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Wind sorting affects differently the organo-mineral composition of saltating and particulate materials in contrasting texture agricultural soils

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ABSTRACT

There is little information about the mineral and organic composition of sediments eroded by wind at different heights. Because of that, wind tunnel simulations were performed on four agricultural loess soils of different granulometry and their saltating materials collected at different heights. The particulate matter with an aerodynamic diameter mainly smaller than 10 μm (PM10) of these soils was obtained separately by a laboratory method. Results indicated that the granulometric composition of sediments collected at different heights was more homogeneous in fine- than in sandy-textured soils, which were more affected by sorting effects during wind erosion. This agrees with the preferential transport of quartz at low heights and of clay minerals at greater heights. SOC contents increased with height, but the composition of the organic materials was different: stable carboxylic acids, aldehydes, amides and aromatics were preferentially transported close to the ground because their were found in larger aggregates, while plant debris and polysaccharides, carbohydrates and derivatives of microbial origin from organic matter dominated at greater heights for all soil types. The amount of SOC in the PM10 fraction was higher when it was emitted from sandy than from fine textured soils. Because of the sorting process produced by wind erosion, the stable organic matter compounds will be transported at low heights and local scales, modifying soil fertility due to nutrient exportation, while less stable organic compounds will be part of the suspension losses, which are known to affect some processes at regional- or global scale.

1. Introduction

Wind erosion (WE) is one of the most important processes in soils of arid and semi-arid environments in the world, both for soil formation and soil degradation. WE affects not only the soils but also other ecosystems far away due to the transport of particulate matter. Particles with a diameter less than 10 μm (PM10) are distributed in the atmosphere, and can stay suspended in the air for a long time. Thus, they affect directly the solar and terrestrial radiation, and cloud formation processes (Conen and Leifeld, 2014; Steinke et al., 2016). Other effects include carbon and nutrient losses at the erosion site and the addition of these materials in either adjacent or distant ecosystems, as well as the iron- and silica fertilization of the oceans (Harrison et al., 1997; Lal, 2003; Martin et al., 1991). Dust emissions also affect society by declining air quality and reducing visibility on roads trigger traffic accidents. Particles of the PM10 fraction, which can be inhaled, influence human health by causing lung diseases and early deaths (Dockery et al., 1993; Pope and Dockery, 2006). On agricultural lands, WE is a soil degrading process that removes predominantly particles of silt and clay and, due to its lower density, the soil organic matter (SOM) (Chappell, 2016; Nerger et al., 2017).

Information about the amount of soil that has been eroded is available for different climatic and land use conditions in the world, showing maximums of several hundreds of tons per hectare, per year (Schäfer et al., 1995; Funk, 1995; Michelena and Irurtia, 1995; Dong and Chen, 1997; Aimar, 2002; Hoffmann et al., 2011; Zobeck et al., 2013). However, the composition of the eroded material has been less studied, although some authors have found that the enrichment ratio (ER), i.e., the proportion between the concentration of a certain element in the eroded material and in the orig-

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inal soil, reaches values of 0.8 to 17, according to the element, the type of soil and the wind velocity (Funk, 1995; Aimar et al., 2002; Ravi et al., 2011; Sharratt et al., 2015; Webb et al., 2012).

WE is a transporting and sorting process resulting in two basic transport modes: the saltation and the suspension flux, which involve the transport of particles across low- and greater heights, respectively. Part of the suspension flux includes the PM10 fraction, which represents the most fertile components of a soil in the clay and fine silt sized fractions and degrades air quality when concentrations are elevated. The PM10 emissions in the Semiarid Central Region of Argentina (SCRA) are mainly caused by WE of agricultural soils, while in other parts of the world the sources are ephemeral lakes and deserts (Gaiero et al., 2004; Tanaka and Chiba, 2006; Lenes et al., 2012). In comparison to dust emissions from desert regions, dust from agricultural soils has special features such as a wider granulometric composition, large SOC content or biologically active components (Fröhlich-Nowoisky et al., 2012; Conen and Leifeld, 2014). Therefore, the SCRA is a suitable region for detailed studies of WE and dust emission processes as a function of the degradation rate or development status of the soils and land use intensity. Both, soil type and land use conditions will determine dust-releasing processes in this region as well as the composition of these materials.

In addition, the mineral and organic soil compounds, which are sorted by size or density during the erosion process, will result in different height distribution profiles. As soil dust from agricultural land is enriched in SOC compared to the original soil these losses will represent a disproportionate depletion of soil quality. Due to the low net primary production of most regions affected by WE, the removed nutrients and SOC can be regarded as an irretrievable loss at the landscape scale, these losses are not balanced (Buschiazzo and Funk, 2015; Goossens and Gross, 2002; Tan et al., 2011; Yan et al., 2005).

In the 1990s numerous measurement campaigns of WE were performed on experimental plots around the world, mainly focused on the quantification of soil loss. Nowadays the focus has changed to a more detailed and qualitative description of all aspects of wind-driven soil processes. This focus involves fine particles and SOC transportation as well as their influence on health, air quality and climate (Ajwa and Sullivan, 2011; Morman and Plumlee, 2013; Nordstrom and Hotta, 2004; Shao et al., 2011; Webb et al., 2016). The aim of this study is focused on analyzing the effect of the wind sorting process on both the mineral and organic composition of the particles transported at different heights from different texture agricultural soils.

2. Materials and methods

2.1. Soil sampling

Soil samples were taken randomly to a depth of 2.5 cm in a 100 m^2 area from four agricultural soils in the SCRA. The soils, covering a granulometric gradient, were two Typic Ustipsamments (TU-I and TU-II) and two Entic Haplustolls (EH-I and EH-II). EH-I and TU-I belong to experimental controlled plots located in Site I (Santa Rosa, Argentina) and EH-II and TU-II, to Site II (Anguil, Argentina). These soils are highly susceptible to WE due to their particle size composition and their relatively low SOM content. These soil characteristics are a product of the dry and windy environmental conditions, as well as management practices based on 70-year conventional tillage, no-irrigation and mixed rotation (wheat-sorghum-alfalfa), which frequently left the soil smooth and flat (Buschiazzo et al., 1998). Further information about the sampled sites is shown in Table 1.

2.2. Wind tunnel simulations

A push-type wind tunnel was used, which consisted of an axial fan driven by a Honda GX6 52 kW engine, a flow straightener and a measuring section of 6 m-length, 1 m-height and 0.5 m-width. More details of the wind tunnel and results of its calibration are published in Panebianco et al. (2016).

Soil samples were prepared for wind tunnel simulations by air drying and sieving through a 2 mm-mesh. The measurement section was filled with a 2.5 cm-thick layer of each soil and levelled to get a comparable grain roughness for all samples. Wind velocity was increased quickly, kept constant for four minutes and measured with a pressure anemometer at 0.05, 0.17, 0.315, 0.48 m-height above the surface. The vertical profile was obtained according to Eq. (1),

$$u_* = \frac{K(\mu_{Z_2} - \mu_{Z_1})}{\ln(Z_2 - Z_1)} \tag{1}$$

being, u_*, the friction velocity expressed in m s^{-1}; K, the von Karman constant (0.4); and u_{Z1} and $u_{Z2,}$ the wind speed at heights Z_1 (0.05 m) and Z_2 (0.48 m). The measurement scheme allowed the calculation of the u_* (Roney and White, 2006). The free stream velocity was measured using a cup anemometer placed at the end of the wind tunnel, at a height of 0.7 m above the surface, out of the boundary layer.

Wind velocity and roughness resulted in an average u_* of 0.71 m s^{-1} (SD 0.10 and CV 14.27%). Simulations were performed in triplicate. The relatively short time of simulations resulted in stable conditions for the duration of the experiments, including wind velocity and horizontal mass flux or depletion of the original soil bed. The material mobilized by saltation during the wind tunnel simulations was collected with Big Spring Number Eight (BSNE) samplers (Fryrear et al., 1998) placed at heights of 0.05, 0.17, 0.315 and 0.48 m above the surface at the end of the wind tunnel. For further information about the experiments, see Avecilla et al. (2015).

2.3. Potential PM10 emission simulations

The particulate matter with a diameter predominantly smaller than 10 μm (PM10 fraction) was separated from each soil with a dust generator (Easy Dust Generator, EDG; Mendez et al., 2013) assembled with an electrostatic trap. This device simulates the

Table 1
Main characteristics of the studied soils.

Soil	Soil classification[1]	Location	Geographic location	Clay	Silt	Sand	Texture	SOC	pH
				%				% ± SD	
TU-I	Typic Ustipsamment	Santa Rosa	36° 33′ S 64° 18′ W	5	7	88	Sandy	1.12 ± 0.02	6.1
TU-II		Anguil	36° 34′ S 63° 59′ W	8	12	80	Loamy sand	0.97 ± 0.01	5.9
EH-I	Entic Haplustoll	Santa Rosa	36° 32′ S 64° 17′ W	10	19	71	Sandy loam	0.90 ± 0.03	6.7
EH-II		Anguil	36° 35′ S 63° 57′ W	17	36	47	Loam	1.04 ± 0.01	6.0

TU-I: Typic Ustipsamment from site I; TU-II: Typic Ustipsamment from site II; EH-I: Entic Haplustoll from site I; EH-II: Entic Haplustoll from Site II; SOC: soil organic carbon content; SD: standard deviation.

[1] Soil Survey Staff (1999).