Wind Erodibility of Organic Soils

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Intensively cropped organic soils are often subject to severe wind erosion. The objective of this study was to measure their physical wind erodibility properties. Four organic soils were collected from Florida, North Carolina, and Michigan. The organic matter content, aggregate density, dry-aggregate stability, aggregate size distribution, and soil water characteristics were measured. Trays (122 by 20 by 6 cm) were filled with field-sampled soils and sieved soils with 80% of aggregates <0.84 mm. Trays of both crusted and uncrusted soil were place in a laboratory wind tunnel and exposed to wind of various speeds. Aggregate densities ranged from 0.93 to 1.13 Mg m^{-3}, which is less than typical mineral soils. Dry-aggregate stability was relatively high [2.9–4.7 ln(J kg^{-1})]. Threshold friction velocity varied from 0.40 to 0.83 m s^{-1} for the field condition and from 0.27 to 0.31 m s^{-1} for the soil with 80% of the aggregates <0.84 mm. The aggregate abrasion coefficients ranged from 0.0006 to 0.0136 m^{-1}, meaning the aggregates should be moderately resistant to abrasion losses. The crust abrasion coefficients varied from 0.039 to 0.123 m^{-1}. Hence, a crusted soil surface should abrade more easily than a well-aggregated soil. The loose erodible material on the crusts ranged from 0.010 to 0.068 kg m^{-2} and varied directly with sand content and inversely with organic matter. The threshold friction velocities of organic soils were slightly higher than would be predicted for comparable mineral soils. From the results of this study, it is expected that for a given wind speed, a nearly equal mass of soil would be eroded from organic soils as from comparable mineral soil.

Abbreviations: AAC, aggregate abrasion coefficient; ASD, aggregate size distribution; CAC, crust abrasion coefficient; DAS, dry aggregate stability; GMD, geometric mean diameter; GSD, geometric standard deviation; LEM, loose erodible material; WEF, wind-erodible fraction; WEPS, Wind Erosion Prediction System.

Wind erosion can be a major problem on organic soils, resulting in severe soil losses (Robertson et al., 1978; Lucas, 1982; Parent et al., 1982; Mokma, 1992; Riksen and De Graaff, 2001; Campbell et al., 2002; Parent and Ilnicki, 2003). There are an estimated 342 million ha of organic soils throughout the world, with approximately 21 million ha of these in the United States (Lucas, 1982). Organic soils range from relatively undecomposed peat (fibric) to well-decomposed muck (sapric), with mucky peat (hemic) an intermediate material. Although the area of these soils is not great in comparison with the total land area, the muck soils are often used to produce high-value crops and are also the most wind erodible. Maintaining adequate soil depth and good soil quality is necessary to keep these soils productive for future use. For a given mass loss, the offsite impacts of dust from organic soils may be larger than that from mineral soils because of their increased volume and other unique properties. Thus, wind erosion needs to be adequately controlled to meet these concerns.

Compared with research on mineral soils, there has been little research conducted on the characteristics of organic soils that control their wind erodibility. Determining these characteristics and properties is essential in understanding the basis for wind erosion on organic soils.

Dry aggregate stability (DAS) is an important soil physical property that estimates an aggregate's ability to resist breakdown by physical forces in the dry state and is often expressed as the amount of energy needed to crush the aggregate (Skidmore and Layton, 1992). The DAS is ultimately determined by the intrinsic soil properties, but is affected by seasonal variations in climate and management. A

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low crushing energy that averaged 1.4 ln(J kg^{-1}) was measured for three organic soils from Michigan (Mokma, 1992).

The aggregate size distribution (ASD) gives an estimate of the amount of erodible-sized aggregates present in the soil. The ASD is often expressed by its geometric mean diameter (GMD) and geometric standard deviation (GSD). The GMD is the aggregate diameter at which 50% of the aggregates are smaller and 50% are larger (Nimmo and Perkins, 2002); the GSD is a measure of the distribution around the GMD value. The GMD was measured for three muck soils in Michigan and ranged from 1.90 to 4.66 mm (Mokma, 1992). Zobeck et al. (2003) reported that the GMD for four organic soils ranged from 2.5 to 7.9 mm. The wind-erodible fraction (WEF), the percentage of aggregates that are <0.84 mm in diameter (Chepil, 1958), can also be used as a way to express the ASD. Woodruff (1970, p. 5–8) found that the WEF for nine muck soils ranged from 22 to 65%.

Aggregate density, which is much less variable with time compared with the DAS and the ASD, can also affect the soil erodibility. If other factors are equal, a wind of a given strength can move larger aggregates that are less dense compared with aggregates that are more dense. Soils with higher amounts of organic matter generally have aggregate densities that are lower than typical mineral soils. Woodruff (1970, p. 5–8) found that aggregate densities averaged 0.94 Mg m^{-3} for nine muck soils, while Mokma (1992) found mean aggregate densities of 0.69 Mg m^{-3}. These differences probably arise from the degree of decomposition, the organic matter content, and the composition of the mineral component.

The wetness of the near-surface soil is another factor in determining the wind velocity required to initiate soil movement and in determining the abradibility of the surface aggregates. Chepil (1956) found that increasing the moisture content in excess of −1.5 MPa matric potential reduced erosion rates to near zero. Even small increases in soil moisture contents have been found to increase the wind velocity required to initiate soil particle movement (Saleh and Fryrear, 1995; Cornelis and Gabriels, 2003). The threshold wind speed seems to be controlled by the thickness of the water films around the soil particles. Thus, finer textured soils would require greater water content to prevent soil movement compared with coarser textured soils (Bisal and Hsieh, 1966). Low temperatures increase the air density, thus decreasing threshold wind speeds, while air humidity plays a complex role (Neuman, 2003; Ravi et al., 2006). Also, as the aggregate water content is increased, abrasion loss rates tend to decrease (Hagen et al., 1988). Because of their high specific surface area, organic soils can hold large amounts of water (Lucas, 1982), which should aid in reducing their erodibility.

Another critical parameter for wind erosion control is the threshold friction velocity (U_t^*), which is a measure of the driving force of the wind when erosion begins. The U_t^* can be affected by numerous soil properties, including ASD, soil texture, crust properties, and water content (Gillette et al., 1980).

Using a wind tunnel, good estimates of the mobile soil mass available to initiate erosion at various wind speeds can be determined. Soil loss amounts have been measured for some organic soils (Woodruff, 1972, p. 4–5). It was concluded that the relationship between the weight of soil eroded and the percentage of aggregates >0.84-mm diameter for mineral soils was true for organic soils as well.

The resistance of immobile soil aggregates or a crusted soil surface to withstand abrasion losses by saltating particles can be expressed as the abrasion coefficient (Hagen et al., 1992). Abrasion coefficients (L^{-1}) are defined as the ratio of the mass of soil abraded from the aggregates or a crust for a given unit area (M L^{-2}) per unit mass of abrader blown past the aggregates or crust for a unit width across the air stream (M L^{-1}). A low abrasion coefficient would signify that the soil aggregates or the surface crust is stable to saltating particles and would be difficult to abrade.

The loose erodible material (LEM) is the loose, unconsolidated soil material that is ≤0.84-mm equivalent diameter and is lying exposed on crusted surfaces. When crusted, the soil surface can be very stable, but the LEM lying exposed on the surface can be easily moved by the wind and act as an abrader in destroying the stable surface crust and embedded immobile soil aggregates.

The Wind Erosion Prediction System (WEPS), developed by scientists at the USDA-ARS Wind Erosion Research Unit, is a process-based, daily-time-step model that simulates weather, field conditions, management, and erosion (Hagen, 1991; Wagner, 1996). The WEPS incorporates the latest wind-erosion science and technology, and is designed to be a replacement for the Wind Erosion Equation. But the WEPS and other physically based erosion models need additional wind erodibility data for organic soils. The purpose of this study was to determine the erodibility parameters for different organic soils to improve wind-erosion-model predictions. The soil physical properties of organic matter content, aggregate density, DAS, ASD, and soil moisture characteristics were measured. Threshold friction velocities, soil-loss amounts, aggregate and crust abrasion coefficients, and LEM amounts were also determined for different organic soils.

MATERIALS AND METHODS

Soil Description

Four different organic soils were selected and sampled by the NRCS (Table 1). All soils were classified as mucks, meaning that they are well-decomposed organic soils. No peat samples were considered because of their rapid change to mucks once tilled. All samples were collected with a square-nosed shovel from the 0- to 5-cm depth. The soils were placed into burlap sacks or plastic bags and shipped to the laboratory. At the lab, the soils were placed into tubs and allowed to air dry.

Table 1. Description of the organic soils used in the study.

Soil series	Taxonomic classification	Location	Previous crop
Terra Ceia muck	euic, hyperthermic Typic Haplosaprist	Palm Beach County, FL	sugarcane
Scuppernong muck	loamy, mixed, dysic, thermic Terric Haplosaprist	Perquiman County, NC	corn
Thomas muck	fine-loamy, mixed calcareous, mesic Histic Humaquept	Sanilac County, MI	corn
Palms muck	loamy, mixed, euic, mesic Terric Haplosaprist	Ingham County, MI	corn

Soil Physical Properties

Tests were conducted on air-dried samples to determine the organic matter content, aggregate density, DAS, ASD, and soil moisture characteristics. All tests except DAS were replicated six times for each of the soils and the results were averaged. For DAS, 180 aggregates from each of the soils were crushed.

The organic matter content was measured on oven-dried soil (105°C) by using the dry-ashing method (Karem, 1993). For texture analysis, a muffle furnace and then H_2O_2 were used to remove the organic matter. The mineral fraction was dispersed by adding sodium hexametaphosphate, and the sand fraction was then determined (Gee and Bauder, 1986). Aggregate density was determined for 1-, 2-, 3-, 4-, and 5-mm-diameter aggregates with an envelope density analyzer (GeoPyc 1360, Micromeritics, Norcross, GA). Procedures were followed according to Micromeritics (1996). The DAS was measured with a soil-aggregate crushing-energy meter as described in Boyd et al. (1983) to crush 180 aggregates in the 6.35- to 19.05-mm range for the soils. The initial break force and crushing energy were measured for each aggregate. The DAS was expressed as the natural log of the crushing energy per unit mass. The ASD was determined by dry sieving with a rotary sieve (Lyles et al., 1970), with the following sieve designations: 0.42, 0.84, 2.00, 6.35, 19.05, 44.45, and 76.20 mm. Micromesh sieving was performed on the <0.42-mm sample by using a sonic sifter (Model L3P, ATM Corp., Milwaukee, WI). From this ASD attained from rotary and micromesh sieving, the GMD and GSD were found according to the computational procedure outlined in Wagner and Ding (1994), which is a modification of the lognormal distribution of Gardner (1956). This four-parameter lognormal distribution is used in the WEPS to describe the soil ASD. The WEF was calculated from the sieve data and represented the percentage of aggregates <0.84 mm. Air-dried moisture contents were measured for each soil by using the gravimetric method with oven drying (Topp, 1993). Soil moisture release curves were determined according to the procedures outlined in Klute (1986). Moisture contents were found at water tensions of 0.01, 0.033, 0.10, 0.50, 1.00, and 1.50 MPa.

Threshold and Armoring

Wind-tunnel tests were conducted at the USDA-ARS Wind Erosion Research Laboratory located on the campus of Kansas State University. An outdoor push-type wind tunnel was used to keep indoor organic dust to a minimum (Fig. 1). The tunnel dimensions were 13 by 1.20 by 1.47 m. Screens were placed over the entire tunnel cross-section downwind of the fan to promote flow uniformity and decrease longitudinal turbulence. A honeycomb next to the screens was used to decrease lateral turbulence, and spires were placed at the upwind end of the tunnel floor to increase the initial-boundary-layer depth. The tunnel was lined with pea-sized gravel to simulate a surface roughness similar to the organic soils. Trays 122 by 20 by 6 cm were filled with air-dried soils in their field-sampled condition. Trays were also prepared for each of the soils in which 80% of the aggregates were <0.84 mm. Random roughness was measured

Fig. 1. The outdoor wind tunnel used for the study. The tunnel setup shown was used to measure the threshold friction velocity and soil loss.

for each tray by using a pin meter (Wagner and Yu, 1991; Skidmore et al., 1994) and quantified as the standard deviation of the pin heights. The trays were placed even with the tunnel floor. A slot catcher and a Sensit wind eroding mass sensor (Sensit Co., Portland, ND), a device that uses a piezoelectric crystal to detect soil particle impacts (Gillette and Stockton, 1986), were positioned behind each tray. Instrumentation to record the temperature, relative humidity, barometric pressure, wind speed, and Sensit counts was positioned in the tunnel. Wind speed profiles were recorded by using pitot-static tubes at heights of 1, 2, 3, 5, 7.5, and 10 cm above each tray at wind speeds of 3, 4, and 5 m s^{-1}. The profiles were used to calculate friction velocities and aerodynamic roughness values by using the least squares technique described by Ling (1976). After the profiles were recorded above each tray, the free-stream wind speed was increased in 0.5 m s^{-1} increments until a critical number of Sensit counts was reached. Previous runs had shown that saltation across the entire surface had occurred at approximately 2 counts s^{-1}, and this was considered the critical number of Sensit counts. Once the Sensit detected 2 counts s^{-1}, three 15-min runs were made at wind speeds approximately 0.5, 1.5, and 2.5 m s^{-1} higher than the wind speed that produced the critical number of counts. Trays were weighed before and after each run to determine the cumulative weight loss. The value of U_t^* was found by using a modified form of the equation outlined in Hagen et al. (1999):

$$\Delta q = C_{em} C_s U^{*2} \left(U^* - U_t^*\right) \Delta X \qquad [1]$$

where q is the horizontal discharge of soil (kg $m^{-1}s^{-1}$), C_{em} is the coefficient of emission (m^{-1}), C_s is the saltation transport parameter (kg m^{-4} s^2) with a typical value of 0.3, U^* is the friction velocity (m s^{-1}), U_t^* is the threshold friction velocity (m s^{-1}), X is the distance along the wind direction (m), and Δ is a finite difference operator.

The cumulative weight-loss data at certain friction velocities were entered into TableCurve 2D software (SPSS, 1997) to solve Eq. [1] for the threshold friction velocity and the coefficient of emission.

The WEPS uses the immobile clod or crust cover and the aerodynamic roughness on bare, dry soil to determine an empirical value for the static U_t^*. The WEPS threshold estimates were determined for each of the organic soils by using tray data on the immobile clod cover and the aerodynamic roughness. In this analysis, the immobile clod cover for the organic soil was assumed to be the aggregate fraction >0.84-mm diameter, the same as applied to mineral soils.

To calculate the soil loss, the trays were blown at wind speeds in excess of the threshold until all erodible material was removed. For the trays with the field-sampled-condition soil, runs were made at free-stream wind speeds of 12, 14, and 16 m s^{-1}. For the trays with 80% of the aggregates <0.84 mm, runs were made at 8, 10, and 12 m s^{-1}. Trays were weighed before and after each run to determine the amount of soil loss. The soil-loss amounts for the organic soils were compared with those from mineral soils. Chepil (1950) developed tables to determine soil loss amounts from different ASDs and aggregate densities for a variety of mineral soils. Those tests were performed on trays in a wind tunnel with wind speeds of 11.2 m s^{-1} at a 15-cm height. For the organic soil runs, the free-stream wind speed of 12 m s^{-1} was nearly equal to 11.2 m s^{-1} when extrapolated down to the 15-cm height. Thus, accurate comparisons could be made between the soil-loss amounts of the organic soils and those from mineral soils.

Abrasion Coefficients and Loose Erodible Material

Values for the aggregate abrasion coefficient (AAC) were determined by running a known abrader flux of 0.29- to 0.42-mm silica sand over 6.35- to 19.05-mm-diameter aggregates. The aggregates were placed on mesh screens to give a 50% aggregate cover. The screens were 30 by 30 cm in size and had 2-mm openings to allow the abraded soil to fall through. Pea-sized gravel was placed around the mesh screens of aggregates to create an aerodynamic roughness similar to field conditions. Fifteen kilograms of silica sand was placed uniformly across the upwind end of the tunnel and was blown across the aggregates at a wind speed of 11 m s^{-1}, keeping most of the saltation in the lower part of the boundary layer. The screens with aggregates were weighed before and after each run to determine the amount of soil abraded from the aggregates. Abrader flux was found by measuring the amount of abrader in downwind sediment samplers that crossed the screens per unit width across the tunnel. The AACs were then calculated as the ratio of soil loss by abrasion to abrader flux.

Prior wind-tunnel studies on mineral soils have shown that the AAC can be determined from the DAS (Hagen et al., 1992). In this study, predicted AACs were also determined for each organic soil from their DAS.

The crust abrasion coefficients (CACs) were found in a similar manner. Crusts were created by subjecting soil trays to simulated rainfall produced by a rainfall tower. The rainfall tower consisted of a 3-m-long by 0.3-m-wide boom supporting three Spraying Systems Full Jet ¼ HH14W'SQ spray nozzles (Spraying Systems Co., Wheaton, IL). The nozzles were spaced 0.6 m apart, and the boom was 10 m above the floor. Water was filtered to remove any substances that might alter the soil properties. Raindrop size and distribution were measured by using the oil method of Eigel and Moore (1983). Raindrops were caught in petri dishes containing a 2:1 mixture of mineral oil to STP Oil Treatment (First Brands Corp., Danbury, CT). Single petri dishes were placed in a grid pattern under the rainfall tower and were exposed to simulated rainfall by using a shutter device. A digital image was taken of the petri dishes, along with a metric ruler for scale. The images were analyzed to determine raindrop size using SigmaScan software (SPSS, 1999). The kinetic energy per unit volume of rainfall, E (J m^{-2} mm^{-1}), was found by using the equation from Eigel and Moore (1983). The terminal velocity was determined by using the polynomial equation proposed by van Dijk et al. (2002). Median drop size was found by using the same method as Humphry et al. (2002).

Eight trays of each of the organic soils were rained on at a rate of 25 mm h^{-1}. A total of 32 mm of rain was applied. The trays were allowed to air dry after the rainfall events. Four of the trays of air-dried crusted soil were placed even with the tunnel floor, which was lined with pea-sized gravel. The LEM on the crust was found by weighing the trays before and after blowing at a wind speed of 13 m s^{-1} for 5 min with no abrader. Any LEM was removed at this wind speed. Values for the CAC were found from the same trays by running a known abrader flux of 0.29- to 0.42-mm silica sand over the crusted soil trays. Silica sand (7.5 kg) was placed at the upwind end of the tunnel and was blown across the crusted trays at a wind speed of 11 m s^{-1}. Trays were weighed before and after to determine the amount of soil abraded. Abrader flux was determined by measuring the amount of abrader crossing the trays per unit width across the tunnel.

The four other trays that were rained on for each soil were rotary sieved to determine the ASD after a rainfall. Aggregates from the 6.35- to 19.05-mm range were crushed with the soil-aggregate crushing-energy meter to determine the DAS.

Statistical Analysis

Data were analyzed according to the GLM and REG procedures of SAS statistical software (SAS Institute, 2000). All tests were considered significant at $P < 0.05$. To determine if the AAC for the organic soils were significantly different from what would be predicted by the regression equation from Hagen et al. (1992), 95% confidence intervals were found. The original data set was entered into TableCurve 2D software (SPSS, 1997) and fit to the regression line. The confidence intervals were determined by using the set confidence/prediction intervals option. SigmaStat statistical software (Jandel Scientific, 1994) was used to determine significant differences among the erodibility measurements on the test soils.

RESULTS AND DISCUSSION

Soil Physical Properties

The organic matter contents of the soils ranged from 452 to 615 g kg^{-1} (Table 2). These values appear to be typical for many tilled organic soils. In the mineral fraction, the sand contents averaged 30% for the Thomas and Palms mucks, but increased to 58 and 62% for the Scuppernong and Terra Ceia mucks, respectively. The sand content is important because the presence of saltating sand particles during wind erosion serves to accelerate the breakdown of immobile crusts and aggregates by abrasion.

No relationship was found between aggregate densities and diameters for aggregates with diameters ≥1 mm, so the aggregate densities were averaged for the five different aggregate diameters. The aggregate densities ranged from 0.93 Mg m^{-3} for the Thomas muck to 1.13 Mg m^{-3} for the Palms muck (Table 2). These aggregate densities are similar to the values found by Woodruff (1970, p. 5–8), but greater than those found by Mokma (1992). Chepil (1950) found aggregate densities for mineral soils to vary from 1.46 to

Table 2. Physical property data for the organic soils. All values except dry aggregate stability are the mean of six replications.

Soil	Organic matter	Aggregate density	Dry aggregate stability†	Aggregate size distribution		Air-dried moisture
				GMD‡	GSD§	
	g kg^{-1}	Mg m^{-3}	ln(J kg^{-1})	mm		kg kg^{-1}
Terra Ceia	498.6 ab¶	1.10 ab	4.21 b	1.07 a	6.92 ab	0.10 ab
Scuppernong	451.6 a	0.99 ab	2.92 a	1.22 a	8.96 b	0.06 a
Thomas	589.4 ab	0.93 a	2.87 a	1.67 ab	5.96 a	0.15 b
Palms	614.6 b	1.13 b	4.69 c	8.82 b	5.81 a	0.11 ab

† Dry aggregate stability is the mean of 180 crushed aggregates from the 6.35–19.05-mm range.

‡ Geometric mean diameter.

§ Geometric standard deviation.

¶ Means within columns followed by different letters are significantly different at $P \leq 0.05$.

1.66 Mg m^{-3} for aggregates >0.84 mm in diameter. Compared with mineral soils, the aggregate densities were less for the organic soils.

Dry aggregate stabilities for the Terra Ceia muck and the Palms muck were 4.21 and 4.69 ln(J kg^{-1}), respectively (Table 2). Stabilities in excess of 4.0 ln(J kg^{-1}) are considered fairly stable, meaning that the aggregates of these soils should be resistant to abrasion by saltating particles. The Scuppernong muck and the Thomas muck had lower DAS values of 2.92 and 2.87 ln(J kg^{-1}), respectively. These aggregates would be more prone to abrasion losses than would the other two organic soils, but are still fairly resistant. Mineral soils with increasing clay contents have increasing aggregate stabilities (Skidmore and Layton, 1992) and lesser erodibilities (Chepil, 1955). Organic matter, much like clay, promotes soil aggregation and thus increases aggregate stability.

The GMD values for the Terra Ceia muck and the Scuppernong muck were similar at 1.07 and 1.22 mm, respectively (Table 2). The Thomas muck had a slightly larger GMD at 1.67 mm, whereas the GMD of the Palms muck was much larger at 8.82 mm. The GMD values for the soils tested by Zobeck et al. (2003) and Mokma (1992) fell within this range. It seems that GMD values for organic soils can be quite variable and are affected by the time of sampling because both climate and management practices have a large effect on GMD. The WEF amounts ranged from 11 to 51%. All values were in the range found by Woodruff (1970, p. 5–8) except the Palms muck, which had only 11% of the aggregates <0.84 mm in diameter.

The soil moisture release curves (Fig. 2) show that the organic soils can hold considerable amounts of water at all the water tensions. The more organic matter content the soil contained, the greater the water holding capacity was at each tension value. The soil moisture release curves should aid in understanding how soil water contents change as the soil dries. The soil moisture release curve is important for modeling purposes to know when the soil becomes dry enough to start eroding. Chepil (1956) found that soil loss decreased to nearly zero at water tensions of approximately −1.5 MPa, and that increasing the moisture content even slightly required relatively great increases in wind velocity to produce movement of the soil. Saleh and Fryrear (1995) found that even small increases in the moisture content of dry soil required much higher friction velocities to initiate soil movement.

Erosion Threshold

The U_t^* ranged from 0.40 to 0.83 m s^{-1} for the field-sampled condition and from 0.27 to 0.31 m s^{-1} for the soils with 80% of the aggregates <0.84 mm (Table 3). The ASD had a significant effect on U_t^* (Fig. 3). The larger the WEF, the less friction velocity was needed to initiate soil movement. These measured U_t^* values were slightly greater than predicted from the equations used in the WEPS, but not significantly different. The threshold velocity for these low-density organic soils was larger than expected. A possible explanation may be the large degree of angularity of the organic soil aggregates (Fig. 4) (Kohake, 2003). The angularity probably causes the particles to interlock more tightly than particles that are rounder and smoother, such as sand grains. Due to this interlocking, it requires a greater friction velocity to initiate particle movement. Work conducted on stream flows has given similar results. Gomez (1994) found that particles with an angular shape required greater stream power to initiate bed load discharge compared with rounder particles.

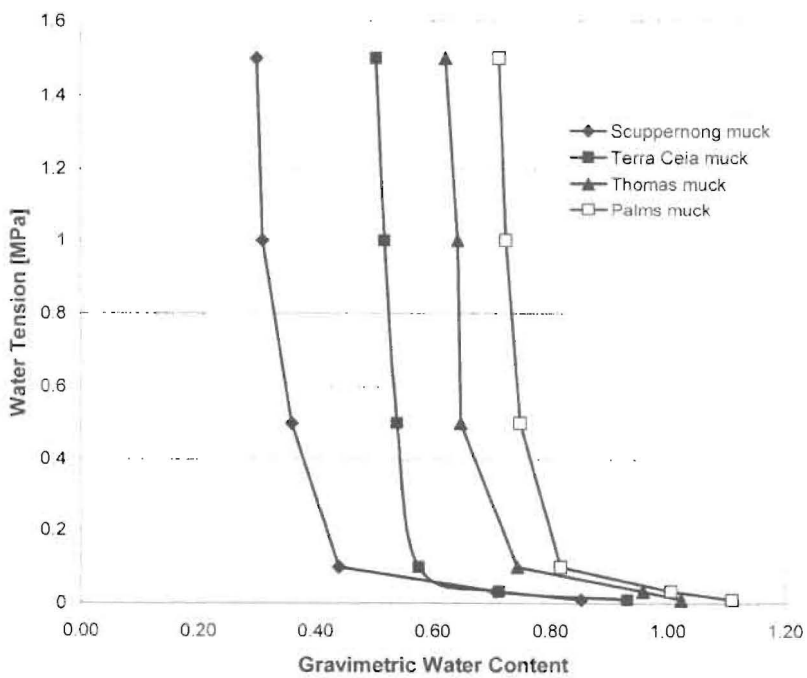

Fig. 2. Soil moisture release curves for the organic soils used in this study.

Table 3. Wind erodibility data for the organic soils in the field-sampled condition and for the prepared organic soils with 80% of the aggregates <0.84 mm.

Soil	U_t^*†	WEPS‡ U_t^* estimate	Aerodynamic roughness	Coefficient of emission	Soil loss amounts at various wind speeds					
					12.5 m s^{-1}	14.5 m s^{-1}	16.5 m s^{-1}	8.0 m s^{-1}	10.0 m s^{-1}	12.0 m s^{-1}
	m s^{-1}	m s^{-1}	mm	m^{-1}	kg m^{-2}					
Organic soils in the field-sampled condition§										
Terra Ceia	0.40 a¶	0.35	0.41 a	0.00053 a	0.35 b	0.71 b	1.36 b			
Scuppernong	0.53 a	0.45	0.75 a	0.00011 a	0.13 b	0.27 b	0.59 b			
Thomas	0.49 a	0.40	0.51 a	0.00018 a	0.10 b	0.31 b	0.75 b			
Palms	0.83 b	0.81	1.61 b	0.00001 b	0.01 a	0.02 a	0.03 a			
Organic soils with 80% of the aggregates <0.84 mm#										
Terra Ceia	0.29 a	0.26	0.11 a	0.00331 a				0.76 a	1.91 a	3.19 a
Scuppernong	0.30 a	0.26	0.11 a	0.00964 a				0.64 a	2.40 a	4.67 a
Thomas	0.27 a	0.26	0.06 a	0.00896 a				1.11 a	2.04 a	3.45 a
Palms	0.31 a	0.26	0.12 a	0.0083 a				0.69 a	1.55 a	2.65 a

† Threshold friction velocity.

‡ Wind Erosion Prediction System.

§ Data for organic soils in the field-sampled condition were replicated six times.

¶ Means within columns followed by different letters are significantly different at $P \leq 0.05$

Data for organic soils with 80% of the aggregates <0.84 mm were replicated twice.

Friction velocity is also affected by the aerodynamic roughness. When immobile aggregates provide shelter, they generally increase aerodynamic roughness and thus require a greater friction velocity to initiate soil movement (Hagen and Armbrust, 1992). This was also true for the organic soils in our study (Table 3; Fig. 5). This helps explain why the Palms muck had a larger value for U_t^* than the other organic test soils. The soil loss amounts also differed for the organic soils (Table 3), with the roughness and ASD of the Palms muck having a significant effect. These amounts represent the mobile soil available to initiate erosion on large fields. They may also represent total soil loss for a single wind-erosion event from a short strip near a nonerodible surface without abrasion. Average, aggregated, mineral soil loss amounts measured in wind tunnels (Chepil, 1950) were all within the 95% confidence interval of the measured organic soil loss amounts for the field-sampled conditions, except for the Scuppernong muck.

In this sample, the actual loss amount on a mass basis was less for the organic soil than would be predicted for a mineral soil with the same aggregate size distribution. These results tell us that organic soils have similar masses of mobile soil as mineral soils do, which confirms the earlier conclusion of Woodruff (1972, p. 4–5). Because of their lower densities, however, organic soils should erode in larger volumes.

Abrasion Coefficients and Loose Erodible Material

The AAC values for mineral soils have been found to range from near zero up to 0.08 m^{-1} (Hagen et al., 1992). The AACs for the organic soils fell within this range, with mean values from 0.0006 to 0.0136 m^{-1} (Table 4). These values are relatively small, meaning the aggregates of organic soils should not abrade easily. This would be expected because of the relatively high DAS values that these soils had. Comparing the measured with the predicted AACs showed that the regression equation seems to hold for organic soils at the higher DAS values. The Terra Ceia muck and Palms muck fell within the 95% confidence intervals of the regression line

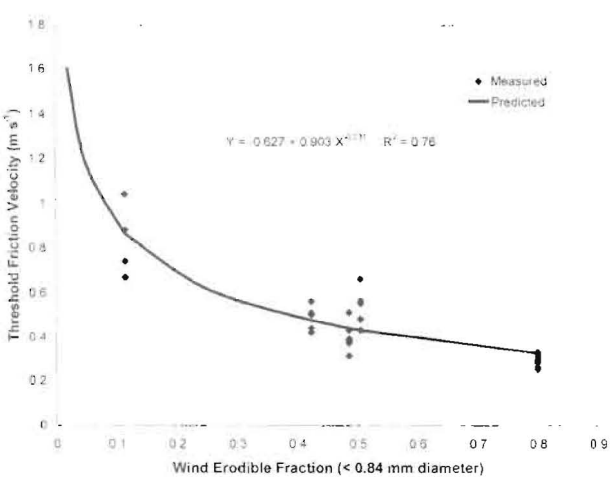

Fig. 3. Decrease in threshold friction velocity with increasing wind erodible fraction.

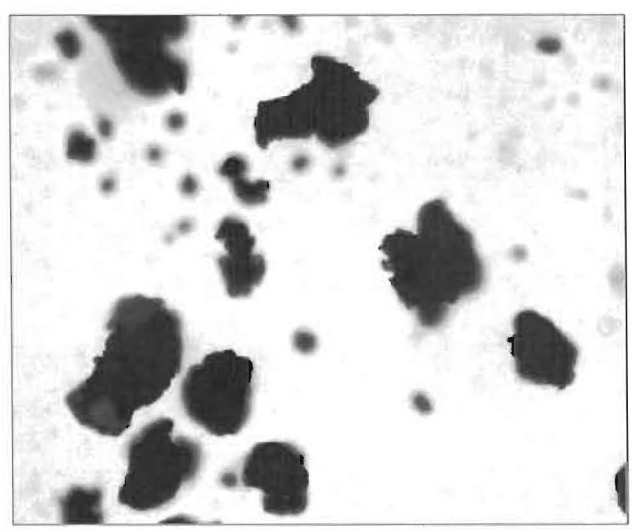

Fig. 4. Aggregates <100 μm from a typical organic soil.

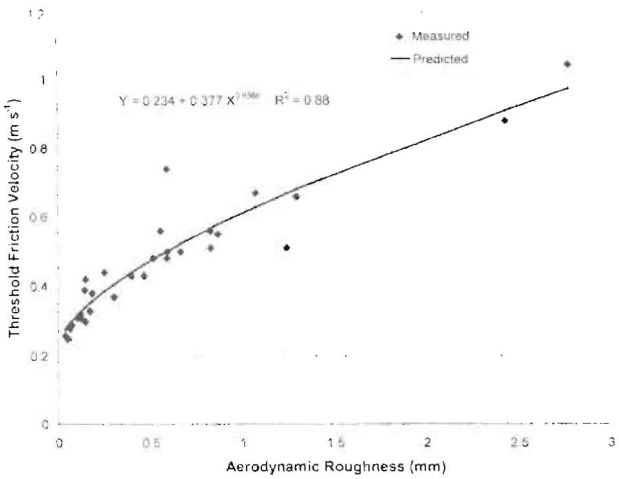

Fig. 5. Effect of aerodynamic roughness on threshold friction velocities.

found by Hagen et al. (1992). The Scuppernong and Thomas mucks fell outside the 95% confidence interval. The regression equation seems to hold at the higher DAS values, but overpredicts the AAC at lower DAS values. Because the organic soils have lower aggregate densities, they may absorb more saltation impact energy without breaking than the weak mineral soils with a brittle structure. This could explain why the mineral soil equation overpredicts the abrasion coefficient at the lower organic aggregate stabilities.

The average rainfall kinetic energy used to create the crusts to determine the CAC was 25.0 J m^{-2} mm^{-1}. These kinetic energy values are comparable to the reported values of kinetic energy for natural rainfall at similar intensities (Hudson, 1995; Carter et al., 1974). The median drop size was 1.69 mm.

Previous studies have found that CACs differ widely for different soils. The CACs were from 0.13 to 0.18 m^{-1} in one study (Hagen et al., 1992) and from 0.002 m^{-1} for silt loam and clay soils to as much as 3.179 m^{-1} for an organic soil in another study (Zobeck, 1991). The CACs for the organic soils used here ranged from 0.039 m^{-1} for the Palms muck to 0.123 m^{-1} for the Terra Ceia muck. The CAC values were significantly larger than those of the AAC. Thus, a soil crust should be easier to abrade than soil aggregates.

The amounts of LEM have been found to be influenced by soil texture, ranging from 0.091 kg m^{-2} for the coarsest textured soil to 0.003 kg m^{-2} for the finest textured soil (Potter, 1990). The amounts of LEM for the organic soils fell between these, with values ranging from 0.010 to 0.068 kg m^{-2}. The organic matter was inversely correlated ($R = 0.93$) and sand content was directly correlated ($R = 0.78$) with the LEM. Complete texture analysis was not accomplished for these organic soils, but the mineral sand component had an effect on the LEM amounts. Their official series descriptions indicate that the Thomas and Palms mucks formed in soils with a clay loam subsoil. The Scuppernong muck is dominated by sands in the lower mineral horizons. The underlying materials for the Terra Ceia muck can range from sandy to clayey. It is reasonable to assume that the mineral portion of the upper layers would have textures similar to these lower layers. The Scuppernong, which has the most sands, had the largest amounts of LEM. The Thomas and Palms mucks, which formed in clay loam soils, had the lowest values. Because the crust resistance to abrasion after rainfall was relatively low, the amount of loose, sand-sized aggregates available on the surface will have a significant effect on the erodibility of these organic soils. Hence, it would be useful to develop a widely accepted methodology so that the near-surface sand content of organic soils could be included in soils databases.

Table 4. Aggregate and crust abrasion coefficients (CAC) and loose erodible material (LEM) amounts for the organic soils. All data are the means of four replications.

Soil	Aggregate abrasion coefficients		CAC	LEM
	Measured	Predicted†		
	m^{-1}			kg m^{-2}
Terra Ceia	0.0038 b‡	0.0065	0.123 a	0.034 b
Scuppernong	0.0087 c	0.0362	0.079 a	0.068 b
Thomas	0.0136 d	0.0380	0.053 a	0.010 a
Palms	0.0006 a	0.0027	0.039 a	0.018 a

† Predicted aggregate abrasion coefficient found by using the Wind Erosion Prediction System regression equation and substituting in the dry aggregate stability.

‡ Means within columns followed by different letters are significantly different at $P \leq 0.05$.

The DAS and ASD of the organic soils were determined after trays had simulated rain applied to determine how rainfall affected these soil properties. The GMD decreased and WEF increased for all the soils (Table 5). Thus, after rainfall, the organic soils required less friction velocity to initiate soil movement and should have increased soil loss amounts in response to erosive winds. The DAS decreased for all soils except the Thomas muck, which had a slight increase in the DAS value.

SUMMARY AND CONCLUSIONS

Numerous soil properties were measured for four organic soils to determine their wind erodibility. These data should prove useful to improve the predictive abilities of physically based wind-erosion models. In the test soils, the organic matter content ranged from 45 to 61% and they had much lower aggregate densities compared with mineral soils. The DAS showed that aggregates of these soils had medium to high stabilities. The ASD varied for the soils used in the study and had a significant effect on U_t^* and soil loss amounts. The U_t^* for the organic soils were slightly greater than would be predicted

Table 5. Dry aggregate stability (DAS) and aggregate size distribution data after rainfall

Soil	DAS†	Aggregate size distribution		
		GMD‡	GSD§	WEF¶
	ln(J kg^{-1})	mm		%
Terra Ceia	3.48 a#	0.81 a	4.76 a	52.3 a
Scuppernong	2.73 a	0.61 a	5.16 a	61.8 a
Thomas	3.05 a	0.63 a	4.08 a	62.2 a
Palms	4.12 b	1.34 a	4.11 a	34.7 a

† Obtained by crushing 25 aggregates from the 6.35–19.05-mm range.

‡ Geometric mean diameter.

§ Geometric standard deviation.

¶ Wind erodible soil percentage <0.84-mm diameter.

Means within columns followed by different letters are significantly different at $P \leq 0.05$.

for mineral soils with the same ASD. Soil loss amounts showed that a wind of a given strength should erode equal weights of soil from organic and mineral soils. Amounts would be greater when looking at volumes of soil eroded because organic soils have lower densities. The AAC revealed that aggregates of organic soils should be moderately resistant to abrasion. This coincides with the aggregates having medium to high stabilities. The CAC values were higher than those of the AAC, meaning that a crusted soil surface should be easier to abrade than a well-aggregated organic soil. Amounts of LEM varied inversely with organic matter and directly with sand content. After rainfall, these soils had a smooth surface, a weak crust, and adequate sand-sized LEM to support erosion. Hence, in large fields, they will require significant wind erosion control measures. Soils with >80 to 90% organic matter may differ from these tested soils, so additional wind erodibility measurements are needed on organic soils.

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