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Hydrological responses on saline-sodic soil slopes in a coastal reclamation area of China

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ABSTRACT

Evaluation of the effects of slope gradient and rainfall intensity on the hydrological responses on slopes can provide important information for soil and water conservation. We conducted simulated rainfall experiments to study the hydrological response of a saline-sodic soil on slopes with different gradients (6°, 11°, 22°, and 35°) and rainfall intensities (85, 95, 110, and 125 mm h^{-1}). Higher effective rainfall intensities significantly reduced the times to ponding and runoff. While the infiltration coefficient did not always increase with increasing slope gradient, it consistently increased with increasing rainfall intensity on slopes of 6°, 11°, or 22°. The mean flow velocities and stream power values tended to increase with increasing slope gradient but did not change consistently with changes in rainfall intensity. Hydraulic shear stress and its logarithm could predict sediment losses that were <20 kg m^{-1} h^{-1}. However, stream power and its logarithm were better predictors of a wider range of sediment losses from slopes with saline-sodic soil. These results suggest that existing hydrological and erosion models should be adjusted to take into account the effects of salinity and sodicity.

1. Introduction

Soil erosion is a combination of the detachment and transport of soil materials by natural agents (Ellison, 1947). An accurate understanding of the processes involved in soil detachment and transportation is the main objective of process-based models. These processes are highly dependent on the hydrological responses that occur in soils on slopes. Quantifying these responses to rainfall is necessary for a better understanding of the erosion mechanisms.

The partitioning of rainwater, primarily into infiltration and runoff, and some relatively minor components, e.g., splash from the soil surface, during a rainstorm, has been investigated under a variety of conditions (Essig et al., 2009; Langhans et al., 2011). Rainfall intensity plays a major role in determining the rate and degree of seal formation and the shape of the corresponding infiltration and runoff curves (Betzalel et al., 1995). Defersha and Melesse (2012) found that, while the mean runoff rate increased with increasing rainfall intensity (55–120 mm h^{-1}) for all soil types tested (Vertisols, Cambisols, and Regosols), the proportion of runoff, as signified by the runoff coefficient, did not increase for storms of given durations. Wang et al. (2013b) also found that the rate of surface runoff from bare soils increased with rainfall intensity (45.5–123.9 mm h^{-1}). Soil thickness, surface roughness and mulches also have an important effect on the partitioning of rainwater (Fu et al., 2011; R Mkens et al., 2002; Jean et al., 2000; Jomaa et al., 2012). Wang et al. (2013b) concluded further that the final infiltration rate and the subsurface runoff rate were both affected significantly by interactions between rock fragment cover and rainfall intensity. Mandal et al. (2005) evaluated experimentally the influence of surface stones on infiltration and runoff under field conditions. They found that surface stones could retard surface runoff, and increase final infiltration rates. These studies suggested that the effect of rainfall intensity on the partitioning of rainwater would also be affected by other factors, including soil type and surface conditions.

The influence of slope gradient on partitioning of rainwater into infiltration and runoff has been found to be inconsistent (Luk et al., 1993; Janeau et al., 2003). Slope gradient influences several critical factors affecting the partitioning of rainwater, including the effective rainfall intensity, overland flow depth, surface storage, and surface sealing (Poesen, 1984; Luk et al., 1993). Fox et al. (1997) found that the infiltration rate decreased with increasing slope gradient (2%–20%) but remained unchanged on steeper slopes (20%–39%). They attributed this result to changes in the depth of overland flow and surface storage and noted that the degree of surface sealing did not change with slope angle. However, Assouline and Ben-Hur (2006) reported that the final infiltration rate, which reflects the degree of surface sealing, increased

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with slope gradient (5%–25%). More permeable seal layers were formed as slope gradients increased, which was attributed to reduced compaction of the surface seal due to lower raindrop impact energy along with higher seal destruction rates that generally occur when the slope gradient increases (Poesen, 1986; Warrington et al., 1989). Notably, the soil investigated by Fox et al. (1997) was a sandy loam (28% clay, 22% silt, and 50% sand), which was more susceptible to surface sealing (Fox and Bryan, 2000) than the soil studied by Assouline and Ben-Hur (2006) that was a sandy soil (10% clay, 2% silt, and 88% sand).

Factors influencing the flow velocity on different slopes are also subject to debate. Govers (1992) described an empirical relationship between the mean flow velocity and discharge from slopes of 3.5%–45% for soils ranging from stony sands and silty loams to Vertisols; the empirical relationship was unaffected by slope or soil properties. This relationship was also described by Nearing et al. (1997) but varied with the soil type and level of discharge. However, Abrahams et al. (1996) tested the application of Govers' relationship to the naturally-formed, or self-formed rills, on hillslopes of a semiarid rangeland but found that their data did not support Govers' relationship. They claimed that the slope and soil properties had nearly as much influence as discharge on flow velocity. Gimenez and Govers (2001) investigated Govers' relationship further: the flow velocity was clearly independent of slope when the rill beds could change, which was due to the interactive feedback between the changing morphology of the rill bed and the changing flow conditions.

Various flow hydraulic variables have been proposed and used as predictors of sediment loss by overland flow (Nearing et al., 1991; Elliot and Laflen, 1993; Leonard and Richard, 2004). Nearing et al.

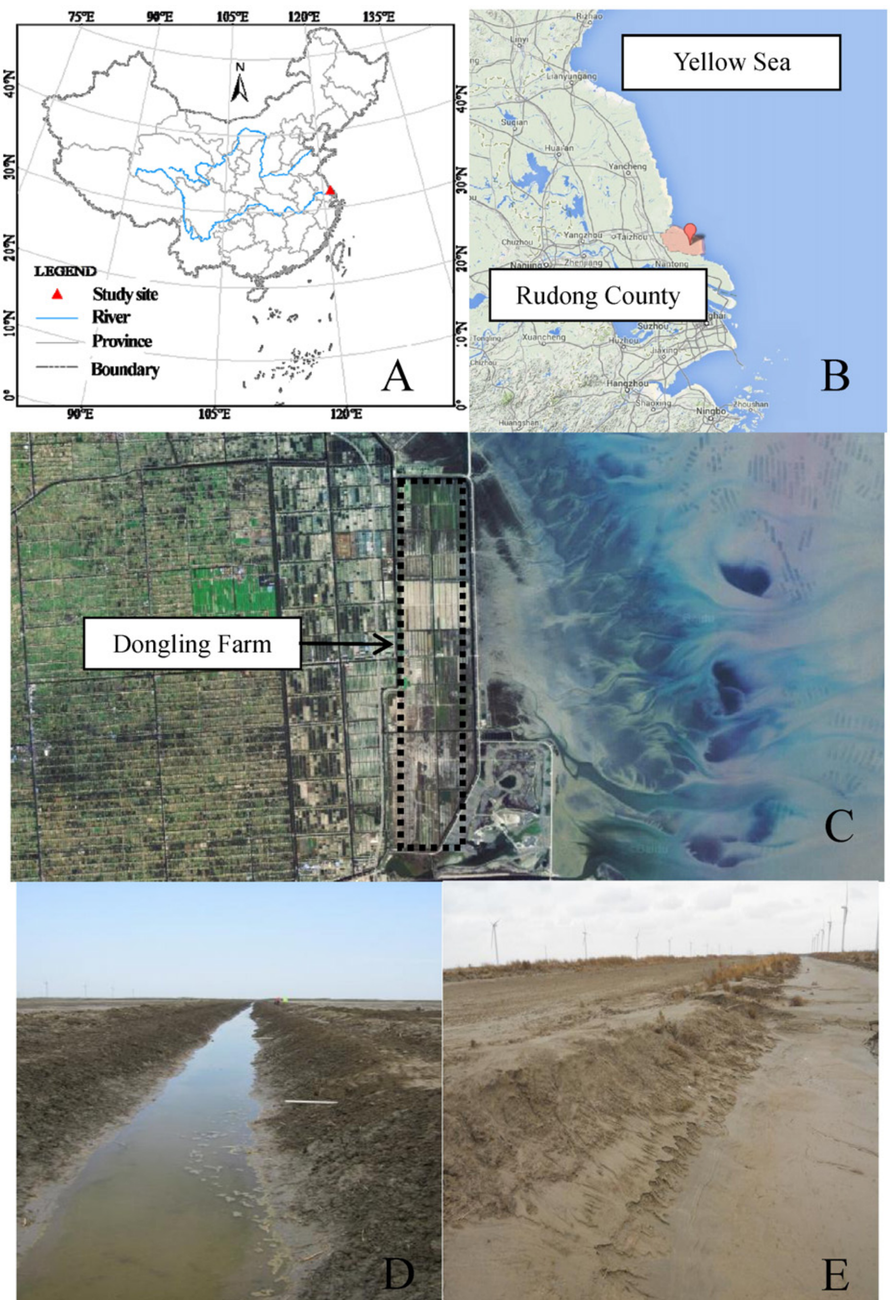

Fig. 1. Locations in (A) Jiangsu Province, China, of (B) the study site, (C) the soil collection site, and an illustration of (D) a recently excavated drainage channel, and (E) the same channel after only one year after excavation at Dongling Farm.