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Soil splash detachment and its spatial distribution under corn and soybean cover

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ABSTRACT

To evaluate the effects of splash erosion on crops, throughfall and splash detachment were measured in different crop-growth stages and rainfall intensities under corn and soybean cover. The relation between splash detachment under the crop canopy and leaf area index and throughfall intensity was analyzed. The characteristics of the spatial distribution of splash detachment under the crop canopy were discussed as well. The results indicated that, compared with bare soil, the average splash detachment rate under the canopy during corn growth was reduced from 77% to 43%, with an average of 68% approximately, while a soybean canopy can reduce the splash detachment rate from 77% to 48% with an average of 61% approximately during the growth stage. The splash erosion detachment rate increased significantly with increasing leaf area index and rainfall intensity. The throughfall was concentrated in the centers of rows as crop grows, and a sharp increase in the splash detachment rate was caused by concentrations of throughfall under the canopy, which resulted in uneven distribution of splash detachment. The spatial distributions of splash detachment depended on the spatial distributions of throughfall under the crop canopy. The change in throughfall intensity under the canopy was the main reason for the variation in splash detachment. The reduction of kinetic energy because of interception by the crop canopy contributed to a decrease in splash erosion. However, large raindrops formed at the tips and edges of leaves can generate substantial erosion, and this part of the splash may become the main portion of splash erosion under the canopy. These results indicated that continuous and concentrated raindrops impacted splash detachment and caused its uneven distribution under crop cover.

1. Introduction

Splash erosion is a process of detachment and transportation of soil which is caused by the impact of raindrops reaching the soil surface. It happens mainly before runoff starts or at the beginning of runoff (Zheng et al., 2008). The impact of raindrops detaches the soil, destroys soil structure, increases runoff turbulence, and enhances the detaching and transporting capacity of surface flow. It makes a great contribution to the development of sheet erosion (Zhu, 1981). Splash erosion is also an important component of the soil-erosion process. Law and Sreenivas started the study of splash erosion as early as the 1940s, after which many researchers developed similar discussions (Law and Parsons, 1943; Sreenivas et al., 1947). Some of their results linked splash intensity with factors such as cover, slope, soil erosion propensity, and physical parameters of rainfall (Liu et al., 2011; Ma et al., 2010; Miao et al., 2011; Zheng et al., 2009; Zhou et al., 2008, 2009). Typically, the higher the speed at which raindrops hit the soil, the more soil is splashed; the larger the diameter of raindrops, the bigger will be the impact area, and higher rainfall intensity means more erosion (Guo, 1997; Han et al., 2010; Morgan, 1982; Moss and Green, 1987; Zheng et al., 2008). The relationship between splash erosion and rainfall physical parameters can be described using rainfall kinetic energy and momentum (Gao and Bao, 2001; Jiang et al., 1983; Law and Parsons, 1943; Mou, 1983; Xu, 1983; Zhang et al., 2002).

The effect of crops on splash erosion was different from that of forest and grassland because of the special environment and of human management in the crop growth stage. Sreenivas et al. (1947) was one of the earliest researchers studying splash erosion under crop cover. He found that splash intensity decreased with increasing canopy density and decreasing canopy height. However, Morgan (1982) presented different opinions after further research. He suggested that there was a complex relation between rainfall energy and splash erosion. He supported the conclusion that the reduction in the value of rainfall energy was not proportionate to the amount of interception by the crop

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canopy. The effect of crops on splash was mainly dominated by changes in throughfall intensity, the diameter distribution of water drops under the canopy, and throughfall energy. He also noted that the effect of crops on splash was changed not only by rain characteristics, but also by crop coverage, surface soil crust, rainfall intensity, and various other factors must be considered while evaluating the effects of crops on splash erosion. With further research, Noble and Morgan (1983) discovered that the proportion of large raindrops forming at the edges of kale leaves (*Brassica oleracea* Linnaeus) to total rainfall did not correspond to their effects on splash detachment and that the effects were not proportionate. Finney (1984) believed that as crops like kale, beets (*Beta vulgaris* Linn.), and potatoes (*Solanum tuberosum* L.) grew, the increase in canopy interception would make throughfall decrease, but that dripping water from leaf edges would still increase. He concluded that this would result in more drastic splash erosion because of the larger raindrops and the higher energy of dripping water forming at leaf edges in some regions under the crop canopy, although total splash erosion was decreased. After examination of corn and soybeans, Morgan (1985) found that the effects of these two crops on splash erosion were exactly opposite. Splash erosion increased with corn coverage and was about 1.5–2 times the erosion on bare soil when the canopy coverage was greater than 90%. For soybeans, splash decreased as canopy coverage increased, and erosion was only 20%–60% of that on bare land when the canopy coverage became greater than 90%. The growth of the corn canopy enhanced raindrop splash erosion because of the interaction among size of throughfall raindrops, falling distance, and splash erosion; on the other hand, when the falling distance of throughfall raindrops is greater, they may accumulate more energy and strengthen splash (Morgan, 1985). Inside or underneath canopies, there was no splash when the distance was less than 0.3 m. However, as distance increased, erosion ability would increase gradually, and the erosion propensity of raindrops would increase rapidly, especially for raindrops falling from more than two meters high (Moss and Green, 1987). From Morgan's results, splash intensities in different areas under canopies exhibited substantial differences, an observation which also explains the uneven distribution of splash in the space under crop canopies (Ma, 2009; Morgan, 1982, 1985; Noble and Morgan, 1983). Armstrong and Mitchell (1987, 1988) hypothesized that the spatial distribution of throughfall under the canopy was a critical factor for splash erosion. It was assumed that it would strength splash at some locations under crop canopies because of the concentrated distribution of rainfall. They found that the potential splash intensity for a soybean canopy varied from 5% to 304% of that on bare land. The effects of crop canopy on splash erosion are complex, and significant differences exist among crops because of the diversity of their morphological and structural characteristics.

Corn and soybeans are important food and commercial crops on the Loess Plateau. The growth periods of the two crops coincide with the timing of rainstorms. The purpose of this research is to evaluate throughfall, splash erosion, and LAI under crop canopies during different growth stages and to discover the relationships between splash erosion and LAI, throughfall intensity, and rainfall intensity to determine the spatial distribution characteristics of splash erosion with respect to the throughfall distribution. This study will provide the practical basis for water and fertilizer management of cropland as well as for the study of soil erosion, thus making a contribution to further understanding of fundamental erosion process and mechanics.

2. Materials and methods

2.1. General information

The research area is located in Yang Ling, Shanxi Province, which is on the southern edge of the Loess Plateau. Experiments were conducted in the Simulated Rainfall Hall at Northwest A&F University. The simulated rainfall laboratory has been in operation since it was finished in 2005. It has an area of 200 m^2 and a height of 4.5 m. A rainfall simulation system was installed on the ceiling of the lab. The rainfall simulator was designed and constructed by the Institute of Soil and Water Conservation, Yangling, China. The downward-facing sprinkling rainfall simulation system was similar to that used by Jin et al. (2008). Four nozzles were positioned at a drop fall height of 4 m. The rainfall simulator consisted of two 3 m-long sprinkler booms, each positioned 30 cm apart on each sprinkler boom, and two nozzles fixed 1.5 m apart. Different rainfall intensities could be achieved by changing the hydrostatic pressure by moving the valve system horizontally. The mean drop size of the rainfall simulator was 1.8 mm, and the kinetic energy of the rainfall simulator was approximately 75% of that of natural rainfall (Ma, 2009). The effective rainfall area of the simulator was 3 m × 3 m, and rainfall uniformity was >80% as calculated by the following formula using rain gauge.

$$RN = 1 - \frac{\sum_{i=1}^{n} |P_i - \overline{P}|}{n\overline{P}} \tag{1}$$

where RN is the rainfall uniformity (%), P_i is the rain capacity in the ith rain gauge (mm), $\overline{P}$ is the average rain capacity (mm), and n is the number of rain gauges.

2.2. Research design

The corn used in this study was Zhengdan 958 and was started from seed on June 20, 2009. According to the local conditions, the row and plant spacings in cornfields were 60 cm and 25 cm. On each, crop plants were cut at ground level. The crops were grown nearby, so that plants could be taken quickly into the laboratory. The leaf area and the effects on splash erosion under throughfall during the growing season were tested. The soybeans used in the research were Zhonghuang 13 and were started from seed on June 30, 2007 with a planting density of 20 cm × 40 cm. Planting management was conducted according to local custom, and the whole growing period of corn was divided into a seedling stage (V4), an early jointing stage (V6), a middle jointing stage (V9), a late jointing stage (V12), and a tasseling stage (VT) according to the growth and leaf conditions of corn plants. The whole growing period of soybean was divided into an initial blossoming stage (R1), a full flowering stage (R2), an initial pod-filling stage (R4), and a pod-bearing stage (R6). Simulated rainfall was provided during the corn and soybean growing period in each growth stage. The soil used in this study was Eum-Orthic Anthrosol, which is a kind of Cumulic soil in WRB. To avoid wilt during long-duration experiments, the rainfall intensities in each growth stage were 40 mm h^{-1} and 80 mm h^{-1}, with 30 min of rainfall according to the local storm characteristics that are concentrated in summer and autumn. The crop growth, vegetative growth stages and average leaf area for each sample date are shown in Table 1.

2.3. Measurement of throughfall

To test throughfall and splash intensities for the cropland at different places and growing times, eight corn or soybean plants were cut randomly and taken to the laboratory during the observation period. They were fixed on iron stands and placed in the same position as on the cropland to simulate the real spacing conditions outside. The row spacing of corn was 60 cm—the same as actual conditions—and the row length was 100 cm; the row spacing of soybeans was 40 cm, and the row length was 70 cm. Rain gauges 5.5 cm in diameter and 7 cm in height were placed under the crop canopy in a matrix pattern (Fig. 1). With a design rainfall intensity of 30 min, these gauges collected and measured water amounts inside and calculated rainfall intensity at different spots under the canopy.