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The dynamic effects of pastures and crop on runoff and sediments reduction at loess slopes under simulated rainfall conditions

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ABSTRACT

Ryegrass (*Lolium perenne* L.) and alfalfa (*Medicago sativa* L.) are widely-planted pastures, and spring wheat (*Triticum aestivum* L.) is one of the common crops on the Loess Plateau of China where serious erosion exists. However, their roles in regulating runoff and sediments have not been fully understood. This study investigated the effects of these vegetation types at various growth stages on reducing runoff and sediments in soil boxes under simulated rainfall conditions. Growth stages were set as: early stage (late May), middle stage (late June), and late stage (late July). Four indices were used to assess the capacity of reducing runoff and sediments in terms of runoff reduction benefit (RRB), sediment reduction benefit (SRB), ratio between runoff and sediment reduction (RRSR), and soil average/stable infiltration rate. The results showed that at the early and middle stages, RRB, SRB, RRSR, and soil average/stable infiltration rate were the largest for ryegrass followed by spring wheat and alfalfa. At the late stage, however, alfalfa following ryegrass performed better than spring wheat in reducing runoff and sediments. With the growth of vegetation, the capacity of ryegrass and alfalfa in reducing runoff and sediments increased. The RRB and SRB for the late-stage ryegrass were 69.5% and 98.6%, respectively, while they were 61.6% and 95.4% for the late-stage alfalfa, respectively. Spring wheat at middle stage performed best in reducing runoff and sediments over the whole growing period, with the RRB and SRB of 65.31% and 97.63%, respectively. In particular, the SRB for different vegetation types at all stages were over 90%, and were apparently higher than the RRB. In addition, the RRSR increased greatly from the early to middle growth stage for all vegetative treatments, indicating that the reduction in runoff was more effective than the reduction in sediment when vegetation grew mature. Since the majority of heavy rainstorms fall in the late growth stage (July–September) on the Loess Plateau, the functioning of artificial grass in reducing slope runoff and sediments should be stressed and investigated in further details.

1. Introduction

The hilly region of the Loess Plateau may be subject to the strongest soil erosion around the world and is the main source of sediments of the Yellow River (Tang, 2004). Planting trees and grass has been shown as an effective way in reducing soil and water loss (Braud et al., 2001; Breshears et al., 2003; Helmers et al., 2012; Hernandez-Santana et al., 2013; Molina et al., 2007; Wainwright et al., 2000; Yu et al., 1997; Zhao et al., 2009; Zhu, 2006). As a result, the relationship between vegetation and runoff and sediment is usually the main parts in studying the ecological and environmental problems in this region (Gan et al., 2010; Li et al., 1992a; Liu et al., 2010; Xu and Sun, 2006). Since the implementation of "grain for green" project in western China in 1999, the role of grass in controlling soil erosion has been stressed especially in arid and semiarid zones where the primary native vegetation type is usually grass. Therefore planting appropriate artificial grasses becomes an important part of the goals of reasonable land utilization in the hilly region of the Loess Plateau (Shan and Xu, 2009).

A large body of literature has focused on the effects of vegetation on runoff and sediment reduction in the hilly region of the Loess Plateau. For instance, Zhu et al. (2010) studied the effect of grass on slope erosion based on a field rainfall-simulation experiment, and assessed the functioning of grass in reducing erosion. They found that grass greatly affected rainfall erosivity, and finally decreased slope sediment yield. Pan et al. (2006) investigated the processes of runoff and sediment generation under indoor rainfall simulation conditions. They found that the sediment yield, runoff volume, and slope velocity for grass plots were apparently reduced compared to bare soil control. Yu (2010) characterized the dynamics of surface runoff, sediments, and infiltration under different vegetation treatments by field simulated rainfall events, and found that vegetation roots had the largest influence on reducing runoff volume and sediment yield. However, when assess the functioning of

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artificial grass in reducing runoff and sediments, most of previous studies usually used bare grounds as controls and missed to compare the difference between grass and widely-planted crops on the Loess Plateau (Gan et al., 2010; Pan et al., 2006; Yu et al., 1997; Zhao et al., 2013; Zhu et al., 2010). In fact, the majority of precipitation in this region falls between July and September. Nonetheless, there is little bare ground during this period, and the co-existence of natural vegetation, artificial grass and crops is the most common land use patterns in the hilly areas of the Loess Plateau (Zheng et al., 2007). Since sloping cropland is the primary source of soil erosion (Tang, 2004), there is a need to understand how crops affect runoff and sediment yielding as well as the difference of its role with artificial grass in this region. In addition, the efficiency of different vegetation types in reducing runoff and sediments is also different (Wei et al., 2007). It is even varying greatly at different growth stages. However, only a few efforts have been done to understand the effects of growth stages on vegetation functioning in reducing runoff and sediments.

The main objective of this study was to examine the effects of two pastures and one crop on runoff and sediment yields and the changes with growing stages through rainfall simulation experiments. We primarily analyzed runoff and sediment yielding for different treatments, and discussed the effect of different artificial grass species on reducing runoff and sediments. Two pastures were ryegrass (*Lolium perenne* L.) and alfalfa (*Medicago sativa* L.) and the crop was spring wheat (*Triticum aestivum* L.), which have been widely planted in the hilly areas of the Loess Plateau.

2. Materials and method

2.1. Study site

The experiments were conducted at the field monitoring station located in Linghou, Wuquan Town, Yangling District, Shaanxi Province. The Yangling District is located on the western Guanzhong Plain of Shaanxi Province, north of the Weihe River (E107°59′–108°08′, N34°14′–34°20′). It is 7 km long from north to south and 16 km wide from east to west, covering a total area of 94 km^2. The elevation of the district is greatest at the northern end and falls gradually on moving southwards, from 540.1 m asl to 418.0 m. The Weihe River runs along its southern border. The district is located in the terraces and the first, second, and third floodplains of the Weihe, with the town of Wuquan lying on the third floodplain. The annual mean precipitation and evapotranspiration are 637.6 mm and 884.0 mm, respectively.

2.2. Experiment setup

We used an artificial rainfall device to simulate rainfall (Fig. 1). The device consists of the Mariotte bottle as a watering device, the needle plate to produce raindrops, the water tank to supply water for the needle plate, and the vibration generator to produce a uniform distribution of raindrops across the soil box. The Mariotte bottle can supply a constant water level for the water tank to produce uniform distribution rainfall. The aeration pipe is used to adjust the water level in the water tank to produce different rainfall intensity. The needle plate comprises about 650 hypodermic needles, including two types 7# and 8# needles, which were used to produce the low ($\leq$1.0 mm min^{-1}) and high intensity rain ($>$1.0 mm min^{-1}). The rain intensity ranged from 0.3–3.0 mm min^{-1} and the rainfall height is 1.0–1.7 m. The maximum rainfall area is 1.0 m $\times$ 1.5 m and the coefficient of uniformity of rainfall is more than 80%. The rain drop diameter is 0.5–2 mm and its mean velocity is 4.78 m s^{-1}. The mean rainfall kinetic energy per unit time per unit area is 0.2193 J m^{-2} s^{-1}. According to the rainstorm statistical characteristics in the loess hilly regions (Wang and Jiao, 1996), we chose 1.5 mm min^{-1} for this experiment.

The runoff plot is a mobile soil bin with a gradient adjustment device to allow their slope to be adjusted from 0 to 57.7% (Fig. 1). Referred to the previous studies, we set the runoff plot as 1.2 m (length) $\times$ 0.8 m (width) $\times$ 0.45 m (height). They were fitted with four wheels. The plot had apertures at the bottom to allow free movement of soil water. This experiment selected the gradient of 26.8% which was widely existent in 'grain for green' project.

The original soils in Linghou of Wuquan Town, belonging to clay loam, are distinctively different from the common soils (sandy loam or silt loam) of the hilly areas of the Loess Plateau. To represent the soils of the target region as much as possible, we conducted tests and found that a soil texture similar to that of the target region can be

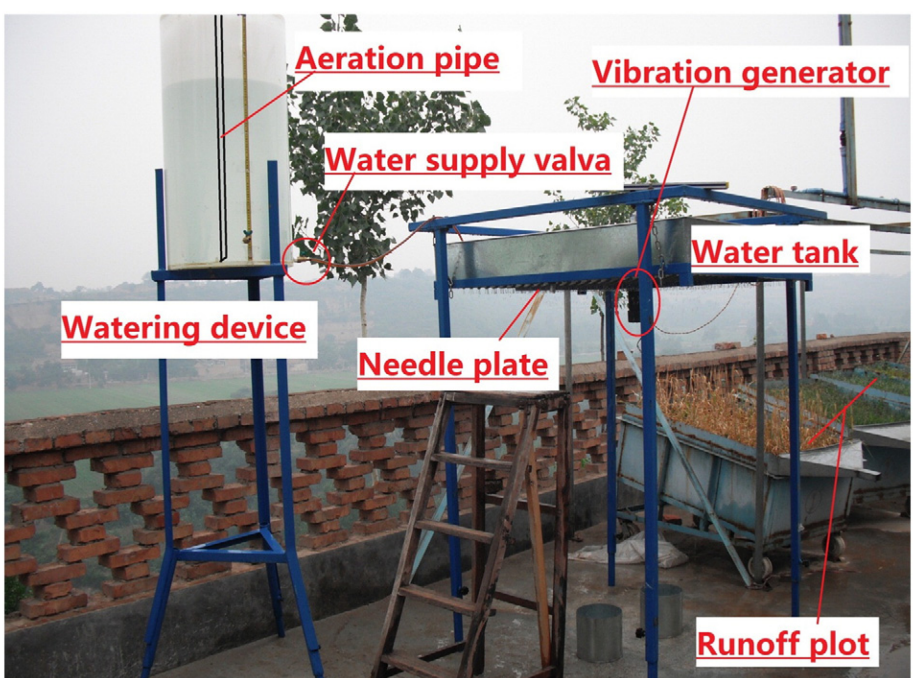

Fig. 1. The artificial rainfall simulator and runoff plots.