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Soil erosion processes on row sideslopes within contour ridging systems

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ABSTRACT

Soil erosion from row sideslopes can result in contour failure and reduce the soil conservation capacity of contour ridges. Understanding soil erosion processes on row sideslopes and their effects will improve our understanding of soil erosion in contour ridge systems. This knowledge will provide guidance for improving the use of contour ridges. In this study, 32 rainfall simulation experiments were conducted in order to analyze the effects of two different microtopography indices (row grade and field slope), two ridge geometry indices (ridge height and ridge width), and rainfall intensity on erosion of sandy brown soil with two replications.

Based on the runoff and sediment yield time series, which was monitored over 1 min intervals, the soil erosion process was classified into periods of interrill or rill erosion. The runoff values for the two periods accounted for approximately 44.2% and 55.8% of the entire runoff value, respectively. Sediment was mainly generated from rill erosion (87.2%). However, interrill erosion occurred most of the time (72.3%). During the interrill erosion period, the ridge width and rainfall intensity significantly and positively affected the amount of runoff (contributions of 33.1 and 28.7%, respectively) and sediment yield per min (14.8 and 17.0%, respectively). Ridge height significantly and positively affected the runoff per min but not the sediment yield per min. In contrast, field slope negatively affected runoff per min, which indicated that the runoff during the interrill period was mainly affected by the ridge geometry, while the sediment yield per min was mainly affected by the microtopography relief. During the rill erosion period, the ridge height significantly and negatively affected the runoff per min because the increasing ridge height prolonged the duration of this period and enhanced infiltration, and the row grade significantly and positively affected the sediment yield per min, which resulted from decreasing soil cohesiveness with increasing row grade. The entire runoff and sediment yield per min during the experiment were influenced by the same factors that influenced the interrill and rill erosion periods, respectively. Interactions between the different factors, especially between ridge height, row grade, and rainfall intensity, play an important role during the erosion process by increasing runoff and sediment yield per min. Therefore, reducing the field slope and using high ridges may reduce contour failure during rainfall events.

1. Introduction

Contour ridging is an effective tillage practice for controlling soil erosion and increasing crop yield (Barton et al., 2004; Quinton and Catt, 2004; Shi et al., 2004; Stevens et al., 2009). In contour ridge systems, the seedbed is mounded above the natural surface to increase soil temperature and moisture, enhance soil depth, control pests and weeds, and increase crop yield (Gupta et al., 1990; Hatfield et al., 1998; Lal, 1990; Wang et al., 2008; X.H. Shi et al., 2012; Z.H. Shi et al., 2012). By increasing the soil surface roughness, contour ridging results in rainwater ponding in the furrow area, which reduces runoff velocity, increases infiltration, and reduces soil erosion (Lal, 1990; Liu and Huang, 2013; Liu et al., 2011; Quinton and Catt, 2004). In addition, nutrients (e.g., nitrogen and phosphorus) in runoff are retained better in contour ridge tillage compared with up- and downslope tillage (Barbosa et al., 2009; Ma et al., 2010; Stevens et al., 2009).

Although the functions of contour ridges in soil conservation have been widely acknowledged, they remain uncertain due to the variations of field slope and microtopographic relief. When the field slope is steep enough so that the ridge top is below the furrow on the upper side of the ridge, the soil conservation capacity of the contour ridge is lost (USDA-ARS, 2008). Due to the microtopographic relief of sloped land, it is impossible to perfectly align the ridge with the contour. Thus, depression areas will be formed in the furrows when the contour ridges are mounded (Cui et al., 2007; Griffith et al., 1990). During a rainfall event, runoff from ridge sideslopes and furrows will accumulate in these depressions. When the ponded rainwater exceeds the storage within a contour row, it overflows the ridge. Rill erosion occurs when the shear stress of this overflow exceeds ridge stability. At this point, the dominant form of erosion transitions from interrill to rill erosion (USDA-ARS, 2008). The rill erosion increases the probability of contour failure. After contour failure, the concentrated rainwater will enhance

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soil erosion with high erosive power (Flanagan and Livingston, 1995; Hatfield et al., 1998; USDA-ARS, 2008). Serious soil erosion induced by contour failure is a common phenomenon in sloped land in North China (Fig. 1).

Soil erosion on the row sideslope is affected by the length and steepness of the row sideslope (Kinnell, 2000; Meyer and Harmon, 1987). The length of the row sideslope positively affects soil erosion (per unit of area) when small rills develop where the hydraulic shear of flowing water is sufficient to denude soil particles from the soil matrix (Kinnell, 2000; Meyer and Harmon, 1987). Another case is when the erosion process is dominated by raindrop detachment and flow transport rather than raindrop detachment and raindrop-induced flow transport, because the system of raindrop detachment and flow transport has sufficient hydraulic shear to entrain the raindrop-detached particles, while raindrop induced flow transport only operates in shallow flow through the combined action of raindrops (Kinnell, 2000). In addition, Meyer and Harmon (1987) observed that soil erosion slightly increased and soil cohesiveness decreased as the slope increased from 5 to 30%.

The contour ridge system is a combination of ridges, adjacent furrows, and the topography of the field where it is implemented. Thus, erosion is affected by geomorphological factors other than the length and steepness of the row sideslope. For example, contour ridge height is an important factor that influences soil erosion in ridge tillage systems. Greater amounts of runoff are stored between taller ridges, which results in greater infiltration and lower runoff and sediment yield (USDA-ARS, 2008). The contour ridge height and width can be used to determine the length of the row sideslope. The existing row grade in a contour ridge system will result in several depressions where runoff is concentrated. A slight row grade may result in severe ephemeral gully erosion (USDA-ARS, 2008). In addition to the microtopographic features mentioned above, field slope strongly influences the runoff and erosion processes on sloped land (USDA-ARS, 2008).

The influences of these factors (especially field slope or ridge height) on soil erosion in contour ridge systems have been studied already during the development of the USLE (Wischmeier and Smith, 1978) and RUSLE (Renard et al., 1997) soil erosion models. In the RUSLE2 user guide (USDA-ARS, 2008), the soil conservation benefit of field slope on soil erosion is described as a concave curve, increasing from no effect to greatest benefit and then decreasing to no effect with the rise of the field slope. The field slope at which the greatest benefit occurs is related to ridge height (USDA-ARS, 2008). Ridge height has a negative effect on soil erosion and is considered as a subfactor to the support practice factor (P) in the RUSLE2 model (USDA-ARS, 2008). However, the quantitative influences of microtopography indices (e.g., row grade and field slope), ridge geometry indices (e.g., ridge height and width) and their interactions during different rainfall intensities on the sideslope erosion of rows remain unclear. Thus, understanding this soil erosion process and its influencing factors will improve our knowledge regarding soil erosion and will potentially improve soil conservation practices using contour ridge systems. This study addresses the influence of combination of different topographical features and their interactions on the erosion process of contour ridge systems. The specific objectives of this study were to (i) reveal the processes of interrill and rill erosion on row sideslopes; and (ii) interpret the effects and interactions of microtopography, ridge geometry and rainfall intensity on runoff and sediment yield.

2. Materials and methods

2.1. Experimental design

In order to analyze the effects on soil erosion on row sideslopes, 32 rainfall simulation experiments were conducted. Five different factors were analyzed in this study, including two microtopography indices (row grade, RG, and field slope, FS), two ridge geometry indices (ridge height, H, and ridge width, W), and rainfall intensity (RI) in two levels (Table 1). The two levels of row grade, ridge height and width were determined according to a previous field investigation. The effects and first-order interactions of the five factors were arranged in an $L_{16}(2^5)$ orthogonal array created by the Taguchi method. Under this method, the effect and interaction of factors can be calculated and the significance tested using statistical software (e.g., SPSS), and the optimal parameters and their levels can be determined. An important advantage of the Taguchi method is that the overall testing time and experiential costs can be significantly minimized compared with a full factorial design, especially when the number of factors and levels increase (Sadeghi et al., 2012). In this experiment, all treatments were replicated twice.

2.2. Experiment plots

In order to analyze row grade and field slope simultaneously, a new type of experimental plot was designed for this study. The experimental plot consisted of a box including two stainless steel cassettes (80 cm wide and 160 cm long) that were hinged together, which could be filled with soil (Fig. 2). By rotating the screw (a) with one apex fixed on the cassette boundary and another apex fixed on the chassis, the box could be lifted up or down to simulate different row grades between 0° and 15°. The field slope along the plot was obtained from 0° to 20° by rotating the screw fixed under the two stabilizer blades (b).

A sandy brown soil that developed from granite with a sand content of 71.2% (Table 2) was used in this study. The soil collected from the plow layer was air dried before passing through a 10.0 mm sieve. The soil of the plow pan was simulated by packing the soil at a depth of 20 cm (in four 5 cm layers) to a bulk density of 1.6 g cm^{-3} (the measured bulk density in the field). The soil packed into the plot was kept in the same weight in a given row grade treatments by adjusting the levels of the furrow bottoms at a bulk density of 1.2 g cm^{-3}.

Fig. 1. Erosion induced by contour failure in the field (typical slope land in North China).