was excavated using a forklift until the parent material layer appeared, where no roots existed. Such soil (bulk density of 1.28 g cm^{-3}, soil organic matter of 2.2 g kg^{-1}, sand, silt, and clay contents of 11.1%, 60.8% and 28.1%, respectively (USA classification)), represents soil samples without root biochemistrical effect in the present study. The other soil samples (CK2, about 700 kg) were contour-tillage soils, with depth <25 cm, 1.26 g cm^{-3} soil bulk density, 3.8 g kg^{-1} soil organic matter, 10.8% sand content, 57.7% silt content, and 31.5% clay contents, respectively. This kind of soil represents

soil samples with root biochemistrical effect, but without binding effect.

2.2. Soil sample preparing

The soil samples (part1 and part2) were independently passed through a 5-mm sieve after the removal of root fragments and air-dried to a moisture content of approximately 1.3%. Then, we used metal box, with dimensions of 200 cm × 28 cm (length × width), filled with soils in every 5-cm layers to a depth of 35 cm at a bulk density of 1.28 g cm^{-3}. Each layer was roughened by a small rake to minimize the discontinuity between layers. Once the box was prepared, all plots were treated equally and received the same amount of simulated rainwater. To promote purple alfalfa germination, the soil surface was covered with mats, and 1.5 L regular water in a plot was sprayed. When Alfalfa grew being about 5 cm in height, watering frequency was reduced. The *Purple alfalfa* seeds were sown at 10 cm row spacing with plant density of 90 (R1), 180 (R2), 270 (R3) and 360 (R4) stems/m^2 including 4 replicates, and employed a thin layer of soil (i.e., 1.0 cm) without fertilizer applications on 6 May 2013 (Fig.1A). Similar root-texture cotton thread in a diameter of 0.4 mm was chosen as the designed roots in the present study. Cotton thread was gently worn buried in CK2 soil sample at a horizontal angle of about 10° using special designed stainless steel needle. While threading, to prevent fragmentation clods on the surface soil (natural water content of about 10%) sprinkle a little water. Soaked in water for 24 h, to make it fully saturated, and then the conventional scouring was conducted. Thus, the designed roots in the soil have net-link and soil-root bond functions, but no root biochemistry effect, to soil erosion resistance. Therefore,18 plots (4 densities × 4 replications + 2(ck1 and ck2) = 18) were prepared in the present study.

2.3. Soil sample collection for flume experiment

Laboratory-simulated flow experiments were conducted nine weeks after *Purple alfalfa* was planted. The above-ground biomass was chipped to be level to the soil surface, and the residues were cleared. Four special rectangular sampling metal boxes with dimensions of 20 cm × 10 cm × 10 cm (length × width × depth) were driven into the soil in each plot using a hammer. A wooden plank was placed on top of the metal box during hammering for protection. To extract the soil sample from the plot, some soil was dug out with a trowel from the area surrounding the metal box. The soil sample was then lifted in such a way that some soil was sticking out below the open bottom side of the sample. Thereafter, the sampling box was packed using a membrane with a plastic plate attached to the bottom of the metal box to prevent soil loss during transport. Prior to scouring experiment, the samples were placed in a container with a constant water level of 5 cm below the soil surface to allow 12 h for slow capillary rise. The samples were then taken out of the water and drained for 8 h to obtain the same soil moisture before the flume experiment (Fig. 1B). Total 28 samples including 4 replications, were taken from the topsoil for simulated flow experiments.

A concentrated flow experiment was conducted with a hydrological flume (length = 2 m, width = 0.10 m). Simulated runoff flux (4 L min^{-1}) was designed according to the maximum potential runoff yield caused by a typical medium storm in the hilly Loess Plateau on a standard plot (20 m × 5 m). The flume slope of 15° referred to the standard slope of conversion from farmland to forestland in China. The scouring time (15 min) referred to the maximum time frequency for rainstorms in the research region (Fig. 2). During the 15 min duration of each experiment, samples of runoff and detached soil were collected every 1 min during the first 3 min and every 2 min thereafter using 10 L buckets. After the suspended particles had settled, the clear water was drained off, and the sediments were sampled and oven-dried at 105 °C.

2.4. Soil indicator determination

Immediately after each flow experiment, all roots were separated from the soil samples by hand washing on a sieve. Each root segment

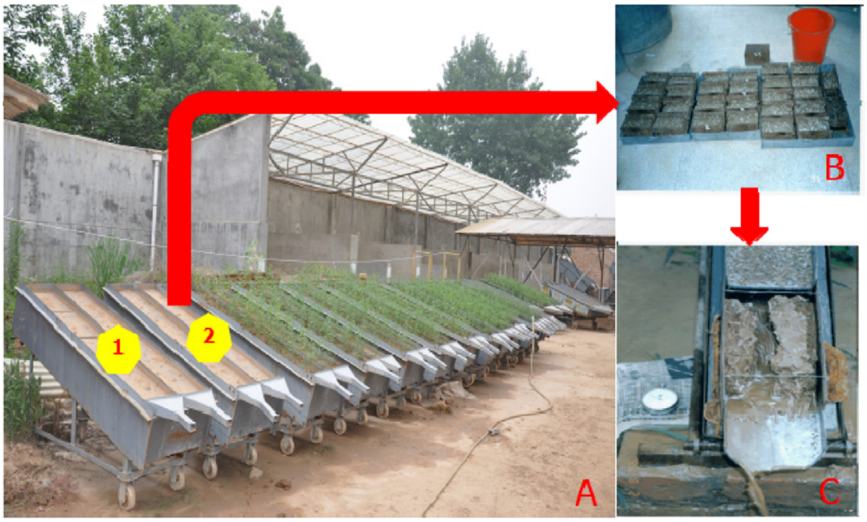

Fig. 1. Basic experimental set-up and process. (A. Experimental treatment diagram; B. Soil samples with designed roots in various density; C. Scouring process in soil samples with designed roots; ①. CK1; ②. CK2).