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International Soil and Water Conservation Research 3 (2015) 170–182

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Effects of rye grass coverage on soil loss from loess slopes

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Received 14 April 2015; received in revised form 25 May 2015; accepted 26 May 2015
Available online 10 August 2015

Abstract

Vegetative coverage is commonly used to reduce urban slope soil erosion. Laboratory experimental study on soil erosion under grass covered slopes is conventionally time and space consuming. In this study, a new method is suggested to study the influences of vegetation coverage on soil erosion from a sloped loess surface under three slope gradients of 5°, 15°, and 25°; four rye grass coverages of 0%, 25%, 50%, and 75%; and three rainfall intensities of 60, 90, and 120 mm/h with a silt-loamy loess soil. Rye grasses were planted in the field with the studied soil before being transplanted into a laboratory flume. Grass was allowed to resume growth for a period before the rain simulation experiment. Results showed that the grass cover reduced soil erosion by 63.90% to 92.75% and sediment transport rate by 80.59% to 96.17% under different slope gradients and rainfall intensities. The sediment concentration/sediment transport rate from bare slope was significantly higher than from a grass-covered slope. The sediment concentration/transport rate from grass-covered slopes decreased linearly with grass coverage and increased with rainfall intensity. The sediment concentration/transport rate from the bare slope increased as a power function of slope and reached the maximum value at the gradient of about 25°, whereas that from grass-covered slope increased linearly and at much lower levels. The results of this study can be used to estimate the effect of vegetation on soil erosion from loess slopes.

Keywords: Loess soil; Rainfall simulation; Slope; Soil erosion; Surface coverage

1. Introduction

Vegetation is one of the key factors influencing soil erosion in various locations such as the Loess Plateau, which is one of the most highly erodible areas worldwide (Zheng, 2006). Loess soil is highly vulnerable to erosion. The effects of grass coverage on runoff and sediment yield from loess slope should be determined for soil and water conservation.

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http://dx.doi.org/10.1016/j.iswcr.2015.05.006

Vegetation can reduce soil erosion by intercepting rainfall, to reduce the kinetic energy of raindrops. Vegetation can also increase soil infiltration by improving its physicochemical properties, decrease runoff and erosion energy, and entrap detached sediment particles, reduce migration of pollutants and loss of soil and water. The extent to which grass affects runoff and sedimentation depends on grass density, runoff velocity, and grass submergence. Grass density can be characterized by grass coverage, whereas runoff velocity and grass submergence depend on slope gradient and rainfall intensity. Thus, factors that influence soil erosion include precipitation, vegetation, and slope gradient, among others (Messing, Fagerstrom, Chen, & Fu, 2003; Vahabi & Nikkami, 2008; Zuazo & Pleguezuelo, 2008). Rainfall energy is identified as the primary cause of erosion, which is prone to occur when the soil lacks protective vegetative covering (Zuazo & Pleguezuelo, 2008). Runoff and its capability for erosion increase with rainfall intensity (Liu, Cao, Wang, & Qin, 2010).

Vegetation coverage influences the entire process of soil erosion. Grass strips of different widths can reduce soil loss by 50% to 99%, and grass density is identified as a key factor affecting sediment reduction (Van Dijk, Kwaad, & Klapwijk, 1996). Runoff and sediment loss have been shown to decrease exponentially with vegetation coverage (Moore, Thomas, & Barber, 1979; Snelder & Bryan, 1995).

Slope gradient is one of the key factors affecting runoff and soil erosion. A study of the effect of slope gradient on soil erosion in the Boise River watershed indicated that the proportion of the eroded area rose sharply with an increase in slope gradient but remained constant with a gradient ranging from 25° to 55° (Renner, 1936). The amount of soil eroded increases with the slope gradient (Fox & Bryan, 2000; Kinnell, 2000).

Slope length is an essential geomorphologic factor affecting soil erosion. The converged flow and energy of transporting the detached sediment increases with slope length, thereby detaching and transporting more sediments. Consequently, sediment yield increases as a power function of slope length and reaches a relatively stable value at the sediment transport capacity at a slope length of 8 m (Zhang, Lei, & Zhao, 2008). In a previous study, when the loess slope length was less than 3 m, runoff converged less, no vigorous incision was observed, and only flow concentration occurred, accompanied by localized washing of fine soil particles into depressions (Bryan & Poesen, 1989). Therefore, when the studied slope is not long enough, splash or sheet erosion may occur, but no rill erosion presence.

The relationship between precipitation and erosion is nonlinear and complicated because of vegetation cover (Xu, 2005). The effects of different vegetation coverage on soil erosion have been widely examined. However, few studies involve the interaction of different factors that influence sediment yield and vegetation coverage. The study conducted in the Lüergou watershed in the China loess area indicated that the precipitation contributes more erosion than vegetation cover (Yu, Zhang, Li, Zhang, & Xie, 2006). Laboratory experiments were conducted under a simulated rainfall intensity of 100 mm h^{-1} and a slope gradient of 15°. On the basis of these experiments, Pan and Shangguan (2006) concluded that the grassplot with different coverages (35%, 45%, 65%, and 90%) produced 14–25% less runoff and 81–95% less sediments compared with the bare soil plot. In addition, a significant negative logarithmic relation existed between the sediment yield rate and the cover. However, given a slope length of only 2 m, this particular condition may not sufficiently long enough to represent the phenomenon of soil erosion from longer slopes. Furthermore, the study only demonstrated soil erosion under one slope gradient and one rainfall intensity. The composite effects of different rye grass coverages, slope gradients, and rainfall intensities on soil erosion were not discussed.

An experiment on the effect of grass coverage on runoff and sediment yield can be performed as a field or a laboratory study. Landform and weather limit the conduct of a field experiment because slope gradients and rainfall intensities would be difficult to control (Morgan, McIntyre, Vickers, Quinton, & Rickson, 1997). Although rainfall intensities and slope gradients can be adjusted artificially in laboratory experiments, the previous studies were generally based on insufficient conditions such as short slopes and gentle gradients. These conditions result from the limited space in a laboratory and the time entailed to grow vegetation. In such a case, the following should comprise the conditions: vegetation coverages only (Pan & Shangguan, 2006), growing time of vegetation only (Zhou & Shangguan, 2007), or vegetation coverages combined with rainfall intensities (Zhang & Liang, 1996). To examine sediment transport in urban runoff on grassland, Deletic (2005) used an artificial turf called Astroturf with different densities to simulate grass cover. The Astroturf density is easier to control, and its material exhibits superior moisture absorption and resilience similar to those of natural grass. However, Astroturf has no root and allows no infiltration on the simulated slope surface, which prevents it from completely simulating natural grass turf. Planting a grass turf