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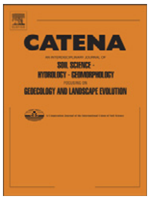

Simulated erosion using soils from vegetated slopes in the Jiufeng Mountains, China

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ABSTRACT

The effects of rainfall intensity, slope gradient and vegetation cover on the intensity of runoff and rate of soil erosion were examined with simulated rainfall. All five affected soil erosion in experimental soil boxes containing *Vitex negundo* var. *heterophylla* (VN), VN with litter (VN-L), *Broussonetia papyrifera* (BP), BP with litter (BP-L), and a control with bare land (BL). The presence of the vegetation and litter layers significantly reduced the rates of sediment yields, the mean rate of sediment yield values of BP-L, BP, VN-L, VN and BL were 2.873 g/min, 11.264 g/min, 4.220 g/min, 16.781 g/min and 21.594 g/min, respectively. The mean rates of sediment yield increased linearly with increases of rainfall intensity and slope gradient, but not beyond a certain gradient. *B. papyrifera* reduced sediments by 6.24 and 25.55% more than *V. negundo* var. *heterophylla* with and without litter layers, respectively. The rate of sediment yield was positively and linearly correlated with runoff shear force, with rates increasing quickly in VN, and the critical runoff shear force of BP was 0.8282 N/m^2, and VN was 0.2098 N/m^2. The results of this study will help to determine appropriate methods for reducing soil erosion.

1. Introduction

The loss of soil and water is severely deleting land resources and degrading eco-environments in many areas of China, leading to reductions in local agricultural and industrial productivity. As severe environmental problems, soil and water loss will affect many aspects, such as nature, the economy, society, and science. Many factors influence the degree of soil erosion, including slope, vegetation coverage, rainfall intensity and duration, and soil type and texture (Sun et al., 2014). Many studies have investigated the rates of sediment yields under various experimental conditions, but few have focused on the magnitude and evolution of the rates with different types of vegetation and their litter layers. This study used simulated rainfall to evaluate the effect of vegetation and their litter layers on the quantitative relationships of rainfall intensity and slope gradient with the rate of sediment yield. This information could be applied to the management of projects for soil and water conservation in the mountainous area of northern China.

Simulated rainfall is an important tool for studying erosion because the experimental conditions can be controlled, and many kinds of natural environments can be simulated within a short period of time (Y. Zhao et al., 2013; Y.G. Zhao et al., 2013). Simulated rainfall, however, are necessarily restricted to small scales, and cannot be directly applicable in practice without verification (Ikiensinma and Manoj, 2013).

Among the factors that affect soil erosion, rainfall intensity is particularly important (Zhang et al., 2011a,b), especially for brief rains (Shigaki et al., 2007), and vegetation can play an important role in preventing erosion (Li et al., 2009). The infiltration of rainwater into the soil is an important process in the water cycles of terrestrial ecosystems (Xie et al., 2003). Infiltration capacities vary with rainfall and soil properties, and a pivotal strategy for reducing erosion is to retain more precipitation locally (Cattan et al., 2009). Soil properties generally change dynamically over time due to the effects of plants, and increasing infiltration can reduce runoff and erosion (Y. Zhao et al., 2013; Y.G. Zhao et al., 2013). The amounts of runoff and sediments are mainly determined by the rainfall intensity. The kinetic energy of raindrops increases with rainfall intensity and will increase the amount of runoff and erosion (Keim et al., 2006; Zhang et al., 2011a,b; Liu et al., 2013).

Planting vegetation or allowing damaged covers to recover is the most effective way to reduce erosion (Garcia-Estringana et al., 2013). Vegetation regrowth tends to ameliorate soil structures, improve hydraulic properties, decrease soil bulk density, and reduce soil erosion (Peng et al., 2012; Li and Shao, 2006). Cumulative infiltration and the time for runoff generation have been reported to decrease as gradients increased, and the gradient positively influenced runoff coefficients and sediment concentrations (Chamizo et al., 2012). The size of the area affected by rain and other experimental conditions can also influence simulated soil erosion (Wang et al., 2009; Chamizo et al., 2012; Kaltenbrunner et al., 2012). Mean sediment yield, simulated in a soil box, was negatively correlated with slope gradients 25°–30° (Wang et al., 2005).

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2. Materials and methods

2.1. Site description

The experiments in this study were conducted at the key Soil and Water Conservation and Desertification Laboratory of the Ministry of Education, located in the Jiufeng Mountains (40°04′N,116°06′E, 145 m a.s.l.), Beijing, China. The study area is a property of Beijing Forestry University. It is on sloping terrain of 10–25% and has a temperate continental climate with a mean annual temperature of 9 °C. The mean of annual precipitation is 600 mm, more than 80% of which falls between June and September. The active growing season extends from April to October. The soil is a shallow (0.3–1 m with an average of 0.5 m), gravelly loam with a 30% coarse (>2 mm diameter) fraction (Pang et al., 2012).

2.2. Rainfall simulator

All experiments were performed in a rainfall simulation hall, containing three main components: slope, rainfall, and control systems. The rainfall simulator is shown in Fig. 1. The slope system consists of soil boxes 2 m (78.74 in.) long, 0.5 m (19.69 in.) wide, and 0.4 m (15.75 in.) deep. The boxes were mounted on four wheels for easy movement and were adjustable to gradients of 0–45°. The bases of the boxes contained many evenly distributed holes to allow unrestricted infiltration. The rainfall system consisted of a cistern, pump, and line pipe. The cistern for storing water was 10 m long, 6 m wide, and 8 m deep. The pump moved the water to the line pipe and through shower nozzles to simulate rainfall. Rain in the hall can be simulated over an area of 256 m^2, separated into four areas, 8 m long and 8 m wide, separately or together. The rain fell from height of 12 m. The system for controlling the rain area and intensity was computer. The parameters of the rain simulator are presented in Table 1.

2.3. Treatments

The experiments used cinnamon soil, which is the most common soil in the rocky mountainous areas in northern China. The soil was passed through a 10-mm (0.3937 in. sieve, air-dried to an initial water content of approximately 10%, and then packed into the boxes in four layers 10 cm (3.397 in. thick to simulate a natural bulk density of approximately 1.34 g/cm^3 (0.77 oz in^{-3}). Each soil layer was raked lightly before adding the next layer to reduce any discontinuities between the layers.

Table 1
Technical details of the rainfall simulator.

Technical details	Values
Maximum rainfall area (m)	16 × 16
Maximum rainfall height (m)	12
Rainfall intensity (mm/h)	0–300
Coefficient of uniformity (%)	>85
Raindrop diameter (mm)	1.47 ± 0.64
Raindrop velocity (m/s^2)	4.78 ± 0.25
Rainfall kinetic energy (J/m^2/s)	0.2193 ± 0.12

Rainfall intensities of 30, 60, and 90 mm/h and slope gradients of 10, 15 and 20° were tested. Two types of vegetation collected from a natural forest were transplanted to the soil boxes: the shrub *Vitex negundo* var. *heterophylla* (VN), and three-year-old saplings of the tree *Broussonetia papyrifera* (BP), the litter collected from 1 m^2 under each type of vegetation, including decomposed, half-decomposed and undisturbed litter, was also collected and added to the corresponding soil boxes. We thus had four treatments containing vegetation: VN, VN with litter (VN-L), BP, and BP with litter (BP-L). A soil box of bare land (BL) served as a control treatment. Generally 5 types of vegetative slopes and 2 replications so that there are 10 soil boxes, one for each of the two replicates of the five treatments. Each box was used multiple times for different combinations of rainfall intensity and slope. We allowed one month between experiments to eliminate the effects of soil loss and changes in the characteristics of the soil surfaces. Pre-testing indicated that even the maximum erosion could not cause gully erosion, so that the soil was able recover to a nearly constant state for each experiment, and that the results would not be influenced by multiple experiments. The parameters of the survey index of the vegetation are shown in Table 2, each of the vegetation type was set one more soil box for two replicates to make the experiments more reasonable.

2.4. Measurements and methods

Runoff was measured in 1000 ml graduated cylinders every 2 or 5 min after its generation, depending on the speed of generation. The collected runoff was dried by oven to determine the amount of sediments. The velocity of runoff greatly influences sediment yield, so the

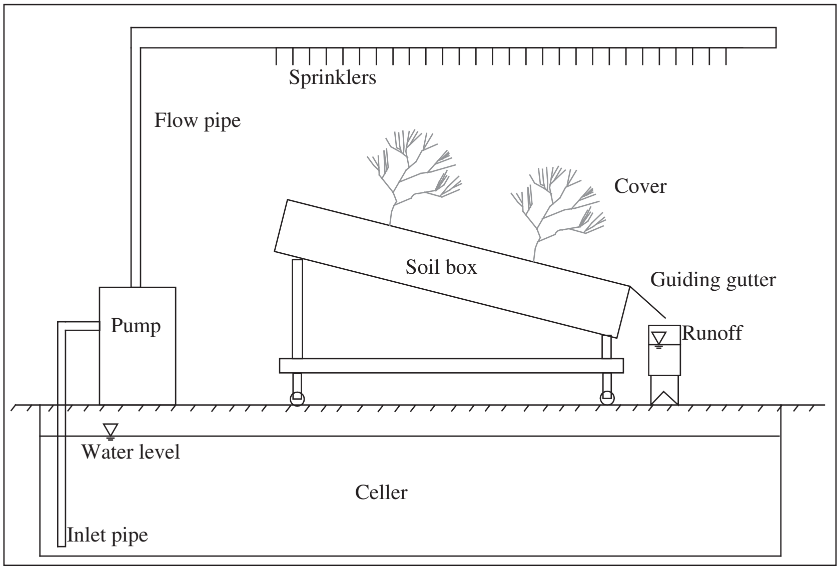

Fig. 1. The rainfall simulator.