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Assessing impacts of rainfall intensity and slope on dissolved and adsorbed nitrogen loss under bare loessial soil by simulated rainfalls

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ABSTRACT

Nitrogen is of key importance to sustain modern agriculture but how to accurately quantify the loss forms of fertilizer-derived nitrogen has been a challenge for bare loessial soil. We employ 30 simulated rainfalls to evaluate effects of rainfall intensity (45, 60, 75, 90, 105 and 120 mm/h) and slope gradient (5°, 10°, 15°, 20° and 25°) on dissolved and adsorbed nitrogen loss. Here, we show that there was an overall increasing trend of runoff yield with increased rainfall intensity and also an overall increasing trend of sediment yield with increased slope gradient. TN loss at different slopes was more concentrated under rainfall intensities of 45 mm/h and 60 mm/h and more dispersed under rainfall intensities of 75–120 mm/h. *t*-Test results showed that there were no significant differences for 6 TN samples at each slope ($p > 0.05$) and 5 TN samples at each rainfall intensity ($p > 0.05$). All NO_3^--N concentration had a slight declining trend at the beginning of runoff yield and then gradually tended to be gentle with the prolongation of rainfall duration. All NH_4^+-N concentration first showed a sharp decreasing trend and then relatively levelled off with the prolongation of rainfall duration, but it was different and unstable for different rainfall intensities, especially in the first 10 min. Adsorbed TN under bare loess soil occupied -t7.0–82.0% of TN loss with an average of 58.6%, while dissolved TN accounted for 18.0–93.0% with an average of 41.4%. NO_3^--N and NH_4^+-N concentrations respectively accounted for 11.8–73.2% and 1.5–13.3% of TN loss under all combinations of rainfall intensity and slope. There were significant differences in variation trends among NO_3^--N, NH_4^+-N and TN loss load under various rainfall intensities and slopes, but they all presented an overall upward trend with increased rainfall intensity. Our results provide the underlying insights needed to guide nitrogen loss control in sloping land of the loess hilly region.

1. Introduction

Loss of soil nitrogen not only causes the decline of land productivity (Gu et al., 2015), but also leads to potential threats to aquatic environment (Sebilo et al., 2013; Singh and Bakshi, 2013; Zhang, 2017; Yue et al., 2017). The essence of soil nitrogen loss is the interactions between surface soil and rainfall runoff (Wu et al., 2013). Nitrogen is lost through various pathways such as leaching, erosions, runoffs, gaseous loss denitrification and chemo denitrification (Dikshit et al., 2009). The loss patterns of soil nitrogen mainly include: i) lateral migration with surface runoff and sediment, i.e. slope loss; ii) vertical migration with water infiltration, i.e. leaching loss (Wang et al., 2008; Zhang et al., 2015b). Many scholars over the world had used isotope tracer technology to do a lot of researches on nitrogen leaching loss from sloping lands (Prosdocimi et al., 2016; Liu, 2016), while Chinese scholars were mainly focused on factor analysis of nutrient loss in sloping fields (Kang et al., 1999; Ma et al., 2002; Fu et al., 2003). The Loess Plateau is one of the most serious soil erosion areas and one of the typically eco-environmental vulnerable areas over the world (Wu et al., 2016b). The inter-annual change of precipitation on the Loess Plateau was significant, and the precipitation in the wet year was 3–4 times than that in the dry year (Wu et al., 2016d). The intra-annual distribution was uneven, and the precipitation in flood season (6–9 months) accounted for about 70% of the whole year, which was mainly in the form of heavy rainstorms (Wu et al., 2016e). The slope is the important source of soil erosion and the basic component of the

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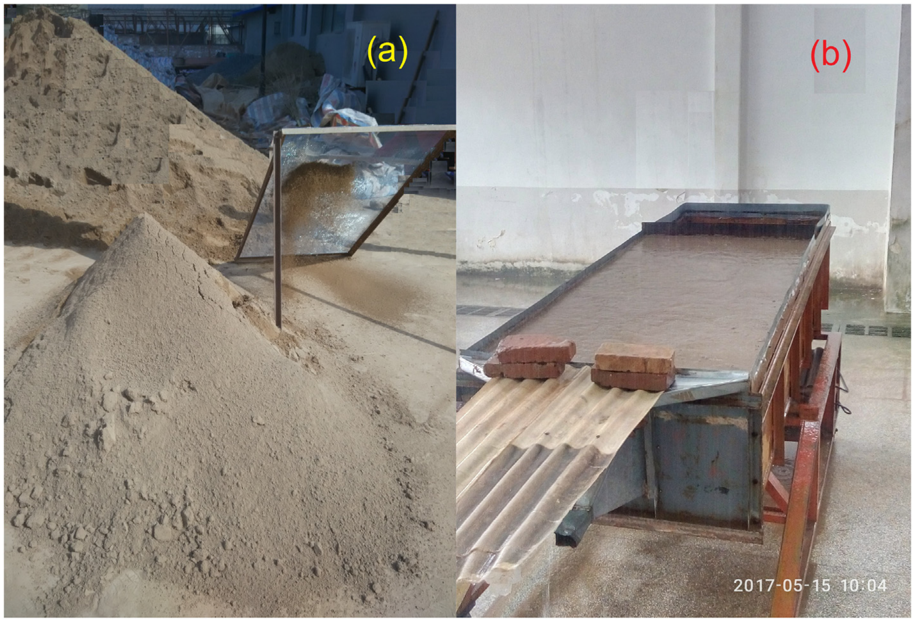

Fig. 1. Tested soil and experimental device: (a) the loessal soil from Zhifanggou Watershed, Shaanxi Province; (b) the designed runoff steel groove for the simulated rainfall experiment.

loess hilly region (Wei et al., 2012). Although Chinese government has taken soil conservation measures such as warp land dams, terraces and afforestation to protect ecological environment of the Loess Plateau since 1997 (Wu et al., 2016c), the percentage of total soil erosion area in the loess hilly area was still considerable. The main challenges for nutrient loss of loessial sloping land include quantifying nitrogen loss patterns in two phases of runoff and sediment, and exploring effects of rainfall intensity and slope gradient on the coupling loss rules of runoff, sediment and nitrogen.

Quantifying the rainfall-runoff process in slope surface is the key to regulating nutrient loss (Chen et al., 2017a). Experimental monitoring and model simulation are two main methods for the quantitative study of soil and nutrient loss (Wu et al., 2012; Zhang et al., 2015a; Wu et al., 2016a; Ouyang et al., 2017). There are many factors affecting soil nitrogen loss, including rainfall intensity, slope gradient, rainfall amount, soil properties, land use types and agricultural measures (Phipps and Crumpton, 1994; Cai et al., 2004; Xie et al., 2014; Chen et al., 2015; Liu et al., 2015). Lu et al. (2012) found that agronomic measures like fertilizer optimization, plastic film, cross ridge, straw mulching could effectively reduce the loss of nitrogen and phosphorus in sloping land of Yunnan Red Soil region. Yan et al. (2014) studied the characteristics of purple soil erosion and nitrogen loss under different fertilizer application levels and tillage methods in the cropping area of winter wheat and summer maize in Chongqing. Zhang et al. (2007) studied the effect of slope gradient on nutrient loss and found that not only soil erosion had a “critical erosion slope”, but soil nitrogen loss also had a “critical nutrient loss slope” when the slope length was considered as a constant. Jiao et al. (2012) designed four treatments including one single-cropping system and three double-cropping systems to evaluate characteristics of surface runoff and nitrogen loss. Wang et al. (2016a) conducted a field runoff scouring experiment on a natural, fallowed loessial slope in order to clarify the influence of vegetation types on surface runoff, sediment transport and nutrient loss. Chen et al. (2017b) conducted a comprehensive study of both rainfall-runoff and runoff-pollutant processes and quantified the impacts of data scarcity on two commonly used methods, including Unit Hydrograph and Loads Estimator, in a typical small catchment of the Three Gorges Reservoir Region of China. Bosch et al. (2015) evaluated impacts of tillage on dissolved losses of NH_4^+-N and NO_3^--N during rotational production of cotton and peanut and found that strip tillage was an effective method for reducing surface runoff and associated soluble losses. Zhang et al. (2017) assessed the effects of rainfall, soil type and land-use change on soil erosion in the Liusha River watershed and found that the greatest variation in sediment yield caused by land-use change occurred where loess was the underlying surface, and red soil showed the next greatest variation, followed by black and finally purple soil.

In summary, most existing studies of soil nutrient loss mainly focused on impacts of various factors including rainfall, slope gradient, scouring flow, farming methods, geographical conditions and soil characteristics on nutrient loss modes, mechanisms and processes (Ma et al., 2016a; Napoli et al., 2017). However, there are few literatures reporting in the related studies about the loss pattern of dissolved and adsorbed nitrogen in two phases of runoff and sediment under bare loess slope. Accurately quantifying dissolved and adsorbed nitrogen loss forms on bare loess soil under different rainfall intensities and slopes is of great scientific significance for nitrogen loss control in sloping farmland of the loess hilly region. The aims of this study are to: i) evaluate the effects of rainfall intensity and slope gradient on runoff, sediment and nitrogen loss under bare loess soil, ii) explore the distribution patterns of nitrogen in runoff and sediment, and iii) reveal the correlations between runoff, sediment and nitrogen loss under different rainfall intensities and slopes. Results may provide scientific reference for nitrogen load estimation and sloping farmland management.

2. Material and methods

2.1. Experimental design

The simulated rainfall experiments were implemented in the Simulated Rainfall Hall of the State Key Laboratory of Soil Erosion and Dryland Farming on the Loess Plateau, Yangling, Shaanxi Province. Two runoff steel grooves (200 cm length × 100 cm width × 45 cm height) with variable slopes of 0–30° were designed according to the existing studies of groove size (Wang et al., 2006; Chen et al., 2017a) and used interchangeably in this study to simulate soil nitrogen loss (Fig. 1). According to the measured results of sloping farmland on the Loess Plateau by Liu et al. (2009), the designed slopes in this study were determined as 5°, 10°, 15°, 20° and 25° which were also consistent with the actual slopes of sloping farmland on the Loess Plateau of China. Because the standard of erosive rainstorm on the Loess Plateau was