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Reduction in soil aggregation in response to dust emission processes

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ABSTRACT

Dust emission by aeolian (wind) soil erosion depends on the topsoil properties of the source area, especially on the nature of the aggregates where most dust particles are held. Although the key role of soil aggregates in dust emission, the response of soil aggregation to aeolian processes and its implications for dust emission remain unknown. This study focuses on aggregate size distribution (ASD) analyses before and after in-situ aeolian experiments in semiarid loess soils that are associated with dust emission. Wind tunnel simulations show that particulate matter (PM) emission and saltation rates depend on the initial ASD and shear velocity. Under all initial ASD conditions, the content of saltator-sized aggregates (63–250 μm) increased by 10–34% due to erosion of macro-aggregates (>500 μm), resulting in a higher size ratio (SR) between the saltators and macro-aggregates following the aeolian erosion. The results revealed that the saltator production increases significantly for soils that are subjected to short-term (anthropogenic) disturbance of the topsoil. The findings highlight a decrease in soil aggregation for all initial ASD's in response to aeolian erosion, and consequently its influence on the dust emission potential. Changes in ASD should be considered as a key parameter in dust emission models of complex surfaces.

1. Introduction

Aeolian (wind) dust emission has a major impact on a variety of environmental and socioeconomic issues. Airborne dust particles can affect climate, biogeochemical cycles, ecosystem productivity, and other components of the Earth system. Dust emission is a major cause of soil loss in arid and semi-arid regions throughout the world (Ravi et al., 2011; Zobeck et al., 2013; Tanner et al., 2016). The loss of nutrients and clays reduces the soil fertility, leading to soil degradation and desertification. In addition, dust events significantly increase air pollution and thus can impact human health (Krasnov et al., 2015; Vodonos et al., 2015). In recent years more soils have become associated with dust emission following anthropogenic activities and disturbance of the topsoil aggregation.

The ability of the topsoil to resist erosion depends on its physicochemical properties, especially on the soil aggregation (Bissonnais, 1996; Hevia et al., 2007; Wang et al., 2014). Soil aggregation refers to the arrangement of solids and void spaces and the bonding materials (mineral and organic) between the particles (Boix-Fayos et al., 2001). Common cementing agents, including clays, organic matter and carbonates, control the aggregate formation and sizes. Aggregate sizes can range between less than 2 μm to a few centimeters in diameter (Tisdall and Oades, 1982; Horn et al., 1994). Changes in external factors, such as climatic conditions and land uses, alter the topsoil properties and thus influence aggregate size and soil erodibility (Lavee et al., 1998; Sharratt et al., 2010; Webb and Strong, 2011; Singh et al., 2012 Tanner et al., 2016). It is generally assumed that soils with a higher amount of large aggregates have stronger resistance against erosion due to their weight (Amézketa, 1999). Only a few studies have referred to the soil aggregation in aeolian processes, but with a focus on the wind erodible fraction - EF that considers only the aggregate size (<840 μm) (Bagnold, 1941; Zobeck et al., 2013). Quantitative information on aggregate strength and stability in wind erosion processes is still lacking.

The emission of dust particles <70 μm from soils is fundamentally linked to the suspension transport mechanisms. However these fine particles are usually part of the soil aggregates and thereby are not available for direct suspension (Ravi et al., 2011). In this case the emission of the fine particles may be enabled by saltation of sand particles and/or aggregates (Shao et al., 1993). The soil aggregates can breakdown to release dust particles either by self-saltating or by the impact of other saltators (Shao, 2008; Kok et al., 2012). Breakdown of larger aggregates during saltation can be explained by the aggregation hierarchy concept, in which macro-aggregates are bonded together from smaller aggregates with weak inter-connections (Tisdall and Oades, 1982; Six et al., 2004).

There are positive relationships between the content of saltators (sand and/or sand-sized aggregates), saltation rates, and dust emission (Shao et al., 1993; Rice et al., 1997; Sweeney et al., 2011; Tanner et al., 2016). Houser and Nickling (2001) showed a short-term direct emission of loose fine particles from the surface, while the increase in

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saltation flux increases the dust emission rates over time. Abulaiti et al. (2014) found an increase in dust emission rates of up to 8 fold in response to entrainment of saltation. Despite the association between sand flux and dust emission, there is a lack in studies that empirically examined how dust is emitted from aggregates during saltation.

We can assume here that aggregate breakdown will lead to reduction in the aggregate size distribution (ASD), increase in saltation fluxes during erosion, and thereby change the dust production over time. This can affect the dust emission potential over time and in the next wind event. The aim of this study is to quantify changes in the ASD under different initial soil conditions and wind shear velocities to determine the influence of aeolian erosion on soil ASD and thus on the dust emission potential. A semiarid loess soil subjected to long and short-term topsoil disturbances which is associated with dust emissions was analyzed along with in-situ aeolian simulations. A recent study in these soils clearly demonstrated the impact of topsoil properties on dust fluxes through using soil parametrization in a numerical model (Katra et al., 2016). The current study will enable a better understanding of the role of topsoil aggregation in dust emissions, aiming to reduce uncertainties which exist in dust emission models.

2. Materials and methods

2.1. Experimental set up

The experiments were performed on a semi-arid loess soil in the northern Negev, Israel (Fig. 1). Basic differences in soil aggregation are related to long-term influences of land uses – grazing soil (G_L) compared with natural soil (N_L). The G_L soil is characterized mainly by bare surfaces with small patches of dwarf shrubs and sparse herbaceous cover. The N_L is confined within a closed area (military base) without human interference during recent decades. The surface is characterized by patches of biological crust, and annual and seasonal vegetation. A total of 36 samples (18 replicates for each soil) were collected from dry topsoils (0–2 cm) for the analysis of physicochemical properties including aggregate size distribution (ASD) (Section 2.2, Table 1).

In order to form a scale of initial aggregate conditions, the N_L and G_L soils were treated in the field to simulate a short-term disturbance caused by human activities that are common in semi-arid soils. The topsoils were artificially disturbed by mechanical operation of a handheld grading rake (Bacon et al., 2011) and footsteps. Thus N_S and G_S represent a reduced soil aggregation state of the original soils N_L and G_L, respectively. A total of 36 samples (18 replicates for each soil) were taken from the treated topsoils. The samples were analyzed only for ASD, considering that no changes in other physicochemical properties are expected following such a short-term treatment.

After the aeolian experiments (Section 2.3) for the four different initial soil conditions (N_L, G_L, N_S, and G_S), the topsoils were analyzed for ASD to determine the impact of wind erosion under two wind shear velocities (Fig. 1D) with 6 replicates for each soil condition (a total of 48 aeolian experiments). Statistical analyses were applied to determine differences in soil properties and aeolian parameters including means, standard deviations, and significances ($P \leq 0.05$) by *t*-test and ANOVA using IBM SPSS Statistics 20.0 software (Corp I.B.M, 2011).

2.2. Soil analyses

The soil samples were tested using standard and advanced soil science methods (Klute, 1986; Rowell, 1994; Pansu and Gautheyrou, 2006) as follows. Aggregate Size Distribution (ASD) was derived using the dry sieving method. The samples were placed on a set of six sieves in diameters (μm) of 63, 125, 250, 500, 1000, and 2000, and were shaken at moderate amplitude of 50 rpm for 8 min on an electronic sieving apparatus with horizontal and vertical motions (RETSCH AS 300 Control, Germany) to avoid aggregate breakdown. After sifting, every size fraction was weighted separately. In the fraction of >2000 μm, rock fragments were extracted from the rest of the soil particles. The results were used to calculate mean weight diameter (MWD) and size ratio (SR)

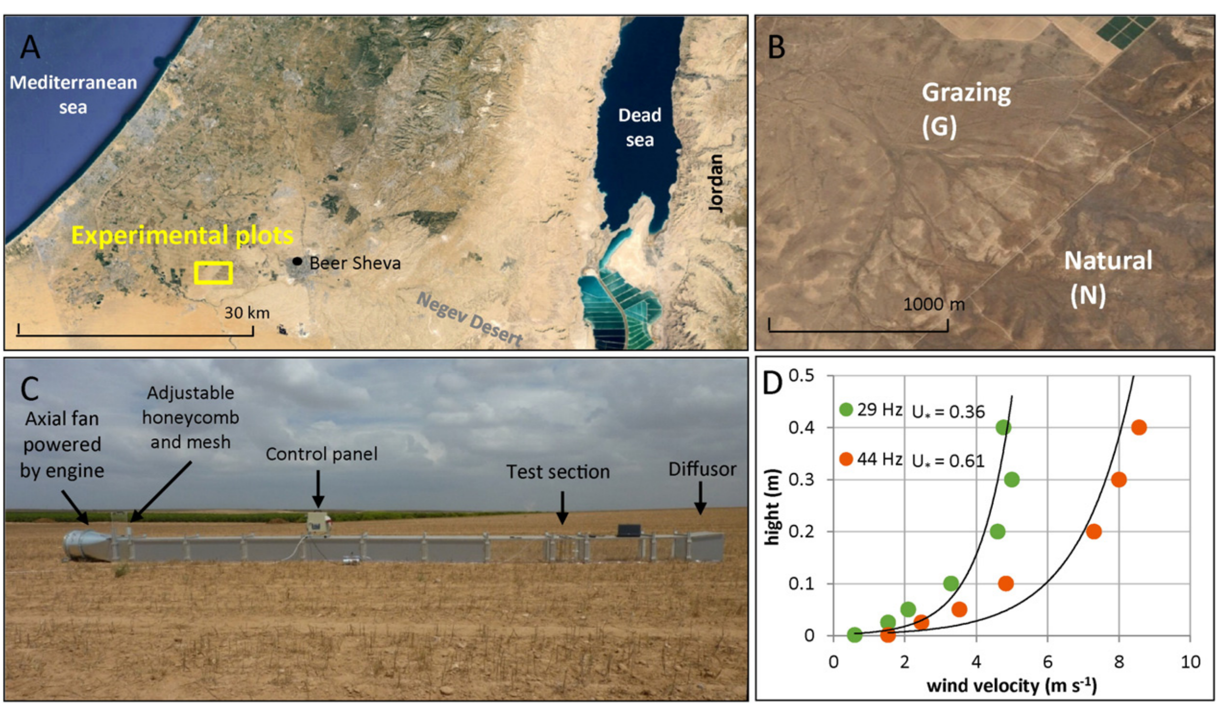

Fig. 1. (A) Location of the experimental soils in the northwestern Negev, Israel. The annual average rainfall is ~200 mm. The dry season extends from April to October with rare rainfall events. Winds are mainly western and can exceed 11 m s^{-1} (at 10-m height). (B) The silt-loam (USDA) soils in natural and grazing areas. (C) The BGU portable wind tunnel used for field experiments on dust emission processes. (D) Wind profile and shear velocities (u_*) measured in the field for fan frequencies of 29 Hz and 44 Hz (maximum velocities of ~5 m s^{-1} and ~9 m s^{-1}, respectively).