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Field wind tunnel testing of two silt loam soils on the North American Central High Plains

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ABSTRACT

Wind erosion is a soil degrading process that threatens agricultural sustainability and environmental quality globally. Protecting the soil surface with cover crops and plant residues, practices common in no-till and reduced tillage cropping systems, are highly effective methods for shielding the soil surface from the erosive forces of wind and have been credited with beneficial increases of chemical and physical soil properties including soil organic matter, water holding capacity, and wet aggregate stability. Recently, advances in biofuel technology have made crop residues valuable feed stocks for ethanol production. Relatively little is known about cropping systems effects on intrinsic soil erodibility, the ability of the soil without a protective cover to resist the erosive force of wind. We tested the bare, uniformly disturbed, surface of long-term tillage and crop rotation research plots containing silt loam soils in western Kansas and eastern Colorado with a portable field wind tunnel. Total Suspended Particulate (TSP) were measured using glass fiber filters and respirable dust, PM_{10} and $PM_{2.5}$, were measured using optical particle counters sampling the flow to the filters. The results were highly variable and TSP emission rates varied from less than 0.5 mg m^{-2} s^{-1} to greater than 16.1 mg m^{-2} s^{-1} but all the results indicated that cropping system history had no effect on intrinsic erodibility or dust emissions from the soil surfaces. We conclude that prior best management practices will not protect the soil from the erosive forces of wind if the protective mantle of crop residues is removed.

1. Introduction

As the global population increases and developing nations grow economically, resultant increases of atmospheric carbon dioxide from the oxidation of soil organic matter and burning of fossil fuels may lead to global climate change and an increased strain to maintain sustainable soil-based agroecosystems (Delgado et al., 2011). The increasing demand for agricultural commodities and decreases in soil productivity will force indigenous populations to use marginal land for production. Much of this marginal land is in arid and semi-arid areas that are susceptible to wind erosion.

Wind erosion is a soil degrading process that threatens agricultural sustainability and environmental quality on a global basis. In the United States alone, 0.7 billion Mg of soil from cropped land is annually lost to the erosive forces of wind or 4.7 Mg ha^{-1} yr^{-1} average (USDA-NRCS, 2007). The soil that is lost is the finer, more chemically active and nutrient rich portion (Zobeck and Fryrear, 1986; Van Pelt and Zobeck, 2007), and may adversely affect soil water dynamics (Lyles and Tatarko, 1986). In addition to on-site effects, fugitive dust emissions from eroding soils is a very common and visible product of wind erosion (Stetler and Saxton, 1995) that damages crops (Farmer, 1983) and negatively impacts air quality (Sharratt and Lauer, 2006).

The benefits of maintaining crop residues on the soil surface for reducing wind erosion have long been recognized.(Chepil, 1944; Woodruff and Siddoway, 1965). Standing residue is more effective than flat residue (Chepil et al., 1963) due to its effect on lessening the wind speed impacting the surface (Nielsen and Aiken, 1998; Aiken et al., 2003). However, flat residue can also be effective and Fryrear (1985) has reported that wind erosion reduction is

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an exponential relation to the percent cover by flat crop residues. He also reports that as little as 20 percent flat residue cover reduces wind erosion significantly. Crop residues also reduce raindrop impact energies and may help preserve non-erodible surface aggregates (Ruan et al., 2001; Blanco-Canqui et al., 2009), further reducing soil erosion by wind.

In recent years, conservation tillage and no-till cropping systems have been increasingly adopted throughout the North American Central High Plains. These cropping systems offer multiple benefits to growers including lower fuel requirements, better water use efficiency, and increased yields (Unger and Vigil, 1998; McVay et al., 2006). In the North American Great Plains, reducing tillage intensity and increasing cropping efficiency has resulted in increased soil organic matter (SOM), increased water stable aggregates, and increased saturated hydraulic conductivity in the upper 5 cm of the solum (Benjamin et al., 2008). It is this increased saturated hydraulic conductivity at the surface that McVay et al. credited with the increased water availability as they only found one site out of five in Kansas where the water holding capacity was greater with no-till. Pikul et al. (2006) stated that dry aggregate size distribution shows promise as a good indicator of wind erodibility and reported a greater mean aggregate diameter for aggregates from reduced tillage systems compared to conventional tillage. Blanco-Canqui et al. (2009) reported an opposite effect at Akron, CO where the mean weight diameter was found to be 50% smaller for no-till and reduced tillage systems compared with conventional practices. They further state that no-till soils may be inherently more erodible if surface cover is removed.

Recent interest in using crop residues to make biofuels has created a value for these materials that may compete with their perceived value in soil and water conservation (Cruse and Herndl, 2009). Graham et al. (2007) claim that if North American growers universally adopted no-till, then over 100 million Mg of corn stover could be harvested without causing wind erosion beyond tolerable loss rates. Considerable research has indicated that crop residue removal may affect agroecosystem functioning and profitability in addition to potentially increasing wind erosion (Sparling et al., 2006; Wilhelm et al., 2007; Liang et al., 2008; Karlen et al., 2011). Wilhelm et al. (2007) state that more stover retention is required to maintain SOM than to control erosion by water and wind and the conservation of SOM is the constraining factor in determining how much crop residue can be removed.

Considering the potential cost of soil degradation and environmental quality that increased wind erosion could create and the uncertainty of management changes to soil properties that control wind erosion, we tested soil erodibility and dust emission potentials from two sites under long-term tillage and crop rotation studies in the North American Central High Plains. Our objective was to use a portable field wind tunnel to determine if the changes to soil properties due to the different management system history had an effect on the intrinsic erodibility or dust emission potentials of the soil surface without crop residue cover.

2. Methods

2.1. Site descriptions

The study was conducted at two locations on the North American Central High Plains with long-term tillage and crop rotation research plots. One location was the Kansas State University SouthWest Extension and Research Center (SWERC) (N 38° 28′ 0″, W 101° 46′ 45″) just west of Tribune, Kansas and the other location was the United States Department of Agriculture-Agricultural Research Service (USDA–ARS) Central Great Plains Research Station (CGPRS) (N 40° 9′ 30″, W 103° 8′ 30″) just east of Akron, Colorado (Fig. 1). Both locations are typical of the Central High Plains with level to slightly undulating fields and silty soils that developed from eolian deposition of loess eroded from Rocky Mountain outwash deposits.

At the SWERC, a tillage study based on a wheat (Triticum aestivum L.) – grain sorghum (Sorghum bicolor (L.) Moench) – fallow rotation was established from a field of native short-grass prairie sod in 1989. In each of four randomized replicate blocks, each phase of the rotation is present for each of the three tillage treatments in each year along with three plots of the undisturbed prairie sod. The tillage treatments are: (1) conventional tillage (C) in which a V-blade sweep plow was used between crops to prepare the ground for seeding and for controlling weeds, (2) reduced tillage (R) in which seedbed was prepared using a sweep plow but only at about 50% as often as C and herbicides were used to control weeds, and (3) no tillage (N) in which herbicides were used to control weeds and planter passage represented the only soil disturbance. The soil at this location is a Richfield silt loam 0 – 1% slope (fine, smectic, mesic aridic Ariustoll) composed of 74% silt and 13% each of sand and clay. The area receives an average 470 mm of precipitation arriving primarily during the growing season from April through September. Annual average air temperature at Tribune is 10.7 °C.

At the CGPRS, an alternative crop rotation study was established in 1990 from a previously cropped field. The study utilized both C and N tillage systems for the standard local rotation of fallow–wheat (FW) in which one crop of wheat is grown in two years with an alternating year of weed-free fallow. Other plots tested at this location were N rotations of: (1) fallow–wheat–corn (Zea mays L.) in which two crops are grown in three years and (2) fallow–wheat–corn–millet (Pennisetum glaucum (L.) R.Br.) in which three crops are grown in three years. In each of the three replicate blocks, each phase of each rotation is present in each year. We tested all plots at the end of the fallow phase. The soil at this location is Weld silt loam 0–2% slope (fine, smectic, mesic Aridic Paleustoll) composed of 38% sand, 40% silt, and 22% clay in the surface horizon. The area receives an average 420 mm of precipitation annually with 80% arriving during the growing season from April through September. Average annual air temperature at Akron is 9 °C.

2.2. Soil surface preparation, sampling, and documentation

At each treatment plot to be tested with the field wind tunnel, the air dry surface was carefully and uniformly prepared. Surface residue, including that partially buried, was removed by hand on a 2 m wide strip 10 m long. This strip was then fully mixed to a depth of 10 cm with two passes of a rear-tine rotary tiller. The strip was then carefully raked flat and any additional residue removed. Finally, a weighted lawn roller was passed over the tilled, raked strip to create a smooth flat surface. Wire flags were placed at the corners of a 6 m long and 0.5 m wide area at one end of the strip to mark the footprint of the wind tunnel working section and great care was made to protect this area from disturbance. The prepared surface was allowed to dry for at least 24 h prior to testing. When the weather provided a possibility of rain, tarps were placed over rigid frames so that the surface would be protected from rain and wind until time for testing. At the SWERC near Tribune, KS, a fourth replicate of the treatment blocks permitted us the opportunity to allow plots to become naturally crusted by raindrop impact from an intense convective rain event after the surface preparation. These crusted plots were also tested with the wind tunnel and the results are presented later in this manuscript.

In the 4 m by 2 m portion of the strip beyond the working section footprint, numerous soil samples were collected and composited from the 0–5 cm depth for laboratory analysis. These samples were carefully transported to wind-free dry buildings at the