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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

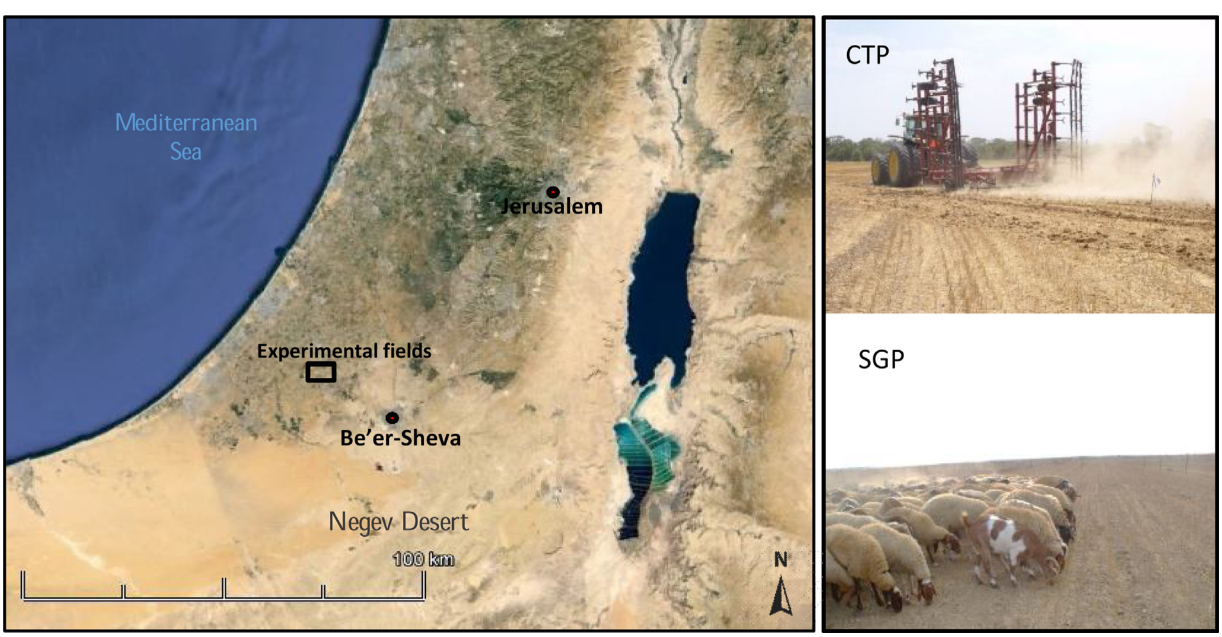

Fig. 1. Location of the experimental fields (CTP and SGP) in the Northwestern part of the Negev region (Israel).

Table 1
Characteristics of the field management and the experimental plots of conventional tillage practice (CTP) and stubble grazing practice (SGP).

Practice	Fertilizers	Weed control	Soil treatment after harvest	Experimental plots (treatments)	Tillage depth (cm)/grazing time (min)
Conventional tillage practice (CTP)	100 kg ha^{-1} UREA ($CO(NH_2)_2$)	1500 cm^3 ha^{-1} Duplosan KV 50 cm^3 ha^{-1} Derby	Mechanical tillage	Disk-tillage (Dt); cultivator-tillage (Ct); no-tillage (Nt)	12–15; 8–10; 0
Stubble grazing practice (SGP)	***	***	Stubble grazing conservation tillage	Over-grazing (Og); medium-grazing (Mg); no-grazing (Ng)	80; 20; 0

solution (0.5%) by sonication (38 kHz). PSD data were calculated using the Fraunhofer model and MaS control software.

Soil water content (SWC) was calculated by the gravimetric method. Soil samples collected at the field were weighed and then oven dried (105 °C, 24 h). The water content was calculated as the difference in sample weight before and after drying.

SOM content (%) was determined by the dry combustion method, calculating the percentage of organic carbon released during combustion by the weight ratio of the sample before and after combustion. 5 g of crushed oven dried (105 °C for 24 h) sample were combusted at 375 °C for 17 h. At this temperature all soil organic carbon oxidizes with no conflagration of mineral carbon (Wang et al., 2012).

Calcium carbonate ($CaCO_3$) was determined as a mass content (%) by the Calcimeter device which is based on the gas-volumetric Scheibler method. When adding hydrochloric acid (HCl) 8% to the soil sample, CO_2 is released by the interaction. The $CaCO_3$ is calculated in accordance with the CO_2 volume released from the sample and by comparison to a standard sample of analytical (100%) $CaCO_3$.

Aggregate size distribution (ASD) was determined by the dry sieving method using an electronic sieving apparatus AS 300Control (www.retsch.com). The sample was placed on a set of six sieves with common diameters (63, 125, 250, 500, 1000, 2000 μm), shaken in a moderate amplitude for 8 min. After sieving, each size fraction was weighed separately. The ASD results were used to calculate the MWD of the soil.

In addition to the lab analyses, field measurements of shear and compaction strengths of the topsoil were performed. The shear strength was determined by a Torvane disc with a range of 0–10 kg cm^{-2}. The compaction strength was determined by a penetrometer with a range of 0–10 kg cm^{-2}. Data were recorded only in the control plots of each agricultural practice because of the heterogeneous topsoil obtained after the soil treatments (tillage, grazing) were implemented. The control plots remained undisturbed with a thin mechanical crust between the stubble rows which enable the measurements.

2.3. In-situ eolian experiments

eolian experiments were conducted in all experimental plots by using a boundary layer wind tunnel (Fig. 2). Boundary-layer wind tunnels enable eolian simulations under standardized quasi-natural wind conditions (Leys and Raupach, 1991; Shao, 2008) and provide quantitative information on eolian particle transport including sand fluxes (Katra et al., 2014a) and dust emission rates

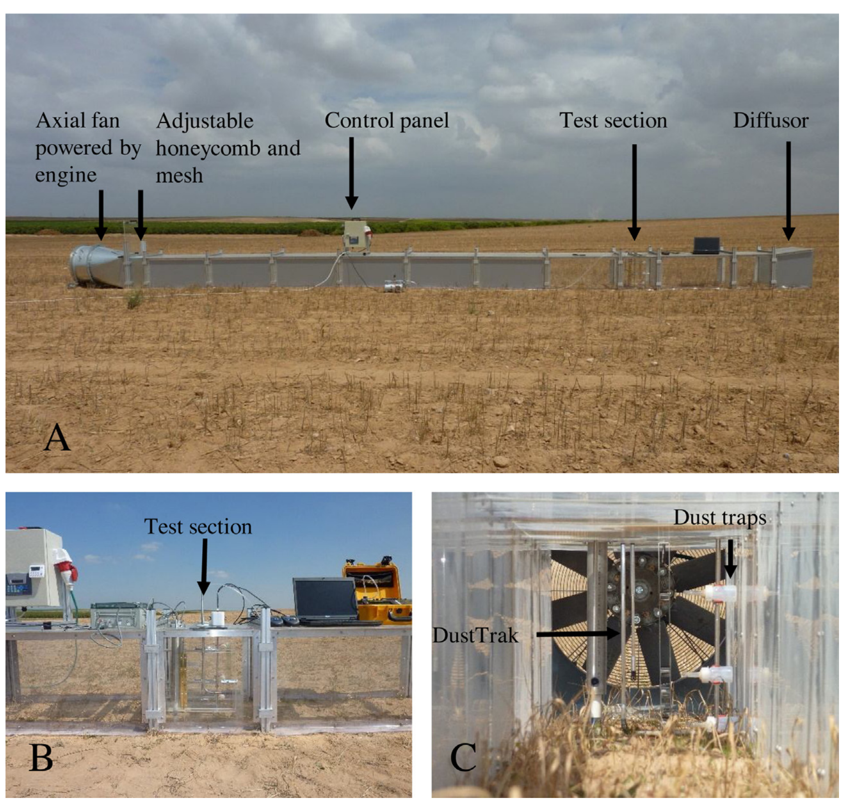

Fig. 2. The BGU portable wind tunnel for field experiments on dust emission processes. The tunnel segments are presented in the air-push configuration in an agricultural field (A). Closer look on the wind tunnel test section (b). Instruments installed in the test section (c).

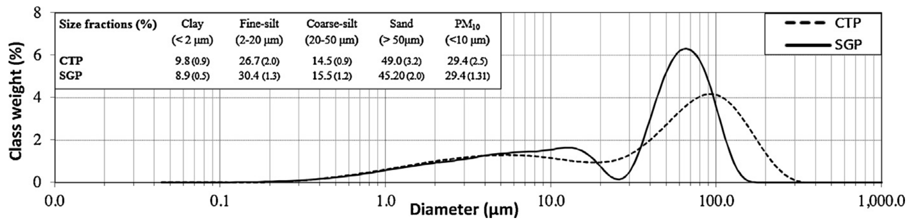

Fig. 3. Particle size distribution (PSD) of the topsoil in conventional tillage practice (CTP) and stubble grazing practice (SGP). Both curves represent the average of all soil treatments in each agriculture practice. Size fractions are presented in the left side of the figure [mean (SD)].

from soils (Sharratt et al., 2010; Singh et al., 2012; Van Pelt et al., 2013; Zobeck et al., 2013b). The cross sectional area of the wind tunnel is 0.5 × 0.5 m with open-floored working sections with a length of up to 10 m. Air push or air suction flow in the tunnel is generated by an axial fan with a maximum velocity of 18 m s^{-1}. Instruments installed in the test section of the tunnel enable quantification of: (1) wind profile for the calculation of frictional velocity and roughness height, (2) samples of total eolian sediments (TAS), (3) sand fluxes and (4) dust concentration profile including PM_{10}.

The wind tunnel was operated in the experimental plots at a fan frequency of 41 Hz (~8 m s^{-1}), which represents common erosive wind speed at the study area. At dry soil condition, soil erosion can initiate at wind speeds >6 m s^{-1} (Kok et al., 2012). At the beginning of each test, the concentrations of suspended particles in the wind tunnel were measured by a real-time dust monitor for background values (DustTrak, TSI). The DustTrak installed in the test section (Fig. 2) enabled recording PM concentration (µg m^{-3}) at intervals of 1 s. The wind tunnel was placed in each plot between the locations of the sampled soils (6 sampling points for each plot/experiment). Each experiment was performed for 420 s. A total of 18 eolian experiments were conducted (nine plots in each agricultural practice). The recorded PM_{10} data were converted into fluxes from the soil surface (mg m^{-2} s^{-1}) based on the dimensions of the wind tunnel. At the end of each run, the TAS samples were collected carefully from the dust traps (located at the test section) and weighed in the laboratory. The TAS flux was calculated based on the sample mass and the trap area within the wind tunnel.

3. Results and discussion

3.1. Variations in topsoil characteristics

Soil susceptibility to wind erosion depends largely on topsoil structure and its physical and chemical properties. Differences in PSD were revealed between the conventional tillage practice (CTP) and the stubble grazing practice (SGP) (Fig. 3), but not between the experimental plots in each of these practices. As expected, tillage and grazing did not had an immediate effect on soil texture. The results show a bi-modal distribution of fine and coarse fractions with the following modes: 5.83 µm (±0.3) and 98.4 µm (±5.1) in CTP, 13.1 µm (±0.7) and 68.3 µm (±2.2) in SGP. Although both soils are classified as loamy according to the USDA textural soil classification, some differences were noted between CTP and SGP in specific size fractions. Significant differences ($P \leq 0.01$) were revealed between the following fractions: clay (<2 µm), fine-silt (2–20 µm), and sand (>50 µm) (Fig. 3). The coarser texture in CTP could be related to the long-term effect of intensive mechanical tillage (compare to conservation tillage in SGP) that uplift dust particles to the atmosphere during operations (Clausnitzer and Singer, 1997) and accelerates wind erosion when the soil remains bare and directly exposed to wind. Hence, the particle size distributions of the soil may change over time because of a winnowing process, where fine material is selectively removed at the expense of coarse material through wind erosion (Churchman et al., 2010). The results support the findings of several other studies that showed coarseness in topsoil texture following prolonged cultivation (Zhao et al., 2005; Churchman et al., 2010).

Major physical and chemical properties for each soil treatment are shown in Table 2. Unlike the other soil properties, MWD was not calculated for the whole practice because soil aggregates are influenced directly by the treatment implemented at the field (mechanical tillage, grazing). In both CTP and SGP, the SWC was significantly ($P \leq 0.05$) lower in the treatment plots (mechanical or grazing) compared with the control plots. This can indicate on a better water-holding capacity in near-surface undisturbed soils (control plots) because of relatively dense surfaces and lower evaporation rates (Schwartz et al., 2010). The low SWC values in all the experimental plots are typical for the dry season (July–August) in the studied soils. No significant differences in SOM content was found between the tillage treatments in CTP. This indicates that SOM is not immediately affected by the tillage implemented. In SGP, although the SOM value in Mg was statistically lower, the SOM at all SGP plots is at a similar level (2.11–2.39%) in means of soil fertility. Nevertheless, a comparison between the practices showed that the soil in SGP contains about 30% more organic matter than the soil in CTP (Table 2). In semi-arid zones where the SOM content is naturally low, such a difference is important for ecological fertility and geomorphological processes (Pariente, 2004). Several

Table 2
Soil water content (SWC), soil organic matter (SOM), $CaCO_3$ content, and mean weight diameter (MWD) as measured in conventional tillage practice (CTP) with different tillage operations (Dt: disk tillage; Ct: cultivator tillage; Nt: no tillage) and in stubble grazing practice (SGP) with different grazing intensities (Og: over grazing; Mg: medium grazing; Ng: no grazing) [mean (SD)]. (Different letters indicate on significant differences between treatments and capital letters indicate on significant differences between the total average of each practice).

Site	% SWC	% SOM	% $CaCO_3$	MWD (mm)
Total CTP (average)	1.64A (0.14)	1.5A (0.11)	7.71A (0.84)	*N/A
Nt	1.73a (0.10)	1.54a (0.12)	7.98a (0.79)	0.59a (0.18)
Ct	1.60b (0.16)	1.48a (0.09)	8.05a (0.34)	0.53a (0.13)
Dt	1.62b (0.13)	1.49a (0.11)	7.09a (1.0)	0.86b (0.15)
Total SGP (average)	1.46B (0.09)	2.29B (0.25)	12.26B (1.16)	*N/A
Ng	1.55a (0.08)	2.39a (0.16)	12.13a (0.75)	0.80a (0.17)
Mg	1.45b (0.06)	2.11b (0.27)	12.44a (1.35)	0.64b (0.11)
Og	1.39b (0.07)	2.37a (0.21)	12.22a (1.46)	0.58c (0.13)

*N/A- Not Applicable.

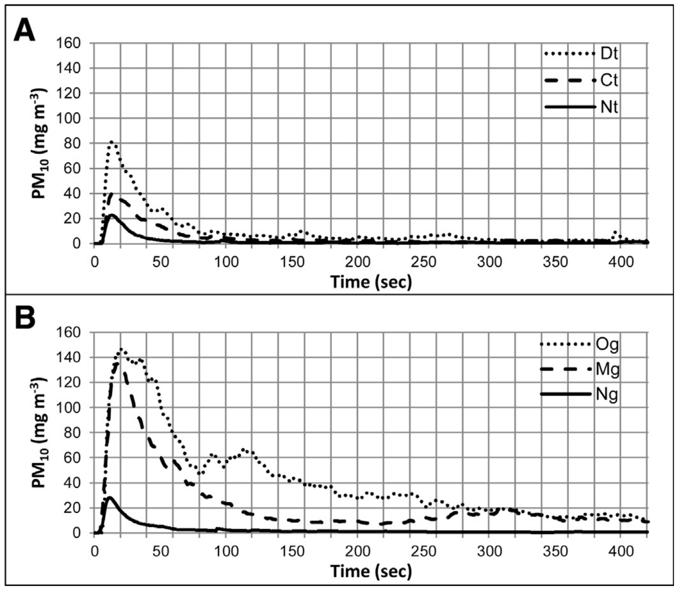

Fig. 4. PM_{10} concentrations emitted from the topsoil during the eolian experiments in conventional tillage practice with different tillage operations (Dt: disk tillage; Ct: cultivator tillage; Nt: no tillage) (A) and in stubble grazing practice with different grazing intensities (Og: over grazing; Mg: medium grazing; Ng: no grazing) (B).

studies have shown that conventional tillage practices lead to a decline in SOM content over time compared to reduced-tillage or no-tillage management (Chan et al., 2002; Lou et al., 2010; Gadermaier et al., 2012; Duval et al., 2013). $CaCO_3$ content was significantly higher in SGP than in CTP, but no differences were found between the treatments in each practice. The $CaCO_3$ in the studied soils is originated from external sources rather than in-situ contribution (e.g., weathering of parent rock). The main source of $CaCO_3$ in the topsoil of the Negev is eolian calcium-reached dust (30% in dust samples) (Katra et al., 2014b). Thus, the differences in $CaCO_3$ between the two practices can be related to long-term mechanical tillage that reduce $CaCO_3$ in the topsoil (Wei et al., 2006) and to erosional processes in the topsoil. The MDW obtained for the studied soils characterized by relatively low values in all plots (0.53–0.86 mm) (Table 2). An average MWD of 2 mm was measured in natural pasture loess soils in China, with a 50% decline in MWD (from 2 mm to 0.9 mm) after 55 years of cultivation (Wei et al., 2014). Although the current study is focused on the immediate effect of different soil treatments, the low MWD measured in the control plots of each practice can be associated with the long-term effect of cultivation on soil aggregates as shown in other studies (Eynard et al., 2004; Pikul et al., 2006; Hevia et al., 2007; Blanco-Canqui et al., 2009; Wei et al., 2014). Unexpectedly, the highest MWD in CTP was measured at the Dt plots, which represent a more aggressive tillage method than Ct (Table 2). The soil surface after the operation in Dt was characterized by multiple large clods (>4 mm) that were lifted up from deeper and more compressed soil layers. Blanco-Canqui et al. (2009) also showed higher MWD values in long-term disk-tilled soils than in reduced and no-till soils, although unlike in this research, the soil was not sampled immediately after the tillage operation. In contrast to the CTP, the MWD results in the SGP are as expected—as grazing intensity increased the MWD decreased in response to the soil disturbance by trampling of the herd. Previous studies have shown a decline in several soil aggregation measures and soil crust cover due to long term grazing (Hiernaux et al., 1999; Steffens et al., 2008; Zhou et al., 2010). The higher MWD values in the control plots of SGP than in the control plots of CTP can be explained by the higher contents of SOM, fine particles (clay–silt), and $CaCO_3$ in the SGP soil. These are important cementing substances for soil aggregation (Tisdall and Oades, 1982; Amezketa, 1999). Although SGP soil showed better aggregation, soil strength was greater at CTP. The average shear strength measured in the CTP was significantly ($P \leq 0.001$) higher (0.06 kg cm^{-2} (±0.03)) than in the SGP (0.02 kg cm^{-2} (±0.01)). Compaction strength in CTP showed an average value of 0.95 kg cm^{-2} (±1.07), while in SGP the strength level was lower than the minimal reading of the device.

3.2. TAS and PM_{10} emissions

The field experiments with the boundary layer wind tunnel were conducted in order to determine TAS (total eolian sediments) and particulate matter <10 μm (PM_{10}) fluxes from the soil. In CTP, the results showed greater TAS fluxes in tillage plots than in the control plot. The TAS flux in Dt (24.08 g m^{-2} min^{-1} (±11.87)) was significantly ($P \leq 0.05$) higher than in Ct (6.07 g m^{-2} min^{-1} (±2.87)) and in Nt (3.35 g m^{-2} min^{-1} (±2.50)). Similarly, in SGP, the greater TAS fluxes were measured in the grazing plots than in the control plot. A significantly ($P \leq 0.05$) higher TAS flux was measured in Og (73.72 g m^{-2} min^{-1} (±34.36)) than in Mg (21.59 g m^{-2} min^{-1} (±8.67)) and in Ng (2.29 g m^{-2} min^{-1} (±1.61)). No significant

Table 3
Average PM_{10} loss from soil with different treatments at both CTP and SGP. The calculated fluxes (mg m^{-2} s^{-1}) based on the eolian experiments are classified for: initial emission (average emission of the first 180 s), steady-state (average emission after the first 180 s) and total (average of the total emission: 420 s) [mean (SD)].

	Agriculture type	CTP			SGP		
	Treatment	Nt	Ct	Dt	Ng	Mg	Og
PM_{10} loss (mg m^{-2} s−1)	Initial emission	1.69 (2.65)	4.8 (5.19)	9.43 (10.11)	2.37 (2.23)	19.98 (18.50)	34.95 (18.62)
	Steady-state	0.32 (0.20)	1.02 (0.29)	2.00 (0.79)	0.39 (1.56)	6.01 (1.56)	10.29 (3.42)
	Total	0.91 (1.87)	2.64 (3.89)	5.19 (7.60)	1.24 (2.23)	12.02 (14.00)	20.89 (17.45)

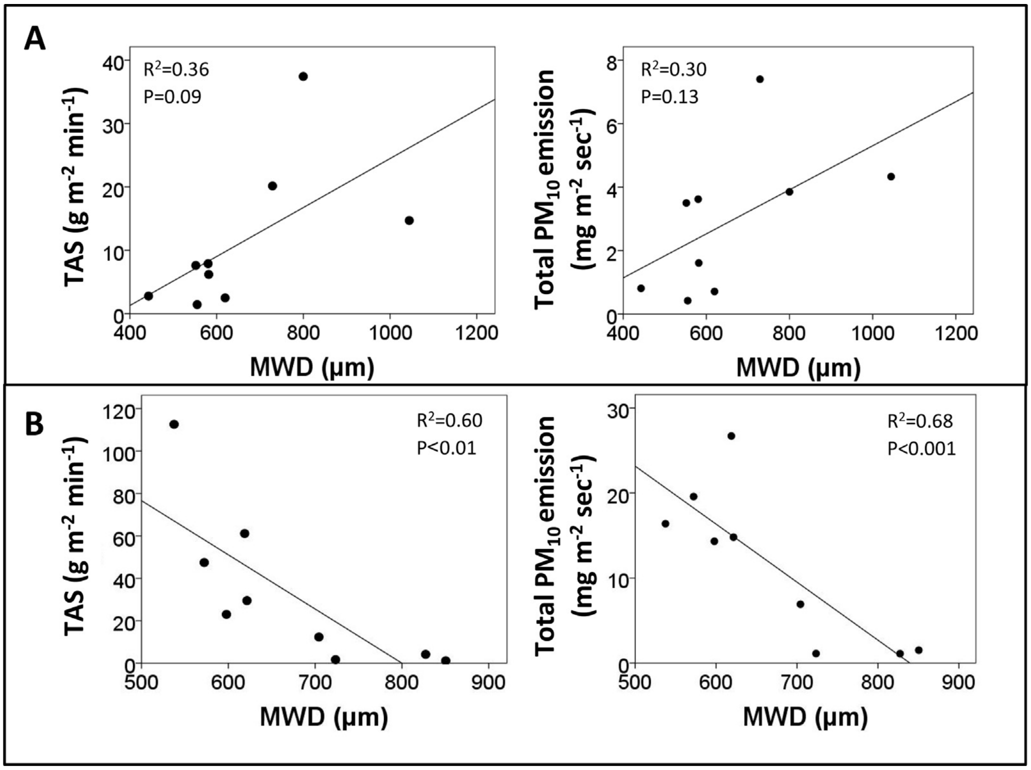

Fig. 5. Correlation between MWD and eolian soil fluxes—TAS (total eolian sediments) and total PM_{10} emission in conventional tillage practice (A) and stubble grazing practice (B). Note the different scales in *X* and *Y* axes.

differences were found between the control plots of CTP and SGP. The PM_{10} concentrations due to eolian emission from the topsoil are presented in Fig. 4. In CTP, higher concentrations were measured in the tillage plots rather than the control plot. The PM_{10} concentration trend along the experiment was characterized by increased emission in the first few seconds of the run, a moderate decline and a steady state after approximately 180 s. In SGP, the trend of PM_{10} emission was similar to that of CTP, but with higher concentration levels over time. The grazing plots showed higher PM_{10} concentrations compared with the control plot.

PM_{10} loss from the topsoil was calculated as fluxes (mg m^{-2} s^{-1}) for each "trend-stage" of the experiment as well as for the total run (Table 3). In CTP, total PM_{10} loss was significantly ($P \leq 0.05$) higher in tillage plots than in the control plot. The total PM_{10} loss in Dt was 5.7 times higher than in Nt, while the PM_{10} loss in Ct was 3 times higher than in Nt (not significant). In SGP, the PM_{10} loss in the grazing plots was significantly ($P \leq 0.01$) higher than the control plot. The PM_{10} loss in Og and in Mg was 16.8 and 9.7 times higher than in Ng, respectively. Similarly to the TAS flux, no significant difference was found in PM_{10} losses when comparing the control plots of both practices. The results of the in-situ eolian experiments indicate that soil loss through both TAS and PM_{10} fluxes is clearly higher under mechanical tillage or grazing than in the undisturbed topsoil in the control plots. The stronger erosion in the disk-tillage plots compared to cultivator-tillage plots can be related to different operation process of each tool. The cultivator teeth operate near the soil surface (5–8 cm) whereas the disk operates in a deeper layer beneath the soil surface (10–15 cm) where it turns and mixes soil layers, thus leaving less stubble on the soil surface. The presence of stubble increases soil roughness and threshold shear velocity compared with bare surfaces (Ravi et al., 2011; Gao et al., 2014). Therefore, the higher erosion rates measured in Dt is associated with a lower amount of stubble on the topsoil. Other studies have also shown increased soil erosion rates due to conventional tillage (Liu et al., 2007; Sharratt et al., 2010; Singh et al., 2012). In SGP, increased grazing intensity led to higher erosion rates due to the reduction of surface cover (in this case the stubble remaining after harvest) from 80% in Og to 50% in Mg as well as mechanical destruction of soil aggregates by animal trampling. The negative impact of grazing on eolian erosion was demonstrated in previous studies (Belnap et al., 2007; Hoffmann et al., 2008; Fister and Ries, 2009; Baddock et al., 2011). In general, the erosion rates discovered in this study were higher in grazing plots than in tillage plots. However, no differences in erosion rates were noted between the control plots of CTP and SGP, indicating a similar wind erosion potential at both agricultural practices. Nevertheless, as mentioned previously, there were major differences in the original soil properties between the two fields that were sampled (due to long-term practice), so no direct comparison can be made to determine whether mechanical tillage or grazing have a stronger impact on wind erosion.

In order to examine the soil susceptibility to eolian erosion and the dust emission potential, the dependence of eolian soil fluxes (TAS, PM_{10}) on the MWD index was examined for each practice. No correlation was found between MWD and TAS and PM_{10} in conventional tillage practice (Fig. 5A). However, in the stubble grazing practice strong negative correlations ($P \leq 0.01$) were found for both TAS and PM_{10} (Fig. 5B). Such negative correlation between MWD and eolian parameters (TAS, PM_{10}) is expected since higher soil aggregation (measured as MWD) should increase soil stability and roughness and therefore reduce soil erosion. The contrasting results can be explained by the aggregate hierarchy concept that classifies soil aggregates by size and stability (Tisdall and Oades, 1982). Primary aggregates (known also as water-stable aggregates or micro-aggregates) are smaller (<250 μm) and more stable than secondary aggregates (macro-aggregates or clods) (>250 μm). In this context secondary aggregates are more susceptible to abrasion by saltating particles (Chepil, 1953; Mirzamostafa et al., 1998;

Amezketa, 1999). The lack of correlation in the CTP could be related to the presence of more secondary less-stable aggregates in the mechanical tillage plots especially after disk-tillage. According to the results, MWD provides limited information about aggregates susceptibility to wind erosion and especially to the abrasive force of saltating particles. For a better evaluation of eolian erosion potential, a measure of eolian aggregate stability should be developed. Moreover, the presence of stubble (Bilbro and Fryrear, 1994; Gao et al., 2014) and crusts (Belnap and Gillette, 1998; Belnap, 2003; Eldridge and Leys, 2003) on soil surface have a crucial role regarding wind erosion potential and they should be considered in further experiments and quantification of soil loss potential.

4. Conclusions

The current study characterized the short-term changes in soil properties and soil loss by eolian erosion at a field scale in response to different rain-fed agricultural practices after harvesting the winter crops. Mechanical tillage in CTP and stubble grazing in SGP had an immediate and direct effect on soil aggregation, but not on soil texture, SWC, SOM and $CaCO_3$ contents. However, major differences in those soil properties were found between CTP and SGP which can imply the long-term effect of each practice on soil properties. Higher erosion rates (TAS, PM_{10}) were measured under mechanical tillage or grazing compared with undisturbed topsoil in the control plots. Disk-tillage resulted with higher soil loss than cultivator-tillage. Stubble grazing was found to be associated with a stronger eolian erosion than mechanical tillage, although direct comparison between these two experimental fields was not enabled due to differences in the inherent soil properties. MWD was noted as a weak indicator for evaluating eolian soil erosion in disturbed heterogeneous agricultural soils. For a better evaluation of eolian erosion potential, especially in disturbed semi-arid soils, an eolian aggregate stability measure should be developed. This measure should be based on the eolian transport mechanisms (Kok et al., 2012) that act differently from the fluvial processes on which most aggregates stability measures are based. Dust emission from agricultural soils can lead to continuous degradation of soil stability and fertility through loss of clay and silt particles. The calculated fluxes from the soils in this study suggest a high soil degradation in both practices. The experimental conditions conducted at the field scale can indicate on the potential for long-term soil loss at larger scales of rain-fed agricultural systems, which should be considered in future agricultural managements.

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