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Degradation of the soil surface roughness by rainfall in two loess soils

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ABSTRACT

The soil surface roughness is one of the main factors affecting wind erosion. Little is known about the influence of rains on the degradation rate of the soil surface roughness in different tillage systems and soil types. The purpose of this paper was to evaluate the dynamics of the oriented (Kr) and the random (Crr) soil surface roughness as affected by three tillage tools: a disk tandem (DT), a lister-bedder (LB) and a drill-hoe (DH), and two rain amounts (7 and 28 mm), in two soil types (an Entic Haplustoll and a Typic Ustipsamment). Measured Kr and Crr decay rates were compared with the predicted data, according to the equations provided by the Revised Wind Erosion Equation (RWEQ). Results indicated that initial Kr values were different in each tillage tool in both soils (LB>DH>DT, $p<0.05$), while Crr values were mostly similar. The degradation rate of Kr (ORR) was in general higher in the Ustipsamment than in the Haplustoll and in DT than in DH and LB, in both soils. The degradation rate of Crr (RRR) was affected by the soil type (mostly higher in the Ustipsamment than in the Haplustoll) but not by tillage. Increasing rains degraded Kr and Crr at higher rates in both soils, but Kr degraded relatively less when its initial values were higher (LB<DH<DT). RWEQ equations underestimated the soil surface roughness decay in both studied soils, between 60 and 72% for RRR and between 90 and 97% for ORR. The accumulated rain amounts (CUMR) and rain energy (CUMEI) allowed a good prediction of the relative degradation of the oriented roughness. The relative Kr variation as a function of the initial Kr value varied potential negatively and were different for each soil and rain amounts. These equations may allow the calculation of the degradation rate of the oriented roughness as affected by certain rain amounts and the initial Kr. In view of these results it must be further investigated if a unique equation can be developed for predicting soil surface degradation for different soils and rain amounts.

1. Introduction

Wind erosion is an important soil degradation process in semiarid regions, which can be substantially reduced by the soil surface roughness (Jester and Klik, 2005). The soil surface roughness modifies the wind profile, increasing the height of the wind shear velocity near the soil surface, decreasing its erosion (Stout and Zobeck, 1996). This makes the surface roughness act as a shelter, protecting the soil surface against the impact of saltating grains (Zobeck and Popham, 2001).

Soil surface roughness can also affect several physical soil properties such as infiltration, solar radiation and reflection, soil temperature, and trafficability (Zobeck and Onstad, 1987). More recent studies consider that soil surface roughness acts at small scales as an erodibility factor determining the resistance or vulnerability of the soil to erosion. At higher scales roughness becomes an erosivity factor, structurally mediating erosive energy of wind and water (Merrill et al., 2001).

The soil surface roughness is a parameter of the SOIL subroutines of most existing wind erosion prediction models, for example the Wind Erosion Equation (WEQ, Woodruff and Siddoway, 1965), the Revised Wind Erosion Equation (RWEQ, Fryrear et al., 1998) and the Wind Erosion Prediction System (WEPS, Hagen, 1991). These models consider precipitation as the most important factor for soil roughness degradation.

RWEQ has been demonstrated to be a reliable model for predicting wind erosion in many parts of the world (Fryrear et al., 1998; Van Pelt et al., 2004; Zobeck et al., 2001) including the semiarid Pampas of Argentina (Buschiazzo and Zobeck, 2008). This model calculates the degradation rate of both, the oriented and the random roughness on the basis of the accumulated rains, the rainfall energy index and a decay factor which depends on soil texture and organic matter contents (Potter, 1990; Saleh, 1997). The degradation rate of both roughness is calculated on the basis of the quotient between their initial and final values after a rain event. This calculation may underestimate K′, the factor that unifies Crr and Kr, and that is used in the model to predict wind erosion amounts. This is because the consideration of a relative Kr value at the start of each successive wind

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erosion period can be much smaller and not related to the initial Kr value. It is known that the height of the ridges is the main factor driving wind erosion (Lyles and Tatarko, 1987; Zobeck and Popham, 2001), therefore we assume that the consideration of the initial Kr value for calculating K′ in successive erosion events can improve the performance of the model for predicting the soil surface roughness decay rate as a function of rains.

Many authors analyzed the effect of rains on the random roughness (Crr), for example Burwell and Larson (1969), Dexter (1977), Johnson et al. (1979) Onstad et al. (1984) and Steichen (1984) found larger Crr changes as a function of increasing rainfall kinetic energies and Onstad et al. (1984), Römkens and Wang (1985) and Potter (1990) as a function of increasing accumulated rainfall. Zobeck and Popham (2001) found that the rate of degradation of the random roughness by rains of the same energies depends on its initial values. In general, this change increases with larger initial roughness values. Zobeck and Popham, 2001 demonstrated that the rate of change in random roughness also depended on the initial roughness value.

The degradation of the oriented roughness (Kr) as a function of rains has been less studied than that of the random roughness (Crr). Lyles and Tatarko (1987) found that the decay of ridge height was better explained by two- and three variable regression equations, where the cumulative precipitation, the sand to silt ratio and the organic matter contents were included. Other studies indicated that the decay of soil ridges is much slower than that of soil aggregates, ridges being more stable and effective for controlling wind erosion when the wind direction was perpendicular to the ridges (Saleh and Fryrear, 1997). Lyles and Tatarko (1987) indicated that the ridge height ratio (the quotient between the final and the initial ridge height) decreases with increasing precipitation, depending on its initial height, which is defined by tillage type and soil conditions at the time of operation. These authors also found that cumulative rains were the primary factors influencing changes in ridge height, while soil properties were secondary factors. Saleh (1997) concluded that soil ridge decay is influenced by the initial roughness value.

The calculation of soil surface degradation rates by RWEQ includes a soil factor which depends on clay and organic matter contents. This factor reflects the stability of soil aggregates against the degradation effects of rains. López et al. (2007) demonstrated that the equation considered by RWEQ for calculating the amount of erodible fraction (aggregates finer than 0.84 mm, directly related to the potential erosivity of the soil), does not predict this fraction adequately for soils of the semiarid Pampas of Argentina. These authors concluded that properties regulating the aggregate stability of soils of this region are different from those considered by RWEQ.

Another issue to be considered in relation to the calculation of the degradation rate of the soil roughness by wind erosion prediction models is use of both the accumulated rainfall amounts (CUMR) and the storm energy (CUMEI). Some authors suggest that CUMR can be used without considering CUMEI (Cogo et al., 1984; Mannering et al., 1966; Potter, 1990; Zobeck and Onstad, 1987). If this is true the SOIL ROUGHNESS subroutines of the RWEQ can be simplified as the calculation of CUMR is much simpler than that of CUMEI.

Based on former results, the objective of this study was to evaluate the dynamics of soil roughness decay (oriented and non-oriented) as a function of rains, in different tillage systems in two different textured soils. The purpose of this analysis was to evaluate if equations of RWEQ can be used in their present state for calculating the degradation of both, the oriented and the random roughness of soils of the semiarid Pampas of Argentina.

2. Material and methods

Two different textured soils of the semiarid Pampas of Argentina were used for this study: a loamy-sand Entic Haplustoll and a sandy Typic Ustipsamment (INTA et al., 1980). The Haplustoll was placed within the Experimental Field of the Faculty of Agronomy of La Pampa National University (36°34′ S and 64°16′ W), and the Ustipsamment within the Experimental Field of the Anguil Experimental Station of INTA (36°52′ S and 64°02′ W).

The Entic Haplustoll had a horizon sequence A–AC–C–C_k (INTA et al., 1980). It content was 11% of clay, 19% of silt, 70% of sand, 1.6% of organic matter and its field capacity was 13.6%. The initial aggregate size distribution for this soil was: >19.2 mm (54.2%), 19.2–6.4 mm (17.1%), 6.4–2.0 mm (7.2%), 2.0–0.84 mm (3.1%), 0.84–0.42 mm (2.4%) and <0.42 mm (16.1%). The Typic Ustipsamment had a horizon sequence A–AC–C (INTA et al., 1980), 7% of clay, 10% of silt, 83% of sand, 2.2% organic matter, 7.8% field capacity and its initial aggregate size distribution was: >19.2 mm (46%), 19.2–6.4 mm (14.6%), 6.4–2.0 mm (6%), 2.0–0.84 mm (2.9%), 0.84–0.42 mm (4.4%) and <0.42 mm (26.1%).

The following treatments were carried out in order to simulate contrasting soil surface conditions produced by different tillage tools: lister-bedder (LB), drill-hoe (DH) and disk tandem (DT). An overview of the soil surface roughness produced by each tillage tool is illustrated in Fig. 1 and their characteristics are listed in Table 1. The random and the oriented roughness data produced by each tillage tool are presented in Table 2. Ridges had approximately 1:1 side slopes in this study, differing from the 1:3 sized slopes provided by RWEQ.

The effect of rains on the degradation rate of the soil surface roughness was performed with a rain simulator. This device consisted of a square frame supported by four expandable foots that allowed its leveling. The square frame supported a tube connected to a nozzle and a manometer. A Miscela CM 46, 1.75 HP motor was used to pump the water from a 2000 L tank. The nozzle was a 460.968.30 CG model, developed by Lechler GmbH, Fellbach, Germany. The nozzle was placed at 3.4 m height above the soil surface and covered a diameter wetting area of 4 m. The experiment design is presented in Fig. 2.

Rain simulations were carried out at a constant water pressure of 1 kg cm^{-2}, corresponding to a water flow of 42 mm h^{-1}. Two simulations times were used: 10 and 40 min, which represent 1.83 and 7.30 Mj ha^{-1} and total rains amounts of 7 and 28 mm, respectively.

The rain energy at each simulation time was calculated with the following equation (Foster et al., 1981):

$$e = 0.119 + 0.0873 * \log i \tag{1}$$

where e is the rain energy in Mj ha^{-1} and i is the rain intensity in mm h^{-1}, when $i \leq 76$ mm h^{-1}.

Determinations of random and oriented soil surface roughness were carried out before and after rain simulations by quintuplicate in all cases. The readings were averaged in order to obtain a unique Crr and Kr value.

The oriented roughness (Kr) was measured on the basis of the height and the wide of the ridges, by means of the following equation (Zingg and Woodruff, 1951):

$$Kr = 4\left[(RH)^2 / (RS)\right] \tag{2}$$

where Kr is the soil oriented roughness in cm; RH is the ridge height in cm and RS the ridge spacing in cm. The initial Kr values of each treatment in both soils are presented in Table 2.

The random roughness (Crr) was measured parallel to the ridges by means of the chain method (Saleh, 1993) and calculated with the following equation:

$$Crr = (1 - L_2 / L_1) * 100 \tag{3}$$

where Crr is non-oriented roughness; L_1 is the full length of the chain and L_2 is the horizontal distance between chain ends when placed on the soil surface. Crr was measured on ridge crests. The chain was 1 m