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Runoff hydraulic characteristics and sediment generation in sloped grassplots under simulated rainfall conditions

Chengzhong Pan [a,b], **Zhouping Shangguan** [a,c,*]

[a] *State Key Laboratory of Soil Erosion and Dryland Farming on the Loess Plateau, Institute of Soil and Water Conservation, Chinese Academy of Sciences, No. 26 Xinong Road, Yangling, Shaanxi 712100, PR China*
[b] *Graduate School of the Chinese Academy of Sciences, Beijing 100049, PR China*
[c] *Northwest Sci-Tech University of Agriculture and Forestry, Yangling, Shaanxi 712100, PR China*

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Summary Evaluation of grass influence on soil erosion process can provide important information in soil and water conservation. The laboratory experiment was conducted to study runoff and sediment producing processes and runoff hydraulics in the grassplots with different covers (35%, 45%, 65% and 90%) and bare soil plot (control) at a slope of 15°. The results showed that grass significantly reduced runoff and sediment. Compared with bare soil plot, the grassplots had a 14–25% less runoff and an 81–95% less sediment, and played a more important role in reducing sediment at the final stage of rainfall. There was a significantly negative logarithmic relationship between sediment yield rate (SDR) and cover (C): SDR = 1.077–2.911 ln(C) (R^2 = 0.999**). Sediment yield rate of grassplots decreased with rainfall duration, and decreased linearly as runoff rate increased. Overland flow velocities deceased with increase in grass cover, and the cover had greater effect on lower slope velocity than upper one. Froude numbers decreased with increase in cover, and flow regimes of all treatments were laminar and tranquil. Darcy–Weisbach and Manning friction coefficients of grassplots increased as ground cover increased. Therefore, increase in grass coverage can efficiently reduce soil loss and improve ecological environments.

Introduction

Soil erosion is one of the most serious eco-environmental problems in the world. Vegetation has long been recognized as an efficient way to prevent soil erosion, and is widely

* Corresponding author. Tel.: +86 29 87019107; fax: +86 29 87012210.
E-mail address: shangguan@ms.iswc.ac.cn (Z.P. Shangguan).

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used as an important measure of soil and water conservation (Morgan and Rickson, 1995). Grasses have an important effect on slope runoff and sediment. Based on field experiments in which grass stems and leaves were cut close to ground surface, Prosser et al. (1995) concluded that flow resistance and critical shear stress of concentrated overland flow in sediment translocation decreased compared to those of a complete grass cover. Chatterjea (1998) studied runoff and sediment generation on bare and grassplots under natural rainstorm, and concluded that the responses of the bare surfaces to incoming rainfall were more instantaneous and more significant than those of grassplots. Based on comparison experiments under laboratory-simulated rainfall, Pan et al. (2006) showed that grasses and moss significantly reduced sediment yield, and that moss had a negative effect on soil infiltration.

Although numerous studies have mentioned vegetation cover impacts on soil erosion (Thornes, 1987; Trimble, 1990; Stocking, 1994; Morgan and Rickson, 1995; Braud et al., 2001), relatively less information on erosion process in grassplots was provided. Moreover, the differences in soil properties, slope surface conditions, vegetation types, etc. in field experiments tend to have negative effects on the findings. Such emphasis is based more on common sense than on the results of scientific investigations and little is known about runoff and sediment yielding process.

Hydraulic characteristics of overland flow, such as flow velocity, flow depth and friction coefficients, etc., and their relationships have been studied widely on overland flow (Foster et al., 1984; Gilley et al., 1990; Govers, 1992; Abrahams et al., 1996; Nearing et al., 1997). However, few studies have examined interrill flow in vegetation-covered plots under rainfall conditions. Some investigations have demonstrated that vegetation modifies the hydrology of overland flow and this modification has implications for the transfer and deposition of sediment (Evans, 1980; Kang et al., 2001; Neave and Abrahams, 2002). However, it is difficult to understand the erosion process and mechanics on vegetation-covered plots due to lack of sufficient reliable data. Meanwhile, it is a focus on ecological research to illustrate terrestrial eco-hydrology processes at present (Baird and Wilby, 1999).

The objectives of this study are to better understand the influence of grasses on runoff hydraulic characteristics and sediment producing process, and to further clarify the differences among grassplots with different covers. The findings can offer basic data for the building of erosion mechanics model on vegetation-covered slopes, and present a theoretical guidance for the construction of soil and water conservation.

Materials and methods

Experimental conditions

The experiment was conducted in a laboratory under simulated rainfalls, at the State Key Laboratory of Soil Erosion and Dryland Farming on the Loess Plateau, Yangling, China. A side-sprinkle precipitation set-up system, in which rainfall intensities can be precisely adjusted through nozzle sizes and water pressure, was used in the experiments. The height of rainfall simulator is up to 16 m and simulated storm with uniformity of above 85% is similar to natural rainfall in raindrop distribution and size. Calibrations of rainfall intensities were conducted prior to the experiments.

Each of experimental steel plots was 2.0 m in length, 0.55 m in width, and 0.35 m in depth. A metal runoff collector was set at the bottom of the plot to direct runoff into a container. Apertures were formed at the bottom of plot to allow soil moisture to freely infiltrate. Experimental plot slope was adjusted at 15°, which is the threshold gradient for transforming farmland to forestland or grassland in the experimental region. Soils used in the study were a loessial loam collected from Fuxian county in the north of the Loess Plateau, which is susceptible to soil erodibility. The soil texture information is listed in Table 1.

Experimental treatments and measurements

Soil was gently crushed before passing through a 10 mm sieve, and the sieved soil was thoroughly mixed to minimize the difference among treatments. The 30 cm thick soil was packed in each plot in three 10-cm layers to achieve a 1.2 g cm^{-3} bulk density. Additionally, each soil layer was raked lightly before the next layer was packed to diminish the discontinuity. Perennial black rye grass (*Lolium perenne* L.), a commonly seen grazing grass, was used for vegetation cover.

The treatments included: four grassplots with plant space × row space of 15 cm × 15 cm, 5 cm × 20 cm, 10 cm × 10 cm and 5 cm × 10 cm, respectively, and a control of bare soil plot (Fig. 1). All treatments had two replicates. One day before experiment, a specialized soil auger with a diameter of 1 cm was used to determine soil water content of the different treatments. According to the measured values, different amount of water was sprayed with a commonly used household sprayer to minimize the differences in antecedent soil water content among treatments. Soil water content was adjusted to 15% (gravimetrically) for all the treatment plots at the beginning of rain simulation experiments.

The simulated rainfall at an intensity of about 100 mm h^{-1} was employed for about 70 min. For each treatment, runoff-initiating time was recorded; all runoff and

Table 1 Physical properties of the soil used in this experiment

Soil type	Particle size distribution % (μm)						Soil texture
	1000–250	250–50	50–10	10–5	5–1	< 1	
Loessial soil	0.01	2.91	54.61	13.03	12.09	17.35	Sandy loam soil