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Combined influences of wheat-seedling cover and antecedent soil moisture on sheet erosion in small-flumes

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ABSTRACT

Assessing and predicting soil erosion requires knowledge of the influences of antecedent soil moisture and vegetation cover as well as of their combined effects on soil erosion processes. Past research typically focused on either vegetation cover or antecedent soil moisture. Even though these parameters are likely related under field conditions, studies on their synchronous combined effect on soil erosion processes are scarce. We conducted laboratory experiments on soil erosion using simulated rainstorms (intensity 77 ± 4.5 mm h^{-1}; 60 min duration) on a light loamy soil under different levels of wheat-seedling cover and antecedent soil moisture that were both produced by different sprayed applications of water (30, 40, 50, 60 or 70 mm) during a 40- to 44-day growing period. The objective was to explore the effect of the combined effects of wheat-seedling cover and antecedent soil moisture on soil erosion. Wheat-seedling cover and antecedent soil moisture increased with applied water levels from 9.7% to 37.2% and from 8.4% to 12.2%, respectively. The shortest time to runoff was observed for intermediate values of cover and antecedent moisture (60-mm water level). Infiltration rates and total infiltration generally decreased with increases in water applications. Runoff rate and soil loss were not significantly different ($P > 0.05$) among the 40-, 50- and 60-mm water treatments, but abruptly increased under the 70-mm treatment. At the 70-mm level, the total runoff volume and total soil loss were, respectively, between 15% and 37% and between 15% and 45% higher than those at the other water levels were. Antecedent soil moisture was the predominant factor affecting infiltration, runoff and soil loss during the rainstorms. In this study, the effects of the relatively low wheat-seedling covers were obscured by those of the antecedent soil moisture at the small-flume scale. This suggests that the effects of vegetation cover and antecedent soil moisture on soil erosion should be considered together when assessing and predicting soil erosion.

1. Introduction

Soil erosion is a widespread and major environmental threat to terrestrial ecosystems. Its severity varies over time and at different locations on the ground surface, depending on the combined actions of climate, surface runoff, soil composition, topography, vegetation cover, and soil management and conservation practices (Montenegro et al., 2013).

Rainfall is not only the primary cause of most soil erosion by water, it is also a crucial factor that affects certain secondary influencing factors related to erosion, in particular vegetation growth and soil water content (Hou et al., 1996; Asselman et al., 2003). The characteristics of a locality's vegetation, including vegetation type, net primary productivity, vegetation cover, biomass and root to shoot ratio, as well as its soil water content, are dependent on the amount and distribution of rainfall. In general, higher annual precipitation results in more abundant vegetation cover and higher soil water contents, whereas lower annual precipitation results in sparser vegetation cover and lower soil water contents.

The importance of vegetation in preventing soil erosion has long been recognized (Morgan, 2005). In general, vegetation mitigates soil erosion mainly by reducing the detachment forces of falling or flowing water and by consolidating the soil structure thereby increasing its resistance to erosion. Vegetation can reduce the forces of water by intercepting rainfall (Durán and Rodríguez, 2008), thereby reducing runoff (Ziegler and Giambelluca, 1998;

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Wainwright et al., 2002; Rey, 2003; Puigdefabregas, 2005; Durán et al., 2006, 2008) and raindrop kinetic energy (Bochet et al., 1998; Durán et al., 2008), and by retarding overland flow (Styczen and Morgan, 1995). In addition, vegetation can increase soil resistance to erosion by increasing soil aggregate stability and cohesion, and by stabilizing the soil by the binding action of its roots (Gyssels et al., 2005; De Baets et al., 2007). The relationship between vegetation cover and soil loss and/or runoff has generally been described by a negative exponential function (Gyssels et al., 2005). However, some studies have also indicated that this function should be limited to a specific range of vegetation cover for soil erosion (De Ploey et al., 1976; Rogers and Schumm, 1991). Rogers and Schumm (1991) found that the relationship best describing the effect of vegetation cover on sediment yield is neither linear nor exponential when vegetation cover is less than 15%.

In addition, various vegetation morphologies have different effects on soil erosion (Van Dijk et al., 1996; Bochet et al., 2006). Van Dijk et al. (1996) showed that plant height and the completeness of the canopy cover were key features affecting sediment entrapment. Bochet et al. (2006) reported on the variation in the performance of different plant species in reducing runoff and soil loss, and explained that the different effects on erosion resulted from the species' different morphologies and components. Therefore, vegetation can radically control soil and water losses.

Antecedent soil moisture is an important variable affecting soil erosion processes and may be responsible for much of the variation in splash and water erosion rates (Truman and Bradford, 1990). Many previous studies have indicated that antecedent soil water content affected the partitioning of rainfall into infiltration and runoff (Le Bissonnais and Singer, 1992; McDowell and Sharpley, 2002; Wei et al., 2007) and thereby influenced soil erosion (McDowell and Sharpley, 2002; Wei et al., 2007). However, the effects of antecedent soil water content on the infiltration process, runoff production and soil loss are still unclear, and opposing effects have been observed (Kemper and Rosenau, 1984; Luk, 1985; Bullock et al., 1988; Truman and Bradford, 1990; Reichert and Norton, 1994; Le Bissonnais et al., 1995; Rejman et al., 2001; Lado and Ben-Hur, 2004; Bochet et al., 2006; Vermang et al., 2009; Defersha and Melesse, 2012). Bochet et al. (2006) found that antecedent soil water content strongly influenced runoff and soil loss rates; lower erosion rates occurred from soils when they were initially wetter. Conversely, Luk (1985) observed that soil losses from two silt loam soils increased by as much as five-fold as the antecedent soil water content ranged from close to the wilting point to saturation in interrill plots. Similarly, Le Bissonnais et al. (1995) observed that total runoff and erosion were less from soils when they were air-dried than when they were moist because of a delay in seal formation and runoff initiation. Vermang et al. (2009) observed that no runoff or soil loss occurred in their study for the highest antecedent soil water content (19%), while the highest total runoff was observed for an intermediate antecedent soil water content (12%) and the highest soil loss was observed from the soil with the lowest antecedent soil water content (4%).

Rejman et al. (2001) found that soil losses from a Polish chernozem soil were mostly affected by the antecedent soil water content when caused by splashing, while surface micro-topography was the main factor when the losses were due to overland flow detachment and transportation. In addition, the effect of antecedent soil moisture on runoff and soil loss varied with soil type, slope and rainfall intensity (Mamedov et al., 2002; Defersha and Melesse, 2012). The opposing results reported by these previous studies can be attributed, to a certain extent, to the interactions between soil water content and other soil properties such as organic matter and clay contents, aggregate stability, and other factors such as the pre-wetting method and rate of wetting (Levy et al., 1997). Antecedent soil moisture should thus be considered as an influencing factor in at least some soil erosion prediction models (Vermang et al., 2009). Further research still needs to be carried out in order to better understand the relationship between soil loss and antecedent soil moisture.

In most cases, antecedent soil moisture and vegetation cover vary in different areas and at different times within the same region. Soil erosion always occurs on a sloping surface, which generally has differing levels of antecedent soil moisture and vegetation cover. Furthermore, vegetation cover and soil water contents are interlinked due to the water requirement for plant growth. As shown by the studies cited above, increasing vegetation cover typically reduces soil losses. In contrast, increasing antecedent soil moisture might have positive or negative effects on soil loss. It can be hypothesized that combined effects of various levels of vegetation cover and antecedent soil moisture on infiltration, runoff production and soil loss should exist and be dependent on each other. Furthermore, the combined contribution would differ from the independent, individual contributions of vegetation cover and antecedent soil moisture to the variations in infiltration, runoff production and soil loss. However, most previous studies have only investigated the relationships between soil erosion and vegetation cover or antecedent soil moisture as separate factors. Their synchronous effects on soil erosion have never been considered to the best of our knowledge.

Therefore, this study's objective was to explore the synchronous combined effects of a series of vegetation covers and antecedent soil water contents produced by different levels of water application on infiltration, runoff and sheet erosion using small-flume laboratory rainfall simulation experiments. The results should enhance our understanding of the relationships among soil water content, vegetation and sheet erosion and thereby improve the assessment and prediction of soil erosion.

2. Materials and methods

2.1. Experimental design

This study consisted of two stages. The first stage was to produce the different degrees of wheat-seedling cover and antecedent soil water contents, and was a preparatory stage for the second stage, i.e., the rainfall simulation experiment that determined erosion. In the first stage, one vegetation cover species (wheat seedlings) was selected and sown in the small-flumes, which were irrigated by sprayed applications of water at five different levels (30, 40, 50, 60 and 70 mm) during this experimental stage; details are given in Section 2.1.2 below. Under the five different applied water levels, the canopies of the seedlings developed different degrees of cover, while concurrently inducing different antecedent soil moisture conditions prior to the rainfall simulation erosion study stage. Five water levels produced five combinations of cover and water content, and each of these combination tests was produced and investigated in three replications.

The second stage was an erosion experiment and involved the application of simulated rainfall to induce soil erosion. Since the main purpose of the study was to observe the combined effects of vegetation cover and antecedent soil water content on erosion, other variables that would affect erosion were kept constant. Hence, erosion from only one soil type, one rainfall intensity ($90\ mm\ h^{-1}$) and one slope gradient (15°) was considered.

2.1.1. Cultivating wheat

Wheat was selected as the experimental plant species because it is easily controlled during the experimental period and it is a typical crop widely grown on the Loess Plateau. Wheat seedlings