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Sediment flux, wind erosion and net erosion influenced by soil bed length, wind velocity and aggregate size distribution

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ABSTRACT

Knowledge of wind erosion as a dynamic phenomenon changing in space is of importance in measuring and modeling soil erosion. While, many erosion studies have been done on the effect of bed length on wind erosion rate, little attention has been paid to the spatial changes of net erosion rate in different soil bed lengths. The aim of this study is to examine the effect of soil bed length, surface aggregate size distribution and wind velocity on sediment flux and wind/net erosion rates. For this purpose, three soil samples were placed in seven bed lengths ranging from 1 to 7 m and subjected to different wind velocities of 6, 10 and 14 $m\,s^{-1}$ using a wind tunnel. The result showed that total sediment flux increased at longer soil bed lengths, whereas the reverse trend was found for wind erosion and net erosion rates, which was attributed to the gradual saturation of air flow with eroded particles and the formation of armor layer. Depends on soil bed length, the measured wind erosion rate varied from 154.8 to 3783.7 $g\,m^{-2}\,min^{-1}$. Toward the end sections of the bed length, the reduction in net erosion (34.1% to 79.1%) was higher than the reduction in wind erosion rate (18.9% to 50.0%), implying that for every length section, the measured wind erosion rates were higher than the obtained net erosion rates. Soil bed length was found to be an appropriate single variable to predict wind/net erosion rates using a power function. Furthermore, wind erosion rate (Q) was modeled as a function of bed length (L), the mean weight diameter of aggregates (MWD) and wind velocity (V), that was $Q = 6 \times L^{-0.225} \times MWD^{-0.579} \times V^{1.975}$, $R^2 = 0.945^{**}$. It was also found that the soil containing coarser aggregates exhibited less sediment flux and wind/net erosion rates. The findings of this research revealed that the measurement of wind erosion on different bed lengths under laboratory conditions will result in effective discrepancies in the erosion rates, worldwide; however environmental conditions can be different in areal case. Therefore, it is necessary to pay special attention to the scale effect of soil bed length in future soil erosion studies.

1. Introduction

Wind erosion is known as one of the most important causes of land degradation in arid and semiarid regions of the world (Sterk and Raats, 1996; Mendez and Buschiazzo, 2010; Pierre et al., 2014), particularly in agricultural lands (Lopez, 1998; Gomes et al., 2003). This phenomenon is dominant in these regions due to loose, dry, finely and smooth soil surface, low precipitation (< 300 mm annually) and high evapotranspiration, a sparse vegetation cover, and strong winds (Sterk and Raats, 1996; Sterk et al., 2012). In addition, wind erosion can affect air quality and visibility (Viana et al., 2002; Prospero et al., 2014) and human health (Fryrear et al., 2001; Chen et al., 2004). It leads to serious problems on agricultural productivity (Lee et al., 2002; Gomes et al., 2003; Mendez and Buschiazzo, 2010), deposits sediment in ditches and waterways (Hagen et al., 2010), causes aerosol production (Alfaro et al., 1998; Mahowald et al., 2014) and exacerbates aeolian desertification and dust storms (Dong and Qian, 2007).

A number of factors influence wind erosion including soil properties, surface roughness, climate conditions, the length in the prevail wind direction and vegetation coverage (Bagnold, 1941; Zou et al., 2015). Among these factors, the length of eroding soil is an importance agent affects wind erosion (Delgado-Fernandez, 2010). Along the downwind direction, the ability of wind further reduces to detaching and transporting the erodible particles from the soil surface, ultimately reaches to a maximum transport capacity (Cheng et al., 2017). However, some have reported that with increasing horizontal length under steady wind, soil movement rate increases until reach to the maximum transport capacity (Bagnold, 1941; Chepil, 1960; Andreotti et al., 2010). The length to reach the maximum transport capacity is as function of wind velocity and surface conditions (Bagnold, 1941;

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Fryrear and Saleh, 1996; Andreotti, 2004; Dong et al., 2004; Andreotti et al., 2010; Pähtz et al., 2013; Cheng et al., 2017). In addition, for a wind with a constant velocity, this length assumed to be inversely affected by soil erodibility (Chepil, 1960). Thus, one way to control wind erosion is to reduce field length. From another point of view, the concept of self-balancing mechanism and saturated length was first proposed by Bagnold (1941). The self-balancing concept suggests that the extraction of momentum from the surface wind by accelerating particle and the associated shear stress reduction are primarily responsible for limiting the growth of horizontal flux to a stable maximum value. Later studies under field (Zou et al., 2015) and laboratory conditions (Dong et al., 2004; Andreotti et al., 2010; Cheng et al., 2017) approved that the saturation length had a significant impact on the sediment transport capacity. Furthermore, the knowledge of spatial variability in sediment mass flux over an eroding soil bed length is important for modeling of aeolian sediment transport processes and quantifying net soil erosion (Garcia-Oliva et al., 1995). However, there are fundamental differences between sediment mass flux and net soil erosion at different spatial scales (Goossens and Buck, 2011), as aeolian processes are subjected to soil redistribution (Perreault et al., 2013).

Soil surface roughness is an important feature that significantly affects soil erosion by wind over agricultural lands (Webb and Strong, 2011). The soil surface roughness is the resultant of micro-variation in the soil surface elevations across a field due to cultivation (Zhang et al., 2004), tillage practices (Liu et al., 2006), construction (Fryrear et al., 2001), gravel surface (Dong et al., 2002), wind barriers (Fryrear et al., 2001), plant residue (Zhang et al., 2004), particle size distribution (Zamani and Mahmoodabadi, 2013) and sediment deposition (Zhao et al., 2014). The surface roughness affects wind erosion through its interaction with the wind velocity as portion of total shear stress of wind absorbed by surface roughness and the physical protection and sheltering of the soil surface (Webb and Strong, 2011; Furieri et al., 2014). Zamani and Mahmoodabadi (2013) indicated the importance of mean weight diameter (MWD) of surface aggregates as an aerodynamic roughness factor on wind erosion rate and soil erodibility. Another important factor affecting wind erosion rate is wind velocity (Mahmoodabadi et al., 2011). Most of studied reported that higher wind speeds increased wind erosion rate. However, maintaining the surface roughness can reduce the erosive impact of wind on the surface soil, resulting in wind erosion reduction, and therefore this is known as a suitable management practice (Stout and Zobeck, 1996).

This study attempts to provide more information on the changes of wind sediment flux and wind/net erosion rate along soil bed length, with emphasizing on the effects of wind velocity as well as soil particle size distribution. The authors hypothesize that wind erosion and sediment flux can change on different downwind lengths. Most of previous studies have investigated wind erosion in relation to distance on sand beds (Dong et al., 2004; Zhang et al., 2012; Cheng et al., 2017), while little attention has been paid to the effect of soil as an eroding bed with different lengths and aggregate size distributions. However, the effect of bed length on wind erosion rate and sediment flux has been further considered under field conditions, the effect on net erosion under laboratory conditions and by means of wind tunnel has been less studied. Under such controlled conditions, the effects of different affecting factors i.e. wind velocity, aggregate size distribution and soil bed length can be investigated more precisely. Better knowledge of wind erosion processes in relation to these affecting factors is of importance in measuring and modeling of soil erosion. Therefore, the aim of this study is 1) to examine the effect of soil bed length, aggregate size distribution and wind speed on sediment flux and net erosion rate, and 2) to assess the spatial dependence of net wind erosion rate on bed length, and 3) to model wind erosion rate as a function of bed length, soil MWD and wind speed.

2. Materials and methods

2.1. Study area

This study was performed on a soil sample taken from an experimental field located in Kerman province, central Iran (latitude of 30° 14′ N and longitude of 57° 06′ E). According to the Keys to Soil Taxonomy, the soil is classified as Haplocalcids (Soil Survey Staff, 2014). The soil sampling site has been under agricultural cropping for > 10 years, with a conventional management (moldboard plowing, without amendment incorporation and fertilization with urea). The dominant crops had been cultivated in this field were mostly wheat (*Tritium aestivum* L.) and corn (*Zea mays* L.). Prior to the beginning of the experiment, the field has been rested under fallow conditions for 2 years. The susceptibility of the soils to wind erosion has been reinforced by the dry, smooth and pulverized soil surface under conventional tillage. Therefore, the soils have experienced severe wind erosion during recent decades (Zamani and Mahmoodabadi, 2013). In general, dry climate, poor vegetation and adjacency with Dasht-e Lut Desert are most important factors that cause the prevailing wind erosion in the region. According to the meteorological information of synoptic stations in the region, the long-term mean precipitation of the area is 140 mm per annum, about 75% of which falls during the winter and spring. During the recent 25 years, the maximum and minimum amounts of rainfall have been recorded for years 1992 (307.2 mm yr^{-1}) and 1998 (56.3 mm y^{-1}). The average annual temperature for this region is 16.5 °C ranging from 1.9 to 28.9 °C (Mahmoodabadi and Heydarpour, 2014).

2.2. Soil sampling

The soil used for the experiment was collected from 0 to 20 cm depth of the field. The soil sample was air-dried, thoroughly mixed, crushed to pass through 2, 4.75 and 8 mm sieves, separately to prepare three sub-samples with max aggregate sizes of 2, 4.75 and 8 mm, hereafter called D_{2mm}, $D_{4.75mm}$ and D_{8mm}. For each soil sample, some physical and chemical properties were measured. Soil texture was determined by the hydrometer method (Gee and Or, 2002) and the MWD of aggregates was determined using sieving apparatus (Kemper and Rosenau, 1986). Soil pH and electrical conductivity (EC) were measured in the saturated paste and the saturated paste extract, respectively (Page et al., 1992). The content of soil organic carbon (SOC) was determined as described by Walkley and Black (1934), and the percent of $CaCO_3$ equivalent was measured using the titration method (Pansu and Gautheyrou, 2006). The physical and chemical properties of the soils are shown in Table 1. The texture class of all the soils is sandy loam whereas the frequency of larger aggregates differs among the soil subsamples. The amount of calcium carbonate is considerable and higher than 10%, while the content of organic carbon is < 0.6%, which is

Table 1
Some physical and chemical properties of the soils used in the experiment.

Property	Unit	D_{2mm}	$D_{4.75mm}$	D_{8mm}
Clay (0–0.002 mm)	%	9	5	5
Silt (0.002–0.05 mm)	%	13	20	15
Sand (0.05–2 mm)	%	78	75	80
MWD[a]	mm	0.206	0.455	1.082
Bulk density	g cm^{-3}	1.47	1.5	1.41
OC[b]	%	0.195	0.58	0.39
$CaCO_3$	%	14	13.5	13.5
EC[c]	dS m^{-1}	3.35	3.70	3.75
pH	–	7.69	7.83	7.68

[a] MWD: mean weight diameter.
[b] OC: organic carbon.
[c] EC: electrical conductivity.