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Wind erosion potential of lacustrine and alluvial soils before and after disturbance in the eastern Great Basin, USA: Estimating threshold friction velocity using easier-to-measure soil properties

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A B S T R A C T

Disturbance of lacustrine and alluvial soils could increase aeolian dust emissions in the eastern Great Basin, but little is known about the susceptibility of these land surfaces to wind erosion. Threshold friction velocity (u_{*t}), a necessary parameter to estimate wind erosion potential, is difficult to accurately measure; methods to estimate u_{*t} from alternate measurements would be useful. We measured u_{*t} and sediment production rate with a portable wind tunnel, and quantified relationships between u_{*t} and eleven easier-to-measure soil surface properties for both undisturbed and disturbed lacustrine and alluvial soils in Snake Valley, Utah. Soil surface type and disturbance significantly influenced u_{*t}, sediment production rate, and the relationships between u_{*t} and easier-to-measure soil surface properties. Only soils with surficial rock fragments and weak physical crusts reached u_{*t} before disturbance, whereas all surface types reached u_{*t} following disturbance. Soils with weak physical crusts had the lowest average u_{*t} and highest average sediment production rate before and after disturbance. Surprisingly, however, disturbance reduced sediment production rate. Soils with weak physical crusts and surficial rock cover are likely the most susceptible to wind erosion and subsequent dust generation both before and after disturbance. Silt concentration and penetrometer resistance were significant predictors of u_{*t} in undisturbed soils with weak physical crusts and surficial rock cover. Following disturbance, clay concentration and aggregate stability were significant predictors for soils with hard salt crusts and surficial rock cover. Prediction of u_{*t} using alternate measurements is promising, but u_{*t} measurement uncertainty must be considered.

1. Introduction

Aeolian dust is an important biogeochemical flux in many ecosystems (Field et al., 2009; Lawrence and Neff, 2009; Reynolds et al., 2006) and can impact human health (Goudie and Middleton, 2006). Aeolian dust from drylands in the southwestern USA has significantly increased in the past century because of anthropogenic soil surface disturbance (Neff et al., 2008). Deposition of this aeolian dust on mountain snowpack results in earlier spring runoff and decreased water in the Colorado River (Painter et al., 2007, 2010).

The eastern Great Basin, including parts of, Nevada and Utah is a major source of aeolian dust in the western USA (Prospero et al., 2002). Dust from lacustrine soil surfaces in this area often impacts air quality in Salt Lake City and other metropolitan areas of Utah (Hahnenberger and Nicoll, 2012). Any future groundwater extraction from the this area such as that proposed to meet southern Nevada's population growth demands (Southern Nevada Water Authority Water Resource Plan 2009, http://www.snwa.com/assets/pdf/wr_plan.pdf) could potentially increase dust emissions, as groundwater withdrawal has increased dust emissions from similar areas, such as Owens Valley, California (Elmore et al., 2008; Gill, 1996). Additionally, anthropogenic soil surface disturbance from land management activities and potential energy development in this area (Devoe, 2008) could increase dust production by altering or reducing the protective cover of vegetation and disturbing soil surface crusts (Belnap and Gillette, 1998; Belnap et al., 2007, 2014; Field et al., 2009; Miller et al., 2012; Okin et al., 2001, 2006).

Aeolian dust emission is the result of soil wind erosion. Soil wind erosion occurs when the interaction between wind flow and the earth surface transports enough momentum to the soil surface to overcome the gravitational and cohesive forces retarding soil particle movement and sediment entrainment (Chepil, 1959;

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Goudie and Middleton, 2006; Iversen and White, 1982). This transport of momentum is by definition a shear stress. However, it is convenient to transform the shear stress into a new variable with units of velocity. The resulting so-called friction velocity, is a fundamental measure of turbulence intensity near the surface. Although friction velocity is not the only property of turbulence that can govern the movement and/or entrainment of soil particles, it may be the most useful, and is commonly used. Threshold friction velocity (u_{*t} [Bagnold, 1941]) is the minimum friction velocity value required to initiate wind erosion (Greeley and Iversen, 1985). Therefore, soils with relatively low u_{*t} values would be more susceptible to wind erosion.

Threshold friction velocity is influenced by a number of factors including soil texture, soil moisture, surface rock cover, and soil surface crust type (Li et al., 2010). Soil texture fundamentally controls u_{*t} by influencing wind erodible particle size (Bagnold, 1941; Chepil, 1951; Iversen and White, 1982; Singer and Shainberg, 2004). Generally, u_{*t} decreases with decreasing particle size until reaching a minimum around 0.08 mm diameter (Bagnold, 1941; Chepil, 1951). u_{*t} actually increases below this particle size diameter. Soil moisture influences u_{*t} by increasing interparticle cohesive forces with increasing soil moisture, although this relationship is non-linear and temporally variable (Cornelis et al., 2004; Fécan et al., 1998; Ravi et al., 2006). The presence of surface rocks, large soil aggregates, and other non-erodible roughness elements covering the soil surface influences u_{*t} by absorbing a portion of the turbulence induced shear stress and increasing u_{*t} (Chepil, 1950; Marticorena and Bergametti, 1995).

Soil surface crust type also influences u_{*t} (Belnap et al., 2014; Gillette et al., 1982). In particular, soils with physical, biological, or hard salt crusts have higher u_{*t} values than soils lacking such crusts (Belnap and Gillette, 1998; Singer and Shainberg, 2004; Zhang et al., 2008). When well-developed, soil crusts can increase u_{*t} beyond any turbulence likely experienced under natural conditions and prohibit wind erosion (Belnap and Gillette, 1998; Marticorena et al., 1997). However; disturbance of crusted soils significantly reduces u_{*t} (Belnap and Gillette, 1997), sometimes to levels comparable with sandy or loose-uncrusted soils (Marticorena et al., 1997). In the eastern Great Basin, most lacustrine and alluvial soils exhibit some type of soil surface crust.

Because the factors controlling u_{*t}, and thus wind erosion, can be highly spatially heterogeneous (Gillette et al., 1997; Gillette, 1999; Hahnenberger and Nicoll, 2014; Sweeney et al., 2011), average u_{*t} values over large geographic areas do not accurately capture the spatially variable nature of u_{*t} (Okin and Gillette, 2004) and multiple measurements are likely needed (Li et al., 2010). However; threshold friction velocity is time-consuming and difficult to accurately measure, and methods to estimate u_{*t} from alternate measurements would be useful. In the Colorado Plateau and Mojave Desert, Li et al. (2010) found u_{*t} correlated with soil surface strength and percent rock cover, both of which are simple to measure. However, the sandy soils in the Mojave Desert and Colorado Plateau may behave differently than the calcareous and silt- and clay-rich lacustrine soils common in the eastern Great Basin.

Understanding areas likely vulnerable to dust emissions would be useful to land managers tasked with balancing competing land use priorities and mitigating aeolian dust emissions. However; little is known about the specific land surfaces most likely to produce aeolian dust in the eastern Great Basin. Therefore, our main questions were: (1) what is u_{*t} and the associated sediment production rate in lacustrine and alluvial soils in the eastern Great Basin before and after disturbance?; (2) can u_{*t} be estimated from easier-to-measure soil surface properties? We addressed these questions by measuring u_{*t} and sediment production rates at 33 locations on undisturbed and disturbed lacustrine and alluvial soils using a portable wind tunnel in Snake Valley, Utah. At each site, we also documented eleven easier-to-measure soil properties. In this paper, we examine how both u_{*t} and sediment production rate are influenced by soil surface type, and how well relationships between u_{*t} and a few easier-to-measure soil surface properties can be quantified for both undisturbed and disturbed soils.

2. Methods

2.1. Study area

The study area was located in Snake Valley, a broad, hydrologically closed, north–south trending valley on the Utah/Nevada border in the eastern Great Basin (Fig. 1). Major landforms include alluvial fans and fan piedmonts with relatively coarse-textured alluvial soils surrounding lake plains with fine-grained lacustrine materials on the valley floor. Both wet and dry playas occur in the lowest elevations. Relict beaches and sand bars from Pleistocene Lake Bonneville also exist (Hintze and Davis, 2003).

In areas heavily influenced by Lake Bonneville, vegetation is dominantly greasewood [*Sarcobatus vermiculatus*], shadscale [*Atriplex confertifolia*], and Nevada tea [*Ephedra nevadensis*] (personal observation). In near-playa environments, vegetation is mostly salt grass [*Distichlis spicata*], alkali sacaton [*Sporobolus airoides*], and pickleweed [*Salicornia* spp.]. Halogeton [*Halogeton*] and cheat grass [*Bromus tectorum*] grow between shrubs in some areas. A few ranches exist where ephemeral streams enter the valley. Average annual precipitation is 161 mm; average annual temperature is 10.4 °C (Western Regional Climate Center, historical climate summary for Eskdale, UT, http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?ut2607).

All sampling was performed in the Millard County, UT, portion of Snake Valley (approximate center 39° 16′05″N, 113° 53′17″W), below the Bonneville shoreline of Lake Bonneville (Currey et al., 1984). Sampling sites were selected to capture anticipated soil variability in the following sediments: alluvium, mixed alluvial/lacustrine materials, lacustrine gravel and lacustrine sand (Hintze and Davis, 2003).

2.2. Threshold friction velocity and mobilized sediment measurement

Threshold friction velocity (u_{*t}) was estimated using the 15 cm × 240 cm portable, open-bottomed wind tunnel described by Belnap et al. (2007) and Li et al. (2010) (Fig. 2). A pre-weighed fiberglass filter (pore-size approximately 3 μm; Belnap et al., 2014) was inserted into the sampling frame at the end of the expansion chamber to capture mobilized sediment.

All measurements of wind speed were made by a pitot tube inside the wind tunnel attached to a Fluke 922 Airflow Meter/Micromanometer (range ± 16 in-wc., resolution 0.001 in-wc., accuracy ± 1% + 0.01 in-wc., www.fluke.com/922) and recorded in units of pressure (inches of water column [in-wc.]). Measurements of pressure at a constant tunnel wind speed were collected at seven heights above the soil surface (0, 0.318, 0.635, 1.27, 2.54, 5.08, 7.62 and 10.16 cm), and allowed calculation of a velocity profile. Measurement of each velocity profile required approximately 30 s. Wind tunnel design required that all sites be within about 20 m of a road, but care was taken to avoid areas disturbed during road construction and maintenance. All field sampling was conducted during July 2012, and 33 separate sites were visited.

Wind tunnel measurements were performed on both the existing 'undisturbed' soil surface and a disturbed surface at each sampling location. Care was taken to avoid any disturbance before wind tunnel placement on the undisturbed soil surface. The disturbed soil surface was created by driving a 1/2-ton truck once forward and then once in reverse so that that only the front wheels passed twice over the surface.