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Portable wind tunnel experiments to study soil erosion by wind and its link to soil properties in the Fars province, Iran

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ABSTRACT

Soil erosion controlled by the wind effect on the surface, has been largely studied by field in-situ measurements as well as laboratory or numerical simulations. Nevertheless, more in-situ measurements and observations are needed to document this phenomenon for various desert areas. In the present study, we focus on the documentation of different properties of a wide range of semi-arid and arid soils of the Fars province, and how they control the soil erosion by wind. By improving our knowledge on soil properties which lead to the limitation of soil erosion by wind, it will be possible to better prevent wind erosion in the Fars province. Extensive wind tunnel experiments were conducted in 20 different arid and semi-arid regions. For each region, three wind tunnel experiments were done to encounter local soil variability. We determined threshold wind speeds for which soil erosion was observed. Other experiments were conducted at the same high wind speed, and duration conditions, allowing discussing soil erosion rates by wind regarding soil properties. As already documented in the literature, our results pointed out a significant negative power relationship between wind erosion rate and different soil physical properties, including soil surface gravel cover, the mean weight diameter (MWD) of soil particles, and soil clay and moisture contents. Moreover, a nonlinear relationship as a power function was found between the increase of soil organic carbon and the decrease of soil losses by wind in the studied semi-arid and arid soils. We determined critical values of these soil properties for which wind erosion in Fars province is limited under high wind speed conditions. Additionally, the effects of the electrical conductivity (EC), sodium adsorption ratio (SAR), and calcium carbonate equivalent (CCE) on wind erodibility were discussed at low and high concentrations and for different soil textures.

1. Introduction

Soil erosion by wind is a serious environmental problem in many arid and semi-arid regions; it is considered as a soil-degrading process (Webb et al., 2017) that affects over 500 million ha of land worldwide (Grini et al., 2005). In fact, wind erosion degrades soil by removing and emitting in the atmosphere fine soil particles that contain most of the soil organic carbon and nutrients (Van Pelt and Zobeck, 2007). The appraisal of this process at the soil-atmosphere interface is central to estimate of soil loss for soil conservation planning (Black and Chanasyk, 1989). The emission of top soil particles from land surfaces into the atmosphere impacts the soil productivity, and should also be considered for air quality and health issues (Webb et al., 2017; Pi and Sharratt, 2017; Pi et al., 2017).

Soil erosion by wind is a function of the soil erodibility and the wind erosivity (Chepil and Woodruff, 1963). It is a threshold phenomenon controlled by surface winds and soil properties.

There is a minimum wind stress that corresponds to a threshold velocity needed to initiate wind erosion on semi-arid and arid surfaces (Chepil, 1951; Gillette et al., 1982). Non-erodible elements such as vegetation and gravels on an erodible surface not only increase the apparent threshold wind velocity but also reduce the mass erosion rate. Even if the erosive action of the wind depends on its speed, several factors like the size and stability of the soil aggregates, clay content, and near-surface soil moisture affect the threshold velocity (Ravi et al., 2006).

The size and stability of soil aggregates are significant factors that affect the soil susceptibility to wind erosion (Colazo and Buschiazzo,

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2010; Négyesi et al., 2016). In general, soil aggregates are formed through the combination of mineral particles with organic and inorganic substances (Bronick and Lal, 2005; Mahmoodabadi and Ahmadbeigi, 2013). The binding of soil particles into stable aggregates is essential for the production of optimum soil tilth (Harris et al., 1966). Inter particle cohesion is a combined effect of the van der Waals force, liquid and chemical force, and electrostatic force. These effects are sensitive to soil properties, such as the particle shape and texture, the soil mineralogy, the packing arrangement, and the presence or absence of bonding agents such as soil moisture and soluble salts (Shao and Lu, 2000).

Soil texture can play a dominant role in the susceptibility of a soil surface to wind erosion (Belnap et al., 2007; He et al., 2008; Pasztor et al., 2016). Sandy soils are inherently more erodible than fine-textured soils, as they have less salt, clay and silt to enhance physical crusting and soil aggregation (Chepil, 1953; Colazo and Buschiazzo, 2010).

Soil moisture contributes to the binding forces keeping particles together (Cornelis et al., 2004) and to the soil aggregate formation (Webb and Strong, 2011) through adhesion and capillary effects (McKenna-Neuman and Nickling, 1989). The moisture of surface sediments is then one of the most significant factors governing the initiation of particle movement by the wind and hence the Aeolian transport rates (Dong et al., 2007).

Additionally, soil organic carbon is an important soil component (Mahmoodabadi and Heydarpour, 2014), which acts as a binding agent and as a nucleus in the formation of aggregates (Bronick and Lal, 2005). Accordingly, increase of soil organic carbon can enhance soil aggregate stability and formation (Mahmoodabadi and Ahmadbeigi, 2013) and, as a consequence, decrease soil erodibility (Bronick and Lal, 2005).

The effects of salinity (Mahmoodabadi et al., 2013) and sodicity (Ghadiri et al., 2004) on soil properties have been pointed out especially in arid and semi-arid regions. For instance, high levels of sodium enlarge soil erosion due to its destructive effect on soil structure (Ghadiri et al., 2004). Salts such as halite, lime and gypsum have different influence on soil erodibility by wind, which is related to factors like density (Ekhtesasi et al., 2003) and soil texture (Chepil, 1954; Tatarko, 2001).

In this study, we focus on wind erosion in Iranian semi-arid and arid areas of the Fars province located in the southwestern part of the country. Even if numerous studies investigated the link between wind erosion and soil properties, little is known about the controlling factors of the soil potential to wind erosion in the Fars province, and such a study could help us in wind erosion prevention and control programs. We propose to document physical and chemical properties of various natural semi-arid and arid soils of this region. Using an in-situ portable wind tunnel, threshold wind velocities for which soil erosion occurs are determined, and relationships between soil properties and wind erosion rates are studied under high wind speed condition.

2. Material and methods

2.1. Study area description of the in-situ measurement sites

Iran is located on the belt of arid and semi-arid regions of the world (Moradi et al., 2011) and suffers from dust events (Taghavi et al., 2017). Two-thirds of the country are within a dry climate (Zamani and Mahmoodabadi, 2013), and more than half of the Iranian provinces are suffering from critical wind erosion (Amiraslani and Dragovich, 2011; Rezaei et al., 2016). Frequent and intense dust sources are identified in Iran as for instance the Sistan Basin (Rashki et al., 2012), Al-Howizeh/Al-Azim marshes (Cao et al., 2015) and Kavir and Lut deserts (Rashki et al., 2015). Ginoux et al. (2012) also identified dust sources along the west coast of Iran.

Fars province is located in the south of the central region of Iran (Fig. 1a), from 27° 2′ to 31° 42′ northern latitude and 50° 42′ to 55° 36′ eastern longitude (Moradi et al., 2011). The area of this province is about 133.299 km^2, covering 8.1% of Iran. Based on De Martonne (1926) aridity index, all regions of Fars province are generally placed in arid and semi-arid classification (Nafarzadegan et al., 2012). Due to low annual precipitation, varying between 100 mm in the southern parts and > 400 mm in the northern parts (Nafarzadegan et al., 2012), and semi-arid and arid climate, draught is a common occurrence in this province (Tehrani et al., 2016), and many lakes of the province have been dried. Moreover, dust storms are of natural hazards in this province (Ghasem et al., 2012). Several intense dust storm events have been reported in this province, as for instance in summer (17 July 1998, 13 August 2001, and 28 August 2013) or spring (24 April 2008 and 28 February 2009), during which high wind speeds between 16 $m\,s^{-1}$ and 20 $m\,s^{-1}$ at the height of 10 m were measured. For example, the dust storm of 28 February 2009, reported in the southeast of the province, led to the decrease of visibility to 800 m (Mazidi et al., 2015).

Soil erosion by wind occurs during high wind speed events. These meteorological events are most of the time rare, leading to sporadic and pulsed dust particle emission in the atmosphere. In order to illustrate the occurrence of high wind events, the maximum wind speeds measured at three meteorological stations in the Fars province, including Shiraz (29° 32′ N and 52° 36′ E), Abadeh (31° 11′ N and 52° 40′ E), and Eghlid (30° 54′ N and 52° 38′ E) between 1990 or 1995 and 2017 are presented for each month in Fig. 2. High wind speeds higher than 7 $m\,s^{-1}$ and up to 30 $m\,s^{-1}$ (measured at 10 m height) are observed at these stations, even higher wind speeds being registered at Eghlid. These maximum wind speeds are generally associated with west to southwest directions at Shiraz, southwest but also west and north directions at Abadeh, and southwest direction at Eghlid (Fig. 2). The geographic locations of the three meteorological stations are shown in Fig. 1a.

In order to study soil erosion by wind using a portable wind tunnel in the Fars province, 20 arid and semi-arid regions were selected in the different geographic areas of the province, providing a variety of soils with different properties. Flat lands with as few vegetation, rock and pebble covers as possible and with no apparent crust were chosen. Fig. 1 presents the geographic locations (a) and general views of the 20 study regions in Fars province (b), which have different soil textures (fine, medium and coarse) and land use types: seasonal or abandoned agricultural fields, plains, rangelands, dried lakes or rivers. The average slope of soil surface is below 1%, and the majority of the studied regions have poor to moderate vegetation covers. The features of the studied regions, which were determined in the field, are listed in Table 1.

2.2. Wind tunnel experiments

Much of what we know about Aeolian processes comes from wind tunnel-based investigations (Gillette, 1978; Van Pelt and Zobeck, 2013). Mobile wind tunnels are essential tools for the field examination and quantification of wind erosion processes on natural non-imitated surfaces under standardized, quasi-natural wind conditions (Maurer et al., 2006). In fact, wind tunnels allow generating wind erosion for controlled conditions such as the area exposed to wind, soil surfaces, and wind speed, direction, and turbulence (Pi and Sharratt, 2017).

In order to determine wind erosion for the selected regions, a portable wind tunnel is used. This device was designed, constructed and calibrated in the Dry and Desert Regions Research Center of Yazd University of Iran. This wind tunnel is based on a previous version with a weaker wind generator (maximum wind speed of 12 $m\,s^{-1}$), which has been successfully used in previous studies (e.g. Azimzadeh et al., 2002; Ekhtesasi et al., 2003; Azimzadeh et al., 2008).

The portable wind tunnel used in this study consists of three main parts, including:

(1) A jet fan blower with 2-hp power, as a wind generator which can generate wind speeds in the range of 0.5–22 $m\,s^{-1}$ at the height of 0.25 m.