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Variable effects of saltation and soil properties on wind erosion of different textured soils

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ABSTRACT

Wind erosion largely depends on saltation. Nevertheless, the effect of the composition of the saltation fraction of different textured soils is poorly understood, as is the relative influence of both saltation and soil properties on wind erosion. In order to answer these questions, wind erosion of six differently textured soils were simulated with a wind tunnel. The following saltation conditions were considered: injected saltation, in which the saltation fraction of each soil was added to the soil bed; no saltation, in which the soil eroded naturally, without injection of its saltation fraction; and only saltation, in which the saltation fraction was injected in absence of the soil bed. Results indicated that total erosion amounts increased as a function of the abrasion energy of the saltating particles but also with decreasing aggregation rate of the saltation fraction. The aforementioned agrees with a lower aggregate stability and higher amounts of the erodible fraction of sandy soils. Though saltation of individual sand grains produced impacts of higher kinetic energy on the soil surface of sandy soils than of fine textured soils, the relative erosion (quotient between the erosion occurred with and without saltation) was higher in finest soils, indicating a larger effect of saltation, probably due to the larger fragmentation of aggregates in these soils. Results of this study indicated that both the composition of the saltating fraction and also the intrinsic properties of the soil determined wind erosion.

1. Introduction

The magnitude of wind erosion has been mostly attributed to the saltation movement (Bagnold, 1941) based on the fact that saltating particles fall on the soil surface, transferring their momentum and mobilizing new particles to the air (Dong et al., 2002). Because of this, the relationship between saltation and wind erosion has been frequently studied. Many of these studies used pure quartzite sands that resemble, in shape, micro solid spheres (Bauer et al., 2004; Cheng et al., 2009; Creyssels et al., 2009). Shao et al. (1993a,b) found that the abrasion of a surface is related to the diameter of the saltating particles, which determines the kinetic energy of each impact. Dietrich (1977) and Greeley et al. (1982) concluded that the key parameters in controlling abrasion are the kinetic energy of the particles impacts and the bonding strength of the eroded material, and that the amount of material mobilized by the impact of a particle is a function of its diameter and transportation speed (Bridges et al., 2005).

The use of pure sand as the saltating material allowed a good understanding of the mechanics of the saltation process and the elucidation of the relationship between saltation and wind erosion. Nevertheless, the use of this kind of saltator partially reflects the real situation in soil, whose/which saltation fraction can be composed of individual particles but also aggregates. As a matter of fact, Alfaro (2008) mentions that when the saltation fraction is composed mainly of individual mineral particles, the energy that is triggered on the soil surface is higher than when it is composed of aggregates. He attributed this difference to the higher density of mineral particles than of aggregates, which are frequently formed by low dense organic substances. Hagen (1984, 1991) and Hagen et al. (1988) found that the abrasion of aggregates by saltating particles was proportional to the kinetic energy of these abrasive particles, and that soil losses caused by the use of soil aggregates is 10% higher than when sand is used as an abrader. Other authors have mentioned that the relationship between saltation and wind erosion varies as a function of soil texture. Grini and Zender (2004) showed that coarse-textured soils contained more saltators with high kinetic energy than fine-textured soils. Rice and McEwan (2001) suggested that the amount of eroded soil increases exponentially as the proportion of fine materials in the soil decrease.

The particle size distribution is a frequently used parameter in the classic approach for wind erosion modeling (Marticorena and

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Bergametti, 1995; Shao et al., 1996; Alfaro et al., 1997; Alfaro and Gomes, 2001) but the effects of the composition of the saltation fraction on wind erosion rate is generally not considered. Under this approach, it can be expected that soils with a saltation fraction that comprises a higher proportion of low density aggregates, and hence lower kinetic energy, will produce less mass when exposed to increased saltation than sandy soils. On the other hand, it can be supposed that aggregates that are less cohesive can also be broken in subsequent finer fractions. This will result in larger amounts of transportable material and hence, will produce more successive impacts, increasing the wind erosion process in a non linear way and augmenting the total mass transported downwind. The rupture of aggregates during the wind erosion process was generally analyzed and discussed in the context of dust emission (Shao, 2008; Kok et al., 2012) but less information is available on the influence of the aggregation rate of saltating particles on wind erosion amounts.

The interaction between the magnitude of saltation and the characteristics of the soil surface on wind erosion has not been studied in detail. At this point, the following question is stated: under comparable wind erosion conditions, do sandy soils erode more than fine textured soils due to the higher saltation energy of their saltators or because of their higher susceptibility to be eroded by wind?. It is widely known that sandy soils are more erodible than fine textured, because of their lower binding effect between individual particles, which produces higher amounts of erodible fraction (López et al., 2007). Ta (2007) found that the rate of abrasion of the soil is proportional to the impact energy and inversely proportional to the contents of the fine materials of the soil.

The aim of this study was to analyze, in soils of variable textures, the effect of both, the characteristics of the soil surface and the composition of its saltation fractions on wind erosion amounts.

2. Materials and methods

2.1. Soil sampling and analysis

Six soils placed along a north–south transect were analyzed within the semiarid area of central Argentina. The selected soils had variable textures: between sandy and loamy (Table 1 and Fig. 1). The classification of the soil textural classes was made according to USDA (Soil Survey Division Staff, 1993).

Undisturbed soil samples were taken from the first 2.5 cm topsoil. A portion of the sample was air-dried and hand sieved through 2 mm in order to homogenize it. Another subsample was air dried and sieved with a rotary sieve (Chepil, 1962). This device is a rotating nest of concentric cylindrical sieves with 0.42, 0.84, 2.0, 6.4 and 19.2 mm square openings. With this method the percentage of the <0.84 mm size aggregates, the erodible fraction of the soil (EF), was calculated with the following equation (Colazo and Buschiazzo, 2010):

$$EF = \frac{W < 0.84}{TW} \times 100 \quad (1)$$

where EF is the erodible fraction (%), $W < 0.84$ is the weight (g) of <0.84 mm aggregates, and TW is the initial weight (g) of total sample.

The dry aggregate stability (DSS)) was calculated after a second dry sieving of each aggregate size (Skidmore et al., 1994) using Eq. (2),

$$DSS = \left[1 - \frac{W < 0.84_2}{W > 0.84_1}\right] \times 100 \quad (2)$$

where $W < 0.84_2$ is the weight (g) of aggregates that went through the 0.84 mm sieve after a second sieving and $W > 0.84_1$ is the weight (g) of aggregates retained on the 0.84 mm sieve after the first sieving.

The saltation fraction of each soil (0.2–0.5 mm, van Pelt et al., 2010) was separated manually by dry sieving. The textural composition of each saltation fraction was determined by means of the wet sieving and pipette method (Schlichting et al., 1995). This analysis was carried out on dispersed and less-dispersed samples, allowing an estimation of the aggregation state of each soil, which was achieved by calculating the relative variation of the clay fraction (<0.002 mm) between the two dispersion pre-treatments. Dispersion treatments included the destruction of free carbonates (with 6% acetic acid) and organic matter (with hydrogen peroxide), a dispersion with sodium hexametaphosphate, the agitation in water for 30 min at 1500 rpm, and an ultrasound treatment at 35 kHz for 15 min. The less dispersed sample was only agitated in water for 30 min at 100 rpm.

A relative soil aggregation index (RSI)) of the saltation fraction was obtained by means of Eq. (3),

$$RSI = clay * OM \quad (3)$$

where clay is the percentage of the <2 μm – sized fractions of the soils determined with the pipette method, and OM the organic matter contents of the soil. The use of this coefficient was based on the consideration that both soil components are the main factors affecting soil aggregation in soils (Perfect et al., 1995; Mirzamostafa et al., 1998).

The grain size distribution of the saltation fraction of each soil was also determined with a laser particle counter Malvern Mastersizer Model 2000 (Fig. 2). This method allowed a more precise determination of the grain size distribution than the pipette

Table 1
Main characteristics of the studied soils.

SOIL		S1	S2	S3	S4	S5	S6
Geographical coordinates		36° 33′S 64° 18′W	39° 23′S 62° 37′W	33° 40′S 65° 22′W	36° 34′S 63° 59′W	36° 32′S 64° 17′W	36° 35′S 63° 57′W
Textural class		Sand	Loamy sand	Loamy sand	Loamy sand	Sandy loam	Loam
	Clay (<0.002 mm)	49.9	92.5	82	74.9	102.3	171.6
Grain size distribution ($g\ kg^{-1}$)	Silt (0.002–0.053 mm)	67.3	99.7	124.2	124	186.2	355.5
	Very fine sand I (0.053–0.074 mm)	87.2	55.2	230.6	69.6	135.8	129.3
	Very fine sand II (0.074–0.105 mm)	176.2	80.7	366.9	191.7	180.8	129.1
	Fine sand (0.105–0.250 mm)	543.2	569.4	171.9	287.2	342.1	173
	Medium and coarse sand (0.250–2 mm)	76.2	102.5	24.4	252.6	52.8	41.5
	Clasts (>2 mm) (%)	0	6.7	0	0	0	0
OM ($g\ kg^{-1}$)		13.7	20.8	7	18.4	13.1	28.2
$CaCO_3$ ($g\ kg^{-1}$)		5.5	6.5	8.7	5.5	4.3	8.8
EF (%)		71.6	84.3	79.1	57.5	49.5	21.2
DSS (%)		62.2	82	54.4	80.7	85.7	95.7

OM = organic matter; EF = erodible fraction, DSS = dry aggregate stability.