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

R. Scott Van Pelt[a,*], Matthew C. Baddock[b,c], Ted M. Zobeck[b], Alan J. Schlegel[d], Merle F. Vigil[e], Veronica Acosta-Martinez[b]

[a] USDA-Agricultural Research Service, Wind Erosion and Water Conservation Research Unit, Big Spring, TX, USA
[b] USDA-Agricultural Research Service, Wind Erosion and Water Conservation Research Unit, Lubbock, TX, USA
[c] Griffith School of Environment, Griffith University, Brisbane, Australia
[d] Southwest Extension and Research Center, Kansas State University, Tribune, KS, USA
[e] USDA-Agricultural Research Service, Central Great Plains Research Station, Akron, CO, USA

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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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* Corresponding author. Address: USDA-Agricultural Research Service, Wind Erosion and Water Conservation Research Unit, 302 W. I-20, Big Spring, TX 79720, USA. Tel.: +1 432/263 0293; fax: +1 432/263 3154.

E-mail addresses: scott.vanpelt@ars.usda.gov (R. Scott Van Pelt), m.baddock@griffith.edu.au (M.C. Baddock), ted.zobeck@ars.usda.gov (T.M. Zobeck), schlegel@ksu.edu (A.J. Schlegel), merle.vigil@ars.usda.gov (M.F. Vigil).

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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

Fig. 1. Test locations on the Central Great Plains of North America.

respective locations for oven drying at 60 °C to constant weight followed by passage through a rotary sieve to determine erodible fraction <0.89 mm (Chepil, 1962), and the portion >0.89 mm was run through the rotary sieve a second time to determine dry aggregate (mechanical) stability (Chepil, 1958). Another portion of this composite sample was transported back to the Cropping Systems Research Lab in Lubbock, TX for archival and potential further physical and chemical analysis. Finally, a sample was taken of the upper 0.1 cm at multiple locations next to the tunnel placement footprint to determine surface soil moisture content at the time of test initiation.

2.3. Wind tunnel testing

The portable field boundary layer wind tunnel described in detail by Van Pelt et al. (2010) was used to test the erodibility and dust emissivity of the soils (Fig. 2). The 6 m by 0.5 m working section was carefully placed on the area of prepared surface marked by the wire flags. The working section had compressible foam seals at the soil contact surface and these seals were visually inspected to ensure good contact with the soil surface along the entire length. The flow conditioning section was attached to the upwind end of the working section and the centrifugal blower was connected with a flexible canvas bellows section to complete the flow path of the wind tunnel.

Immediately beyond the exit of the wind tunnel, a small hole was dug to accommodate the saltation collection pan of a 1 m tall vertical slot sampler having a 3 mm opening width. The slot sampler was aspirated with suction fans and aperture velocity was approximately isokinetic with the wind tunnel mean centerline wind velocity of 12 m s^{-1}. Between the slot sampler and the suction fans, two glass fiber filters effectively trapped all particles in suspended flow larger than 0.45 μm. The mass captured is the basis of the Total Suspended Particulates (TSP) determination for individual runs of the wind tunnel. A small portion (1.1 l min^{-1}) was aspirated through a Grimm model 1.108, an optical particle size analyzer that recorded number of particles in 15 size ranges <25 μm diameter per liter every six seconds. This data is the basis for PM_{10} and $PM_{2.5}$, particles smaller than 10 and 2.5 μm in diameter, respectively, determination for individual runs of the wind tunnel.

Centerline wind velocity was monitored during the individual tests using a hot wire anemometer placed through the side of the working section at the 4 m length. A small weather station consisting of a wind vane, cup anemometer, air temperature sensor, and relative humidity sensor was installed on the top of the working section and monitored throughout each individual wind tunnel run.

After wind tunnel installation, tests were initiated when the relative humidity was <60% and the ambient wind speeds were <5 m s^{-1}. The centrifugal blower speed was gradually increased

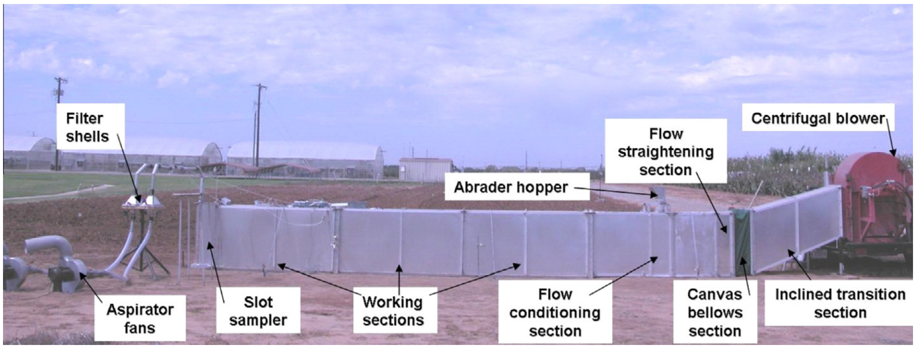

Fig. 2. The portable boundary layer wind tunnel showing the component parts.

until a working section centerline velocity of 12 m s^{-1} was reached. The wind tunnel was run for 5 min without the introduction of abrader sand and this initial run was termed Run 0. During this initial blow-off period, the most readily erodible portions of the rolled surface had been removed by the flow. Following the five minute period, the slot sampler was capped and the suction fans were stopped to allow the replacement of the glass fiber filters and emptying of the saltation pan.

The second and third wind tunnel runs at each test site were conducted with the introduction of well sorted washed quartz abrader sand (86.6% of the mass was between 106 and 500 μm, <0.2% was smaller than 106 μm, and <0.1% was smaller than 53 μm) at a rate equivalent to 14.5 g m^{-1} s^{-1}, a rate comparable to previous laboratory wind tunnel studies (Zobeck, 1991). The abrader material was dropped down inclined tubes in the flow conditioning section onto a 80 grit sandpaper surface to initiate a saltation field for the air flow. This saltation field resulted in sandblasting of any unerodible elements remaining after Run 0 (Shao et al., 1993). The first of these runs was for a period of 20 min to obtain a quasi-steady state dust emission rate from the prepared surface and was termed Run 1. At the end of Run 1, the slot sampler was again capped, filters were changed, and the saltation pan emptied as at the end of Run 0. The second run with introduced abrader was for a period of 10 min and this run was termed Run 2. At the end of Run 2, the filters were collected and the saltation pan was emptied. The wind tunnel was then disassembled and the test section carefully removed for post-test pictures of the surface.

The filters were dried to constant weight in a humidity controlled chamber and were weighed to the nearest 0.1 mg. The optical dust data was analyzed by calculating the volume of sediment in each size range <10 μm, multiplying by a particle density of 2.65 g cm^{-3}, and summing. For the purpose of comparison between runs 1 and 2 and data analysis and presentation in this paper, the data from the last 2 min of each run were used. Statistical analysis for treatment effects was performed utilizing PROC GLM in SAS v. 9.2 (SAS Institute, 2009).

3. Results and discussion

3.1. Soil properties

The percent wind erodible material, also known as erodible fraction, <0.89 mm (EF) and the percent stable dry aggregates (DAS) for each of the plots tested at the SWERC in Tribune, KS are given in Table 1. Measured EF ranged from 22.4% to 51.9% among the 12 plots sampled. Mean EF increased in the order of no-till (N) at 29.6%, conventional tillage (C) at 36.9%, and reduced tillage (R) at 42.6%. Treatment effects on EF were marginally significant ($p = 0.07$) although the order was apparently not related to the amount of tillage disturbance.

Table 1
Percent erodible fraction (EF) and dry aggregate stability (DAS) for the tested surfaces at the Kansas State University Southwest Extension and Research Center near Tribune, KS. Tillage treatments were conventional (C), no-till (N), and reduced (R).

Tillage	Block	%EF	Mean EF	%DAS	Mean DAS
C	1	32.0	36.85	88.9	91.55
C	2	39.7		90.4	
C	3	41.0		92.0	
C	4	34.7		94.9	
N	1	25.0	29.55	91.6	90.30
N	2	22.4		88.7	
N	3	38.3		91.3	
N	4	32.5		89.6	
R	1	45.7	42.60	85.4	89.15
R	2	43.4		85.3	
R	3	51.9		92.7	
R	4	29.4		93.2	

Table 2
Percent erodible fraction (EF) and dry aggregate stability (DAS) for the tested surfaces at the USDA–ARS Central Great Plains Research Station near Akron, CO. Tillage treatments were conventional (C) and no-till (N). Rotations were fallow–wheat (WF), fallow–wheat–corn (FWC), and fallow–wheat–corn–millet (FWCM).

Tillage	Rotation	Block	%EF	Mean EF	%DAS	Mean DAS
C	FW	1	45.6	52.50	89.0	87.87
C	FW	2	51.4		85.4	
C	FW	3	60.5		89.2	
N	FW	1	37.2	34.00	74.3	78.23
N	FW	2	27.8		80.8	
N	FW	3	37.0		79.6	
N	FWC	1	32.1	38.77	68.2	76.40
N	FWC	2	34.2		77.1	
N	FWC	3	50.0		83.9	
N	FWCM	1	47.1	37.63	78.5	76.27
N	FWCM	2	27.5		70.4	
N	FWCM	3	38.3		79.9	

Measured DAS for the sampled plots at Tribune were much more uniform and only ranged from 85.3% to 95.0%. The mean DAS increased in the order of R at 89.2%, N at 90.3%, and C at 91.6%. Treatment effects on DAS were found to be non-significant ($p = 0.44$). Blanco-Canqui et al. (2009) also found minimal differences in the DAS at Tribune in response to tillage treatment and hypothesized that in some soils, reducing tillage may be deleterious to surface DAS due to the illuviation of clays from dispersed surface aggregates and the cessation of re-incorporating of clays from deeper soil horizons. Although wet aggregate stability is increased by decreasing tillage intensity in these soils, this commonly measured soil quality parameter has minimal impact on wind erodibility of the soil.

The EF and DAS measured for the plots sampled at the CGPRS near Akron, CO are presented in Table 2. The EF ranged from 27.8% to 60.5% and the mean EF increased from 34.0% for N to 52.5% for C. Tillage treatment effects were found to be marginally significant for EF ($p = 0.07$). Crop rotation treatments within the N tillage treatment had no apparent effect on EF ($p = 0.72$). The mean EF increased from 34.0% for the fallow–wheat (FW) rotation to 37.6% for the fallow–wheat–corn–millet (FWCM) rotation and 38.8% for the fallow–wheat–corn (FWC) rotation.

Measured DAS for the sampled plots at Akron ranged from 70.4% to 89.2%. Tillage had a marginally significant effect on DAS ($p = 0.08$) and the mean DAS for three C plots was 87.9% compared to the mean for nine N plots at 78.2%. This compares favorably with Blanco-Canqui et al. (2009) who found the DAS for soils at Akron to be approximately 1.5 times greater in C plots than in N plots. Crop rotation within the N tillage treatment had no apparent effect on the DAS ($p = 0.88$).

3.2. Dust emissions

The means and standard deviations of vertical fluxes of Total Suspended Particulates (TSP), PM_{10}, and $PM_{2.5}$, are presented in subfigures a_t, b_t, and c_t, respectively, of Fig. 3 for the uniformly prepared and friable plots at the SWERC near Tribune, KS. In addition, the same measurements are presented for single plots in a fourth replicate in which the uniformly prepared surfaces were exposed to the dispersive forces of a convective rain event resulting in a naturally crusted surface in subfigures a_c, b_c, and c_c of the same figure.

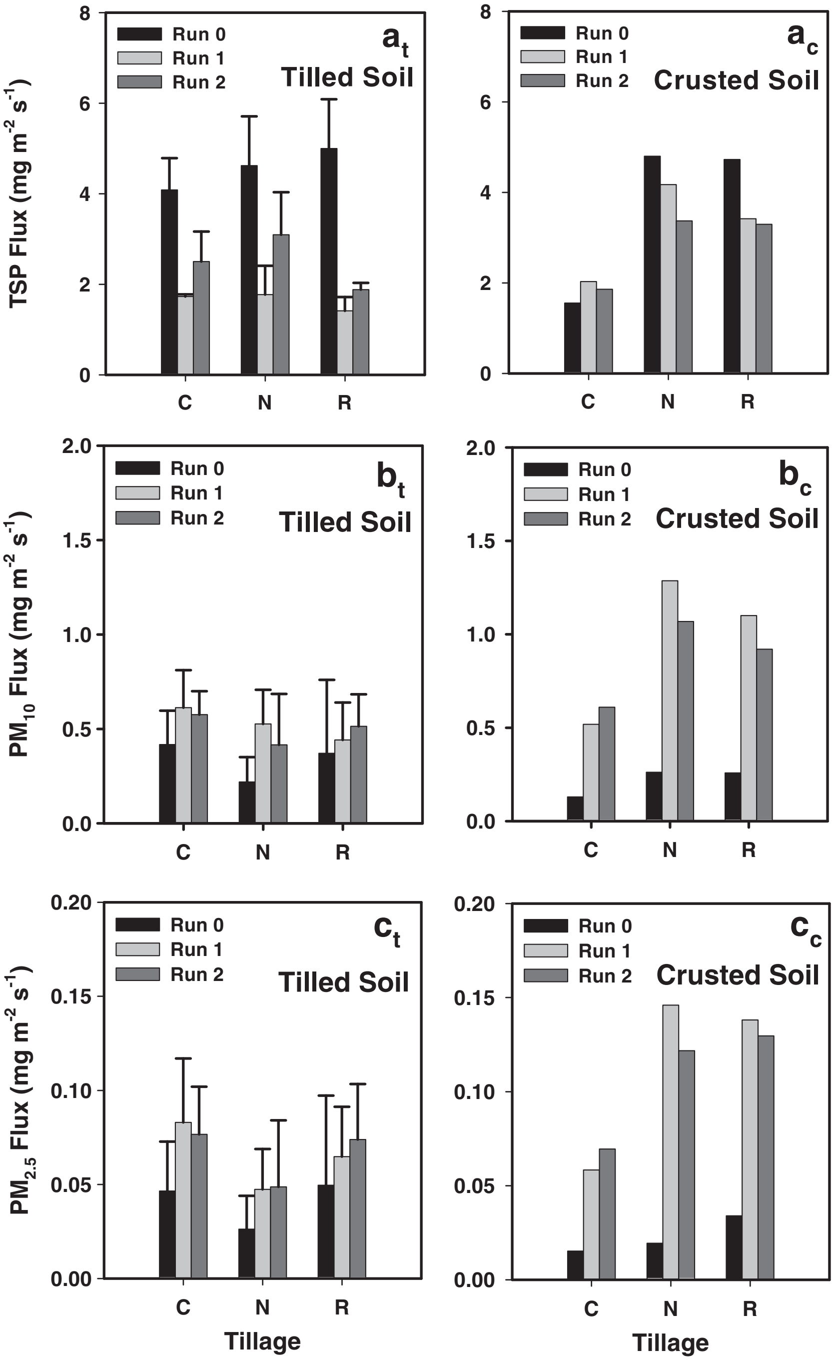

Fig. 3. Means and standard deviations of TSP flux (a_t), PM_{10} flux (b_t), and $PM_{2.5}$ flux (c_t) for three uniformly prepared replicate plots of long-term tillage management treatments of conventional tillage (C), no-tillage (N), and reduced tillage (R). Single observations of naturally rain-crusted plots for the same tillage systems are presented for TSP flux (a_c), PM_{10} flux (b_c), and $PM_{2.5}$ flux (c_c).

Measured TSP surface fluxes for the entire time period of each run on the uniformly prepared plots (subfigure a_t) are remarkably uniform for all runs on a treatment comparison but vary among runs within a treatment. Tillage apparently does not affect TSP flux from the surface. Probability levels of significant treatment effects on TSP entrainment are reported by PROC GLM as ($p = 0.66$), ($p = 0.34$), and ($p = 0.26$) for Run 0, Run 1, and Run 2, respectively. For the naturally crusted plots, subfigure a_c shows the N and R plots produced very similar amounts of TSP for all three runs and more than the C plot. For Run 0, the fluxes for the N and R plots are very similar to the uniformly prepared plots in subfigure a_t, suggesting the addition of abrader apparently is more effective at creating TSP flux for these crusted plots than the friable plots.

Measured PM_{10} fluxes for the last two minutes of each run period for the uniformly prepared plots are presented in subfigure b_t. The measured flux values are reasonably similar for all treatments and only Run 0 shows a consistently lower flux rate when compared to the other runs. As with the TSP flux rates, tillage had no apparent effect on PM_{10} flux based on ($p = 0.46$), ($p = 0.64$), and ($p = 0.52$) probability levels for Run 0, Run 1, and Run 2, respectively. PM_{10} flux is increased to a much greater extent by the addition of abrader for the N and R treatments in the naturally crusted plots shown in subfigure b_c than in the uniformly prepared plots. As with the TSP flux, PM_{10} flux is lower in the crusted C plot than in the N and R plots. This is consistent with dust emission potential data obtained for soils from these plots using a laboratory dust generator (Van Pelt, unpublished data).

Measured $PM_{2.5}$ fluxes for the last 2 min of each run period for the uniformly prepared plots are presented in subfigure c_t. Although the magnitude is less than that noted for PM_{10} fluxes, the pattern is very similar among treatments and runs. Again, as with the PM_{10} fluxes, tillage apparently had no effect on PM2.5 evolution from these soils as indicated by probability levels of ($p = 0.42$), ($p = 0.46$), and ($p = 0.13$) for Run 0, Run 1, and Run 2, respectively. In a manner very similar to that noted for TSP and PM_{10} emissions from the crusted plots, the $PM_{2.5}$ emission as shown in subfigure c_c did not seem to change greatly from that of the tilled soils for the C treatment, but increased notably with the addition of abrader for the N and R treatments when compared to the uniformly prepared plots. Visual evidence indicated significant abrader was trapped by the rougher surface of the uniformly prepared tilled plots, but much less was seen on the post-test surface for the crusted plots. This indicated the potential for more abrasion of the otherwise unerodible crust. Although a surface crust provides protection from creep and saltation of the surface soil, it provides little micro-roughness to prevent abrasion by and capture of saltating abrader emanating upwind from the crust. Abrasion of a crusted soil is a major source of fine dust emissions (Shao et al., 1993).

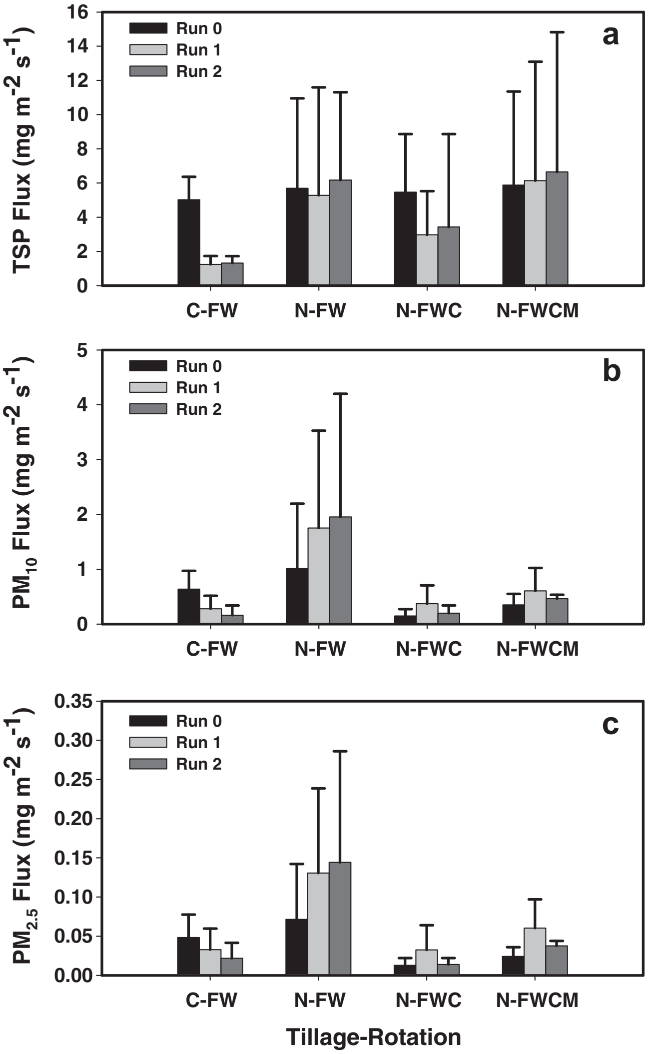

Fig. 4. Means and standard deviations of TSP flux (a), PM_{10} flux (b), and $PM_{2.5}$ flux (c) for three uniformly prepared replicate plots with conventional (C) and no-till (N) tillage systems with crop rotations of fallow–wheat (FW), fallow–wheat–corn (FWC), and fallow–wheat–corn–millet (FWCM).

The means and standard deviations of surface fluxes of TSP, PM_{10}, and $PM_{2.5}$, are presented in subfigures a, b, and c, respectively, of Fig. 4 for each of the tillage and crop rotation combinations tested at the CGPRS near Akron, CO. These plots were tested within one week after completion of testing at the SWERC.

TSP fluxes were, in general, very similar for all tillage and crop rotation combinations in Run 0 as can be seen in Fig. 4a. In Runs 1 and 2, however, the C tillage treatment resulted in less TSP than any of the N tillage treatments. The effects of tillage on the TSP flux from the prepared soil surfaces was not significant as evidenced by probability levels of ($p = 0.86$), ($p = 0.36$), and ($p = 0.26$) for Run 0, Run 1, and Run 2, respectively. Crop rotation also had no effect on TSP emission from the surfaces tested as probability levels were ($p = 0.99$), ($p = 0.73$), and ($p = 0.77$) for Run 0, Run 1, and Run 2, respectively.

The flux rates for PM_{10} are presented in Fig. 4b. From this subfigure, it is readily apparent that the no-till-fallow–wheat (N-FW) treatment produces much more PM_{10} than the same crop rotation with C tillage or any other of the crop rotations tested. In spite of this apparent difference, the probability levels of ($p = 0.64$) for Run 0, ($p = 0.26$) for Run 1, and ($p = 0.42$) for Run 2 would indicate that tillage does not affect PM_{10} emissions. Similarly, probability levels of ($p = 0.43$) for Run 0, ($p = 0.43$ for run 1, and ($p = 0.33$) for Run 2 demonstrate that crop rotation did not affect PM_{10} emissions.

Measured $PM_{2.5}$ fluxes are presented in Fig. 4c. The patterns of $PM_{2.5}$ emission are approximately one order of magnitude less that PM_{10}, but like the plots at the SWERC in Tribune, the patterns are remarkably similar. Probability values of ($p = 0.61$) for Run0, ($p = 0.20$) for Run 1, and ($p = 0.38$) for Run 2 indicate that tillage does not affect $PM_{2.5}$ flux either. Similar to the trend noted for PM_{10} emissions, crop rotation also does not affect $PM_{2.5}$ flux as evidenced by probability values of ($p = 0.36$) for Run 0, ($p = 0.40$) for Run 1, and ($p = 0.25$) for Run 2.

4. Summary and conclusions

Testing of 20 year old tillage and crop rotation plots with a portable boundary layer wind tunnel revealed that tillage management and crop rotation do not affect the intrinsic erodibility of the soil by wind where crop residues are removed and the soil is tilled. Although increases of soil carbon and wet aggregate stability are often observed in response to decreasing tillage intensity and increasing cropping intensity, these factors do not affect wind erodibility of the soil. Our testing of DAS and conclusions at both sites is similar to those found using a greater sample number and noted by Blanco-Canqui et al. (2009). Reports that these cropping systems protect the surface from wind erosion are apparently due entirely to the protection of the surface by crop residues.

The cellulosic ethanol industry should limit the amount of residue removed and adjust its economy to protect the sustainability of the soil resource. Nowhere is this caveat more important than on the semi-arid Great Plains where fallow is often practiced and temporal drought may extend the effective fallow period beyond a single growing season. It is essential these silty soils that form the backbone of the wheat belt on the Great Plains of North America be managed in a way that protects the surfaces with a protective mantle of crop residues so that future soil productivity and air quality will not be negatively affected.

5. Disclaimer

Mention of trade manes or commercial products is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture. USDA is an equal opportunity provider and employer.

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