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Short-term soil loss by eolian erosion in response to different rain-fed agricultural practices

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ABSTRACT

Eolian (wind) erosion is a widespread process and a major form of soil degradation in arid and semi-arid regions. The present study examined eolian soil loss and changes in soil properties at a field scale, in response to different soil treatments in two rain-fed agricultural practices by short-term field experiments using a boundary-layer wind tunnel and soil properties analysis. Two practices with different soil treatments of mechanical tillage and stubble grazing intensities were applied in the fallow phase of the rotation (dry season). Mechanical tillage operations and stubble grazing intensities had immediate and direct effects on soil aggregation but not on the soil texture, and the contents of soil water, organic matter, and $CaCO_3$. Higher erosion rates, measured as fluxes of total eolian sediment (TAS) and particulate matter $<10\,\mu m$ (PM_{10}), were recorded under mechanical tillage and grazing intensities compared with the undisturbed topsoil of the control plots. The erosion rates were higher in grazing plots than in tillage plots. The calculated soil fluxes in this study indicate potentially rapid soil degradation due to loss of fine particles.

1. Introduction

Eolian(wind) erosion refers to the process of entrainment and transport of soil particles by wind. Wind erosion is a widespread process and a major form of land degradation in arid and semi-arid regions (Lal, 1990). Wind erosion winnows the finer, more chemically active components of the soil (especially those including nutrients affecting plant growth) and soil organic carbon. Therefore, it can lead to degradation in soil fertility and structure, as the topsoil is the most fertile layer. Wind erosion also has offsite effects and can strongly affect air quality at the local and regional scales (Zobeck and Van Pelt, 2011). Although wind erosion processes are strongly connected to the climatic conditions, they may be accelerated by agricultural activities (Nordstrom and Hotta, 2004; Ravi et al., 2011; Zobeck et al., 2013a). It has been shown that cultivation can significantly accelerate wind erosion and soil loss compared with uncultivated soils or reduced-till soils (Liu et al., 2007; Sharratt et al., 2010; Singh et al., 2012), when one of the most important properties that controls wind erosion and being reduced by cultivation activities are the soil cover of plant residue (Van Pelt et al., 2013).

Soil susceptibility to wind erosion is related to the physical properties of the topsoil, including surface cover and roughness, surface shear and compaction strengths, soil water content, and soil aggregate size distribution and stability (Feng et al., 2011; Zobeck and Van Pelt, 2011). Soil aggregates form and develop due to the presence of inorganic and organic cementing substances. The main cementing substances are clays, soil organic matter (SOM) and soil carbonates (Tisdall and Oades, 1982; Amezketa, 1999). Assessing soil susceptibility to wind erosion through soil aggregate size distribution and stability measures is a well-known method (Chepil, 1962; Mirzamostafa et al., 1998; Webb and McGowan, 2009; Colazo and Buschiazzo, 2010; Nichols and Toro, 2011). Among these measures are the wind erodible fraction (EF) (<0.84 mm), micro ($<250\,\mu m$) and macro ($>250\,\mu m$) aggregates and the mean weight diameter (MWD). Studies have shown that long-term cultivation can lead to a decline in soil aggregate size and stability (Six et al., 2000; Hevia et al., 2007; Blanco-Canqui et al., 2009) and in SOM content (Chan et al., 2002; Lal, 2002; Lou et al., 2010; Mishra et al., 2010). Moreover, organically managed soils and soils handled with reduced tillage or with no tillage exhibit improved SOM content and aggregate size and stability in the long-term (Pulleman et al., 2003; Gadermaier et al., 2012; Jiang

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et al., 2011; Duval et al., 2013). However, in-situ quantification of the short-term effect of different agricultural practices on soil physico-chemical properties and wind erosion potential has not been clearly performed yet. Clausnitzer and Singer (1997) have found that 82% of PM_{10} (particles that are less than 10 μm in diameter) loss from soil by wind erosion is attributed to land preparation before sowing.

In the present study, we quantified the short-term effects of two rain-fed agricultural practices that apply different soil treatments after harvesting the winter crops (mechanical tillage, stubble grazing) on soil properties and soil loss by eolian erosion. Top soils analyses were integrated with in-situ eolian experiments by a boundary layer wind tunnel to quantify soil stability and particle fluxes from the soil.

2. Materials and methods

2.1. Experimental plots

The study was carried out in agricultural fields located at the Northwestern part of the Negev region (Israel) (Fig. 1). The local loess soil originated mostly from late Quaternary eolian deposits (Roskin et al., 2014) and is classified as loamy according to the USDA textural soil classification. The semi-arid climate in the study area is characterized by an annual average precipitation of ~200 mm occurring mostly between November and March. In drought years, average annual precipitation can reach down to 100 mm. Data from meteorological stations over the last three years were processed to calculate the average amount (hours per year) of erosive wind speeds ($m\,s^{-1}$) in the region: >6 = 194 h, >7 = 92 h, >8 = 31 h, >9 = 12 h. The experiments were conducted at the fallow phase of a rain-fed winter cereal—summer fallow crop rotation (August 2013) which is the major agricultural practice in the study area as well as in many other places throughout the world. Two such systems, that differ in soil treatments after harvest (as well as in weed control and fertilization management), were studied (Table 1). Conventional tillage practice (CTP) is the most common practice in the study area. After harvesting the winter crops land preparation in the CTP includes mechanical tillage of the soil (usually by cultivator or disk) before sowing the following crop. The other system examined is stubble grazing practice (SGP) in which after harvest the stubble is grazed by herds of sheep and goats. In this system conservation tillage methods are applied (no-tillage or reduced tillage by cultivator) since 2005.

Experimental plots were designed in fields representing both practices (Table 1): in the CTP field three different mechanical tillage methods (disk-tillage, cultivator-tillage and no-tillage) were implemented in three replications each (giving a total of nine experimental plots). The tillage operations were conducted perpendicular to wind direction and the size of each plot/replica was 5 × 30 m. In the SGP, three adjacent plots of 20 × 50 m each were fenced, and different grazing intensities were implemented (over-grazing, medium-grazing and no-grazing). The grazing intensity was calculated as number of heads per area per time (Hodgson, 1979). The herd (consisting of 400 sheep and goats) was left to graze for 80 min and 20 min, which led to a 80% and 50% decline of the initial stubble biomass in over-grazing and medium-grazing plots, respectively. After the herd was removed from the field, each grazing plot was divided into three sub-plots with a total of nine experimental plots in which the topsoil analyses and eolian experiments were conducted. A total of 18 experimental plots were prepared (nine experimental plots in each agricultural practice).

2.2. Topsoil analyses

Soil samples were collected from the experimental plots immediately after soil treatments were implemented and before the eolian experiments (see Section 2.3). The samples were extracted from the topsoil layer (0–5 cm) with 6 replicas in each plot, amounting to a total of n = 108 soil samples. The locations from which soil was sampled were marked in order to place the wind tunnel for the eolian experiments. Soil samples were carried carefully to the laboratory for physical and chemical analyses as follows (Klute, 1986).

Particle size distribution (PSD) was analyzed by the laser diffractometer technique (ANALYSETTE 22 MicroTec Plus) (www.fritsch.com) which measures particles in the size range of 0.08–2000 μm. The preparation of each sample included splitting samples by a mechanical device and removal of distinct organic matter. Samples were dispersed in a sodium hexametaphosphate

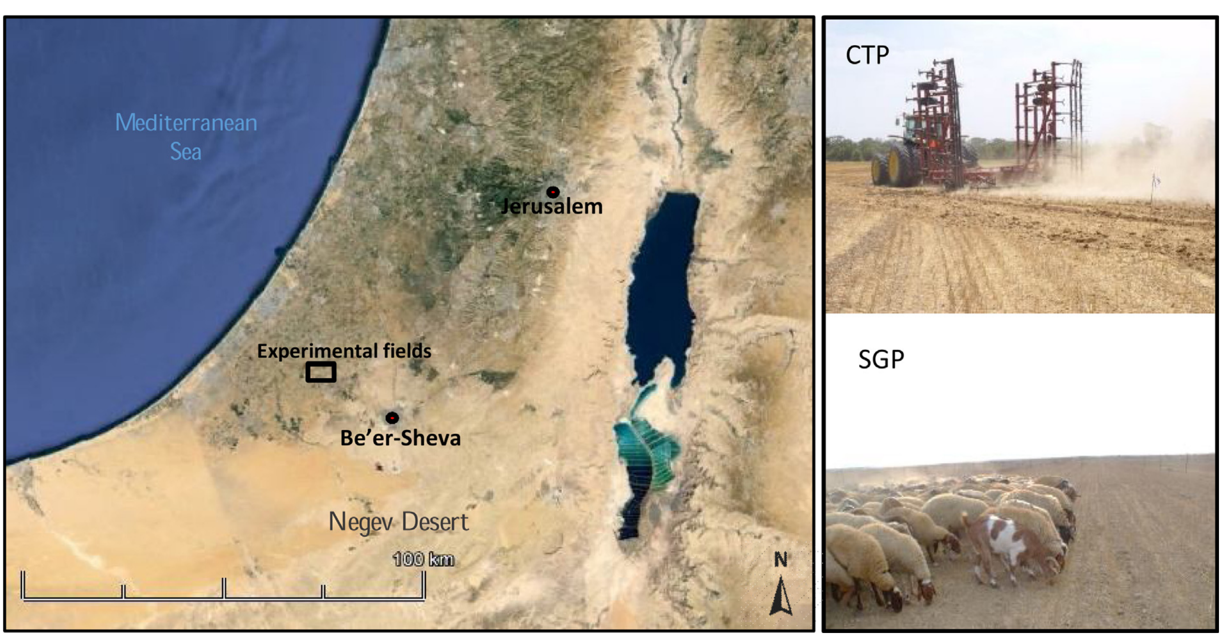

Fig. 1. Location of the experimental fields (CTP and SGP) in the Northwestern part of the Negev region (Israel).