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Soil property effects on wind erosion of organic soils

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ABSTRACT

Histosols (also known as organic soils, mucks, or peats) are soils that are dominated by organic matter (OM > 20%) in half or more of the upper 80 cm. Forty two states have a total of 21 million ha of Histosols in the United States. These soils, when intensively cropped, are subject to wind erosion resulting in loss of crop productivity and degradation of soil, air, and water quality. Estimating wind erosion on Histosols has been determined by USDA–Natural Resources Conservation Service (NRCS) as a critical need for the Wind Erosion Prediction System (WEPS) model. WEPS has been developed to simulate wind erosion on agricultural land in the US, including soils with organic soil material surfaces. However, additional field measurements are needed to understand how soil properties vary among organic soils and to calibrate and validate estimates of wind erosion of organic soils using WEPS. Soil properties and sediment flux were measured in six soils with high organic contents located in Michigan and Florida, USA. Soil properties observed included organic matter content, particle density, dry mechanical stability, dry clod stability, wind erodible material, and geometric mean diameter of the surface aggregate distribution. A field portable wind tunnel was used to generate suspended sediment and dust from agricultural surfaces for soils ranging from 17% to 67% organic matter. The soils were tilled and rolled to provide a consolidated, friable surface. Dust emissions and saltation were measured using an isokinetic vertical slot sampler aspirated by a regulated suction source. Suspended dust was sampled using a Grimm optical particle size analyzer. Particle density of the saltation-sized material (>106 μm) was inversely related to OM content and varied from 2.41 g cm^{-3} for the soil with the lowest OM content to 1.61 g cm^{-3} for the soil with highest OM content. Wind erodible material and the geometric mean diameter of the surface soil were inversely related to dry clod stability. The effect of soil properties on sediment flux varied among flux types. Saltation flux was adequately predicted with simple linear regression models. Dry mechanical stability was the best single soil property linearly related to saltation flux. Simple linear models with soil properties as independent variables were not well correlated with PM_{10} E values (mass flux). A second order polynomial equation with OM as the independent variable was found to be most highly correlated with PM_{10} E values. These results demonstrate that variations in sediment and dust emissions can be linked to soil properties using simple models based on one or more soil properties to estimate saltation mass flux and PM_{10} E values from organic and organic-rich soils.

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1. Introduction

The United States Department of Agriculture, Natural Resources Conservation Service estimates that erosion due to wind on non-federal cropland in the US in 2007 was approximately 0.7 billion Mg yr^{-1} (an average of 4.7 Mg ha^{-1} yr^{-1}) (USDA–NRCS, 2007). In the US, there are approximately 21 million ha of organic soils occurring in 42 states (Lucas, 1982). Wind erosion can be a serious problem in these soils (Lucas, 1982; Parent et al., 1982; Parent and Ilnicki, 2003; Kohake et al., 2010), causing severe soil losses resulting in crop loss and environmental degradation. Losses of 2.5 cm of soil and complete filling in of an agricultural drainage ditch from one storm have been observed (Lucas, 1982). In addition, organic soils are often used in the production of high-value vegetable crops and for a given mass loss, the offsite impacts from organic soils may be greater than mineral soils due to the increased soil volume and lower density of organic soils (Kohake et al., 2010).

The factors that affect wind erosion of organic soils are similar to those that affect mineral soils. Kohake et al. (2010) investigated

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the wind erodibility of organic soils and suggested the most important soil factors are dry aggregate stability (DAS), dry aggregate size distribution (ASD), aggregate density (AD), surface moisture content, crusting and loose erodible material on the crust surface. In addition, the state of the soil structure, such as size, shape, and density of erodible and non-erodible fractions have been listed by Chepil and Woodruff (1963) as some of the most important soil conditions that influence wind erosion.

The DAS is a measure of the ability of soil aggregates to resist breakdown under physical forces. Wind erosion has been related to DAS, as measured by the energy needed to crush an aggregate to a specified end point, called the crushing energy (CE)(Skidmore and Layton, 1992; Hagen et al., 1995) and the amount of aggregate breakdown after repeated sieving in a rotary sieve (Chepil, 1962), called the mechanical stability (Chepil, 1951). In a study of four organic muck soils, Kohake et al. (2010) found the mean CE values to range from 2.73 to 4.12 ln(J kg^{-1}).

The ASD is a description of the distribution of soil aggregates or clods on the soil surface (Zobeck, 1991b; Zobeck et al., 2003a). A rotary sieve is used to determine ASD and the wind erodible material (WEM) of soil, defined as the percent of soil <0.84 mm diameter (Chepil, 1958). The WEM has long been used in conservation planning to estimate wind erosion using the Wind Erosion Equation (Woodruff and Siddoway, 1965). The geometric mean diameter (GMD) and geometric standard deviation are commonly used to describe the ASD (Zobeck, 1991b). In a study of the ASD of three organic (muck) soils in Michigan, the GMD varied throughout the year and ranged from 1.1 to 20.5 mm (Mokma, 1992). The GMD ranged from 1.1 to 8.8 mm in the Kohake et al. (2010) study. Zobeck et al. (2003a) reported the mean GMD of three organic soils in Michigan to vary from 2.3 to 6.6 mm. The mean WEM of the same study varied from 7% to 34%. The WEM observed for nine organic soils from the Midwest US ranged from 22% to 64% (Woodruff, 1970).

Aggregate density is a measure of the mass of soil aggregates per unit volume. Other factors being equal, wind of a given strength can move larger aggregates that are less dense compared with aggregates that are more dense (Kohake et al., 2010). The density of organic soil aggregates will depend upon the type of organic material, level of organic matter decomposition, and the amount and type of mineral matter present. In addition, the density of aggregates tends to decrease with increasing aggregate (or sample) size. For example, the bulk density of large samples of organic soils is often quite low. The surface soil bulk density of Florida organic soils was observed to vary from 0.26 to 0.73 Mg m^{-3} (Zelany and Carlisle, 1974). The surface soil of a cultivated Houghton muck soil in Michigan had a bulk density of 0.30 Mg m^{-3} (Lucas, 1982). In more recent work, the bulk density of organic soil surfaces ranged from 0.19 to 0.64 Mg m^{-3} while the density of 20 mm diameter clods of organic soils ranged in density from 0.58 to 1.11 Mg m^{-3} (Mokma, 1992). In the Kohake et al. (2010) study of four muck soils, the mean density of five different aggregate size classes, ranging in diameter from approximately 1–19 mm, varied from 0.93 to 1.13 Mg m^{-3}. The density of smaller organic soil aggregates and particles may be even greater. The mean densities of 0.29–2.00 mm diameter particles and aggregates from nine organic soils from the Midwest US ranged from 1.57 to 1.70 Mg m^{-3} (Woodruff, 1970). The density of the smaller particles was likely related to the amount of organic matter (OM), relative to mineral matter, contained in each sample. The density of organic soil aggregates increases with increasing sand to OM ratio due to the much greater density of mineral grains relative to OM.

Although Kohake et al. (2010) also noted the importance of soil moisture and crust properties to wind erosion of organic soils. In our study, we used air-dried, tilled and leveled soils to maintain similar moisture and surface conditions for each site.

Relative to mineral-dominated soils, few studies have focused on the wind erosion of organic soils. Portable wind tunnel studies of organic soils in Ohio and Wisconsin and laboratory tests of samples from Michigan and Minnesota suggested organic soils react differently to wind action than mineral soils (Woodruff, 1970). Results from sieving with a rotary sieve suggested that organic soils were less erodible than highly erodible sands and sandy loams. However, wind tunnel tests and incidence of erosion under natural conditions indicated they are highly erodible under certain conditions (Woodruff, 1970). In a laboratory wind tunnel study, Zobeck (1991a) found that the soil loss rate for a sieved organic soil could be an order of magnitude greater than that of mineral soils, with the exception of a loamy sand soil. Under the lowest abrasion feed rate tested in the study, the organic soil loss rate was 2.7 times that of the loamy sand soil.

The Wind Erosion Prediction System (WEPS) developed by scientists at the USDA–ARS is a process-based, daily time-step model that incorporates the latest wind erosion science and technology, and was designed to be a replacement for the USDA–ARS Wind Erosion Equation (Hagen, 1991; Wagner, 1996; USDA–ARS, 2008). The structure of WEPS is modular and includes sub-models that simulate daily weather, hydrology, tillage and crop management, crop growth, soil surface conditions, decomposition, and erosion. The model includes five databases for climate, soils, management, barriers, crop growth, and residue decomposition. A user interface provides a way for the user to enter initial conditions such as field dimensions and orientation, barriers, locations of barriers, management operations, and soil type for the desired simulation region (USDA–ARS, 2008). Given the information provided by the user, the interface accesses the databases for the detailed information needed for simulation. Specific soil-related data needed by WEPS include surface micro-relief (roughness) properties such as ridge height and spacing and random roughness, soil sand and clay content, organic matter and calcium carbonate content, and crust and aggregate properties including aggregate size distribution, dry stability, and density. Further detailed descriptions of the many inputs needed for WEPS are beyond the scope of this paper and have been described elsewhere (Hagen, 1991; Zobeck, 1991b; Wagner, 1996; USDA–ARS, 2008).

WEPS outputs include average and total number of erosion events over the simulation period, soil loss per erosion event, and average creep and saltation material, suspension, and PM_{10} (particulate matter less than 10 μm) leaving the field. WEPS has been field tested and validated for a wide variety of mineral soils (Funk et al., 2004; Hagen, 2004; Feng and Sharratt, 2007) but no similar field studies have been made on organic soils. However, since so little information is available for organic soils, WEPS and other physically-based erosion models need additional data relating wind erosion of organic soils to soil properties. The objective of this study was to determine the effects of organic matter content, aggregate density, stability, and erodible fraction on wind erosion of organic soils to provide further information needed in the development of WEPS.

2. Materials and methods

2.1. Study sites

Soils with a range of surface soil organic matter (OM) contents were identified in Palm Beach Co., Florida and Newaygo Co., Michigan (Fig. 1). Three sites in Michigan were all mapped as Adrian muck (sandy or sandy-skeletal, mixed, euic, mesic Terric Haplosaprists) and were designated as high (MH, 57.5% OM), medium (MM, 40.9% OM), and low (ML, 16.7% OM) organic matter contents (Table 1). Three sites were also identified in Florida and were mapped as