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Citation: PADILLA, J.E. ... et al, 2014. Diffuse-reflectance mid-infrared spectroscopy reveals chemical differences in soil organic matter carried in different size wind eroded sediments. Aeolian Research, 15, pp.193-201.

Additional Information:

- This paper was accepted for publication in the journal Aeolian Research and the definitive version is available at: http://dx.doi.org/10.1016/j.aeolia.2014.06.003

Metadata Record: https://dspace.lboro.ac.uk/2134/17988

Version: Accepted for publication

Publisher: © Elsevier B.V.

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Diffuse-Reflectance Mid-Infrared Spectroscopy Reveals Chemical Differences in Soil Organic Matter carried in Different size Wind eroded Sediments

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Text: 19 manuscript (not including references)
Figures: 6
Tables: 4

KEYWORDS: Wind erosion; dust emissions; MidIR; soil minerals; aeolian; soil organic matter; cropping systems; tillage; soil quality.

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Abstract

Soil organic matter (SOM) influences water holding capacity, aggregation, and diversity. Little information is available regarding the carbon (C) functional groups carried in wind eroded sediments away from the source soil. Mid-infrared (MidIR) spectroscopy was used on wind tunnel-blown sediments eroded from a loam soil during the fallow period of different cropping systems and tillage management in Akron, Colorado. The soil was managed as fallow-winter wheat (Triticum aestivum L.) under conventional tillage (F-Wct) or no tillage (F-Wnt) and fallow-wheat-corn under no tillage (F-W-Cnt). Two wind eroded sediments were evaluated: fine dust (<35 µm mean dia.) and saltation-size material (<175 µm mean dia.). Our study showed that there is a partition of C groups within wind eroded sediments of different sizes and that they can reflect the tillage management history of soil. The fine dust had higher levels of aliphatic CH (2930 cm\textsuperscript{-1}), and clays (3690-3620 cm\textsuperscript{-1}). The saltation-sized material showed higher absorbance for quartz from 2000-1800 cm\textsuperscript{-1} and reduced absorbance from 1250-1050 cm\textsuperscript{-1}. Both wind eroded sediments showed higher absorbance for –OH/NH groups and aliphatic CH from no-till soil. Finer dust sediments, which travel greater distances from the source soil than saltation size material, can carry away higher levels of aliphatic-carbon compounds and clays with potential negative impacts on SOM and the sustainability of these agroecosystems.
1. **Introduction**

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 2009). This exceeds the average rate of natural soil formation from the parent material under agricultural conditions which ranges from 0.45 to 0.91 Mg ha\(^{-1}\) yr\(^{-1}\) (Lal and Stewart, 1990; Pimentel et al., 1995; Young, 1998; Troeh et al., 2004; Sundquist, 2010). This indicates that about 90% of existing US cropland is losing soil faster than its sustainable replacement rate (USDA, 2000 a,b). Thus, research that leads to a better understanding of wind erosion and its impacts on soil quality is of national importance.

The soils from the Central Great Plains (CGP) may experience severe wind erosion due to intense tilling and fallow periods that allow soil water to accumulate for winter wheat (*Triticum aestivum* L.) production. Research plots were established in 1990 near Akron, Colorado to compare the sustainability and productivity of different cropping intensities against winter wheat–fallow. The typical rotation of the region is conventionally tilled winter wheat with summer fallow (F-W\(_{ct}\)), which represents a 50% cropping intensity (CI). This typical rotation has been evaluated under no-tillage (F-W\(_{nt}\)) and with a reduction in fallow periods adding corn to the system under differing tillage practices (F-W-C\(_{nt}\) or F-W-C\(_{ct}\)). Previous studies on these research plots found significant increases in soil organic carbon (SOC) and microbial biomass C (MBC) when fallow periods are eliminated (W-C-M, wheat-corn-millet) after 7–9 years (Bowman et al., 1999; Gajda et al., 2001). Differences in SOC between the F-W-C and
F-W rotations became significant after 15 years when the F-W rotation was under conventional tillage practices (F-W<sub>ct</sub>) (Acosta-Martínez et al., 2007). Increases in soil organic matter (SOM) content through these management alternatives can lead to enhanced cycling and retention of nutrients and water holding capacity and improved aggregate stability (Doran and Parkin, 1994; Franzluebbers, 2002), both of which can reduce the soil susceptibility to erosion processes. Although >20 years have passed since the establishment of the research plots, there is no information on the success of these practices in reducing wind erosion, and the possible benefits this represents to soil and air quality have not been investigated in the CGP region.

The Wind Erosion and Water Conservation Research Unit of the USDA-ARS in Lubbock utilizes a portable wind-tunnel to conduct in-situ controlled studies of the aeolian erosion process (Van Pelt et al., 2010). By using a wind tunnel to recreate the saltation process, this tool is particularly well adapted to simulate wind erosion of soils and sediments. Previous soil quality studies have found distinctions in enzyme activities and bacterial diversity in different dust sized particles serving as fingerprints of the soil source (Acosta-Martínez and Zobeck, 2004; Gardner et al., 2012). However, information of the types of minerals and SOM carried in different wind eroded sediments is lacking. Knowledge of these characteristics will further expand our understanding of the effects of wind erosion on soil processes.

Diffuse-Reflectance Fourier-Transform Mid-Infrared Spectroscopy (MidIR), also known as DRIFTS, can be used to develop accurate calibrations for soil C and other parameters (Bellon-Maurel and McBratney, 2011). The MidIR region (4000–400 cm<sup>-1</sup>) of a spectra contains bands that can be assigned to organic or mineral soil constituents (Nguyen et al., 1991; Janik et al., 2007; Calderón et al., 2011a; Matějková
and Šimon 2012). MidIR has also been used successfully to characterize chemical differences between soil particle size fractions (Calderón et al., 2011a). This is especially relevant given that particle size fractionations carried out in the laboratory are in many ways akin to wind erosion, given that organics and minerals get partitioned differently among the resulting fractions. Spectral analysis of environmental samples has to be done judiciously because: 1) numerous interactions with minerals can complicate the direct assignment of spectral bands to a given chemical composition; 2) absorbance bands for specific functional groups, even in pure compounds, can be found over a range of wavenumbers, and there is some overlap between different functional groups; and 3) a direct comparison of spectral data and other types of soil analytes is often not practical because of technical problems in wet chemistry determinations of soil lignin, proteins, and other biopolymers. Some of the limitations of the technique can be overcome by burning the samples in a furnace to eliminate the organic component in order to elucidate the differences between organic and mineral absorption. Additionally, recent research has shed more light on useful MidIR bands for aliphatic, carbonyl, carboxyl-functional groups and for compounds of different levels of complexity such as polysaccharides, aromatic and phenolic compounds (Bornemann et al., 2010; Calderón et al., 2013).

New information regarding the organic and mineral composition in wind eroded sediments will help determine how wind erosion affects soil function and agricultural sustainability. In this study, we characterized the distribution of soil organic matter (SOM) within two types of wind eroded sediments using MidIR spectroscopy. We generated the wind-eroded sediments from a loam soil under different cropping systems in Colorado by using a portable field wind tunnel and capturing the sediments
with an aspirated saltation sampler incorporating particle size separation and an isokinetic inlet. Our first objective was to assess the relationship between the organic matter and mineral properties of wind-eroded sediments and the soil source. Our second objective was to determine if there were differences in chemical composition between the wind-eroded sediments of different size and due to the different cropping and tillage management histories of the soil source.

2. Methods

2.1. Research plots description and preparation for wind simulations

The study was carried out at the USDA-ARS, CGPRS (40° north; 103° west), on a long-term study location for evaluating alternatives to wheat-fallow. The plots were established in a completely randomized block design with three field replicates of different cropping systems. More details about the experimental design can be found in Bowman et al., (1999). The current study investigated both conventionally tilled (ct) and no-tillage (nt) systems for the standard local rotation of fallow–wheat (F-W) in which one crop of winter wheat (*Triticum aestivum* L.) is grown in two years with an alternating year of weed-free fallow. The other cropping system tested was a no tilled fallow-wheat-corn (F-W-C) rotation in which two crops, winter wheat and corn (*Zea mays* L.), were grown in three years. The site elevation is approximately 1400 m. The soil is a Weld loam (fine, smectic, mesic Aridic Paleustoll) composed of 38 % sand, 40 % silt, and 22 % clay in the surface horizon and of 0 – 2 % slope. The area receives
an average 420 mm of precipitation annually with 80% occurring from April through September. Average annual air temperature at Akron is 9° C.

At each treatment plot tested with the field wind tunnel, the surface was carefully and uniformly prepared. A more thorough description of the soil surface preparation and wind tunnel simulation is given by Van Pelt et al. (2013). In the 4 m by 2 m portion of the plot before the tunnel footprint, numerous soil samples were collected and composited from the 0 – 5 cm depth for laboratory analysis. These samples were oven dried at 60° C to constant weight and passed through a rotary sieve to determine the erodible fraction <0.89 mm (Chepil, 1962) with the portion >0.89 mm run through the rotary sieve a second time to determine dry aggregate 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.

Soil samples were taken from the three field-replicates of each cropping intensity and tillage regimes evaluated (F-WC_nt, F-W_nt and F-W_ct) prior to the wind erosion simulations. These soil samples and the wind eroded sediments were sent to a private laboratory (Ward Labs, Kearney, NE) to determine soil pH (1:1 sample/water ratio), total C and N (LECO TruSpec CN Analyzer, St. Joseph, MI), as seen in Table 1.

2.2 Wind tunnel erosion simulation

The portable field boundary layer wind tunnel described by Van Pelt et al. (2010) was used to test the erodibility and dust emissivity of the soils (Fig. 1). The 6 m x 0.5 m open-bottomed 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. A 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.

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. Saltation was monitored using a piezoelectric-based impact sensor 5 cm above the surface at the exit of the working section. 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, blowing tests were initiated when the relative humidity was <60% and the ambient wind speeds were <5 m s\(^{-1}\). The wind tunnel was run for 5 minutes without the introduction of abrader sand and this initial run was termed Run 1. During this initial blow-off period, the centrifugal blower speed was gradually increased until a working section centerline velocity of 12 m s\(^{-1}\) was reached and the most readily erodible portions of the rolled surface were eroded by the flow. The subsequent second and third runs at a given plot were performed with the introduction of well sorted washed quartz sand (86.6% of mass was between 106 and 500 µm) to act as an abrader of the soil surface 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 fed down inclined tubes in the flow conditioning section onto an
80 grit sandpaper surface to initiate a saltation field in the flow. This saltation field resulted in sandblasting of the soil surface and any unerodible elements remaining after Run 1. The first of these runs was for a period of 20 minutes to obtain a quasi-steady state dust emission rate from the prepared surface and was termed Run 2. The second run with introduced abrader was for a period of 10 minutes and this run was termed Run 3. At the end of Run 3, the filters were collected and the saltation pan was emptied.

Immediately beyond the exit of the wind tunnel, a small hole was dug to accommodate a saltation collection pan below 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\(^{-1}\). The samples for this study were collected using a second self-aspirated sampler (saltation sampler) with an opening 10 cm high and 8.5 cm wide (Fig. 1b). From observation of the blown plume exiting the tunnel, it has been determined that the predominance of sediment exits in the lower 10 cm above the soil surface and thus, the wider opening of this sampler is capable of capturing much more of the entrained sediment. Within this sampler and downstream from its opening, the sediment passes through a zone with increased cross-sectional area that allows coarse saltation-sized sediment to settle from the flow. The flow then passes through a 30 cm long section with floor baffles, which further reduces saltation sized material entering a settling chamber 0.75 x 0.75 x 0.5 meters in size. In this settling chamber, very fine sand (called saltation-size material in this study) is separated from the flow allowing primarily silt and clay particles (called fine dust in this study) to be captured on the glass fiber filters upstream of a recirculatory blower that aspirates the sampling
system. The saltation pan of this sampler was emptied after the initial 5 minutes of tunnel blowing and before the introduction of silica abrader into the wind tunnel flow stream. The particle size distribution of the fine dust and saltation-size material from Run 1 was determined using a Beckman Coulter LS 13 320 series laser diffraction particle size analyzer. Air-dry samples were analyzed using the tornado dry particle feeder.

2.3. Spectral analysis (MidIR) of sample composition in source soil and eroded sediments

All samples were ground with a mortar and pestle, dried at 60 °C, then scanned undiluted in diffuse reflectance mode using a Digilab FTS 7000 Fourier transform spectrometer (Varian, Inc., Palo Alto, CA) with a deuterated, Peltier-cooled, triglycine sulfate detector and potassium bromide (KBr) beam splitter. The spectrometer was fitted with a Pike Auto DIFF diffuse reflectance accessory (Pike Technologies, Madison, WI) and KBr was used as background (Calderón et al., 2011a). Data were obtained as pseudo-absorbance (log [1/Reflectance]). Spectra were collected at 4 cm$^{-1}$ resolution, with 64 co-added scans per spectrum from 4000 to 400 cm$^{-1}$. Data from the source soil, and both the wind tunnel generated fine dust and saltation-size material were averaged using GRAMS AI software version 9 (Thermo Galactic, Salem, NH).

In order to differentiate organic and mineral absorbance peaks that may overlap, all samples (fine dust, saltation size material, and soil) were ashed by heating to 350, 450, and 550°C in a furnace for 3h to remove the organics from the samples.
By burning off the organic component, a MidIR spectrum of the ash-subtraction can be obtained. Spectral subtraction of the ashed samples from the intact sediments was used to enhance the organic features of the spectrum.

Several spectral bands were selected for band ratio analysis. Bands at 3305, 2926, 1651, 1552, 1435, and 1240 cm\(^{-1}\) had high standard deviations and correspond to important functional groups (Table 2). The ratio of 1620/2926 has been used by others as an index of recalcitrant to labile SOM (Demyan et al., 2012). Absorbance at 1874 cm\(^{-1}\) was used as a denominator given that it is a largely quartz band (Table 2) that should show organic to mineral absorbance ratios. The ratios were calculated from the whole dusts and saltation size spectra as simple ratios. Studentized T tests were carried out with the band ratios in order to determine statistical differences between the crop rotation treatments and between dusts and saltation size ratios.

**2.4. Statistical analysis**

Statistical analysis of least significant differences (LSD) were performed to compare the effects of different cropping and tillage management histories on selected properties (total C, total N, and pH) determined for the soil samples utilizing PROC GLM of SAS v. 9.2 (SAS Institute, Cary, NC). Spectral differences between the different sized-wind eroded sediments were determined by principal components analysis (PCA) using PLS Plus/IQ, GRAMS/AI Ver. 9 (Thermo Galactic, Salem, NH). All spectra were mean-centered before the PCA. Spectral subtractions were also carried out using GRAMS/AI Ver. 9.
3. Results and Discussion

3.1. Validation of the ashing and spectral subtraction

In the absence of carbonates, soil mid infrared spectra contain a region that is largely free of mineral interference that encompasses the 2927 cm\(^{-1}\) aliphatic C-H band (Reeves III, 2012). However, mineral bands are an important source of interference that can complicate interpretation of organic absorbance in other regions of neat (whole) soil spectra (Parikh et al., In press). Ashing followed by spectral subtraction can aid in the identification of spectral bands that have organic absorbance and thus help characterize the SOM composition across different samples. Previous studies have used ashing and subtraction to characterize SOM (Chefetz et al., 1998; Cheshire et al., 2000; Reeves et al., 2005; Kaiser et al., 2007; Sarkhot et al., 2007; Simon, 2007; Calderón et al., 2011a; Calderón et al., 2011b), but no consensus exists as to which temperatures are ideal for obtaining the most information about SOM, while avoiding artifactual issues. Possible artifacts brought about by the heating of soil minerals and changes in specular reflection have to be taken in account (Reeves III, 2012). In this experiment, we tested ashing and subtraction at three temperatures: 350, 450 and 550 °C (Fig. 2).

Ashing of the soils resulted in soil total N losses of 48, 74, and 87% at 350, 450 and 550 °C respectively. Soil C losses were 79, 90 and 94 % at 350, 450 and 550 °C respectively, indicating that ashing affects proportionately more soil C than soil N, at the lower temperatures. All three ashing temperatures had subtractive spectra with
peaks at 3325 (O-H and N-H), 2927 (aliphatic C-H), 1640 (aromatic C=C and amide C=O), and 1100 cm\(^{-1}\) (ester, phenol C-O-C, C-OH stretch) (Fig. 2). The 450 and 550 °C ash subtractions formed a shoulder between 1640-1400 that includes bands for amide C=N, aromatic C=C, phenol C-O and aliphatic C-H, suggesting that temperatures below 450 are not enough to fully oxidize and expose SOM spectral features. The 550 °C ashed soil spectra showed a clay Si-OH absorbance loss at 3623 cm\(^{-1}\), and a loss of Al-OH absorbance at 924 cm\(^{-1}\), which were not observed at the 350 °C ashing temperature. Water loss is evident on the 450 and 550 °C ashed subtractions in the inverted peak at 3740 cm\(^{-1}\). The 350 °C subtractive spectrum shows a small peak at 1250 cm\(^{-1}\) (ester and phenol C-O) that is not present on the 450 °C subtractive spectrum.

Our results indicate that the 450 and 550 °C ash subtractions both would be adequate to highlight the organic features in this particular soil type, but the 550 °C has a more complete oxidation of organics. The 550 °C temperature can be a good compromise that enhances organic bands while identifying relatively minor and localized heating and dehydration artifacts. Others have used lower ashing temperatures (400-450 °C) for their ash subtractions, but that may be a function of the particular mineralogy of the soils and soil fractions in question (Kaiser et al., 2008). Ashing at 550 °C removes 87% of the soil N, and 94 % of the soil C. All three temperatures emphasized absorbance at 3325, 2927, 1640, and 1100 cm\(^{-1}\). The lower 350 °C temperature, however, was not enough to accentuate the 1640-1400 region that contains information for aliphatics, aromatics, and N- containing functional groups. The subtraction artifacts at the Si-OH and Al-OH absorbance bands, as well as the
water loss caused by the heating at 550 °C fall outside the organic bands between
3500-2800 cm\(^{-1}\), and the organic fingerprint region between 1740-1100 cm\(^{-1}\).

3.2 Differences in the source soil C attributes under different management history

In the soil samples we evaluated, representing 22 years of plot establishment, SOC was significantly higher in F-W\(_{nt}\) and F-W-C\(_{nt}\) (13.73 and 14.29 g kg\(^{-1}\), respectively) compared to F-W\(_{ct}\) (7.63 g kg\(^{-1}\)) (Table 1). In addition to the differences in SOM quantity among the cropping systems, we found differences in the midIR spectra reflecting differences in the chemical composition of SOM. Fig. 3a showing the unashed soil spectra, shows only slight differences between the crop rotations, underscoring the large influence of minerals on the spectra. However, Fig. 3b shows how ash subtraction enhanced the differences in chemical composition under the F-W\(_{ct}\) compared to F-W-C\(_{nt}\) and F-W\(_{nt}\). The effects of an increase in cropping intensity and no-tillage for this soil were reflected in an increased absorption at the 2930 cm\(^{-1}\) band for the F-W-C\(_{nt}\) and F-W\(_{nt}\) compared to the F-W\(_{ct}\) (Fig. 3b). Carbonates absorb in this spectral region, but the slightly acidic nature of this soil indicates that carbonate artifacts are not of concern in these samples. This feature is attributed to aliphatic CH (Table 2). The spectroscopic and total C measurements agree with Calderón et al. (2011a), who conducted the MidIR assessment on this soil after 15 years of management and found that total soil C and N correlated with the aliphatic CH bands between 2930-2870 cm\(^{-1}\). Aliphatic CH absorbance is also correlated to microbial biomass, suggesting that no till has promoted the microbial growth, which is fundamental to soil functioning. Substances like lignin, lipids, casein, carbohydrates,
and humic acids generally absorb in the 2930-2870 cm$^{-1}$ (Pandey, 1999; Calderón et al., 2011a; Calderón et al., 2013). Figure 3b shows little differences between the agronomic treatments in the region between 1750-1200, which contains bands for many organic functional groups.

Given that we found the lowest C content in the soil under the typical practice of F-W$_{ct}$ (Table 1), we did a subtraction of the spectra from F-W-C$_{nt}$ minus F-W$_{ct}$ or F-W$_{nt}$ minus F-W$_{ct}$ to visualize the differences between the management histories. Comparison of the soil spectra after subtraction of the F-W$_{ct}$ in terms of the organic chemical composition was done to enhance the visualization of spectral differences between the agricultural managements (Fig. 4). For example, the spectral subtraction of F-W$_{nt}$ minus F-W$_{ct}$ revealed differences between conventional and no-tillage practices with greater absorbance for no-tillage at 2930, 1225, and 1050 cm$^{-1}$ (Fig. 4). The MidIR responds semi-quantitatively to increases in carbohydrates in the region between 1225 to 1075 cm$^{-1}$ (Calderón et al., 2013). These results indicate changes in the SOM dynamics due to conventional tillage. For example, the positive value at 2930 cm$^{-1}$, can indicate that the no tillage management history on this soil increased aliphatic (labile) C sources. The absorbance at 1225 cm$^{-1}$ characterizes soils with high SOM, as well as the clay-sized fraction, which has high mean residence time (MRT) and contains most of the SOM in agricultural soils (Calderón et al., 2011a). This could also be an artifact of clay absorbance, but not likely here because of the inverse relationship with 3620 cm$^{-1}$, which is associated directly with clays. In addition to the other two bands, the greater absorbance at 1050 cm$^{-1}$ of no till, which corresponds to the carbon-oxygen bond in carbohydrates (Table 2), could reflect the fact that labile polysaccharides are more available compared to conventional tillage. Additionally, the
soil under conventional tillage (F-Wc) absorbed highly at the clay and silicate bands (also found in wind eroded sediments), which is in agreement with lower SOM compared to nt counterparts.

3.3. Wind eroded sediments collected varied in the particle size distribution, the C and N content, and spectral properties.

The mean diameter of the saltation size sediment and the fine dust sediment obtained from this soil type was in average 175 µm and 35 µm, respectively (Table 3). Specifically, the saltation size material sediment was coarser with about 35 % fine sand, 28 % very fine sand and 19 % silt while the fine dust sediment had only 25 % total sand and 68 % silt. The USDA textural classification of the saltation size material was loamy sand while the fine dust was silt loam. These differences can affect the fate of these wind eroded sediments as the distance particles travel during wind transport is related to the size of the particle. For example, saltating sands, the relatively larger sized material measured here, are usually deposited within the eroding field or very nearby because their transport mode involves particles bouncing along the surface so they are easily stopped by obstructions at the surface. Fine particles however, such as the fine dust sediment, travel suspended in the atmosphere and may travel a great distance before becoming deposited. The maximum distance traveled by dust about 35 µm in diameter during a strong dust storm may be up to 100 kilometers or more from source (e.g. Fig 4, Tsoar and Pye, 1986).

The first important trend that distinguished these eroded sediments of different size was the higher C and N contents carried in the fine dust compared to the coarse
material of saltation sized-sediment. For example, the fine dust carried in proportion
up to 3 times higher C and N compared to the saltation sized material (Table 4). The
amount of C or N carried in the fine dust was also reflective of the differences in
management of the soil source (i.e., replacement of conventional tillage for no-tillage
and/or increase in cropping intensity with less fallow) in this order: F-W-Cnt>F-Wnt>F-
Wct. However, these differences were not observed in the saltation sized material
possibly due to the greater abundance of sandy material and a lower overall surface
area of particles compared to the fine dust. This distinction among the wind eroded
sediments further support the use of different assessments to best evaluate the effects
of wind erosion on soil quality (Zobeck and Fryrear, 1986; Van Pelt and Zobeck, 2007)
as we still have little information on the differences in the labile C traveling within wind
eroded sediments of different size and the implications for the SOM of the source soil
(Acosta-Martínez and Zobeck, 2004; Gardner et al., 2012). The C to N ratio of the
saltation size particles and the dusts have a relatively narrow range (8.2 - 10.8), with
the higher values falling on the saltation sized material (Table 4). These values are
similar to the 9.6-10.9 C to N ratio of the source soils (Table 1). This suggests that the
decomposability of the SOM is similar in the source soils and the sediments, and that
agricultural management did not markedly affect the C to N of the soils and eroded
sediments.

MidIR spectra showed that the fine dust had higher absorbance at 3400 cm$^{-1}$,
which is characteristic of C with low mean residence time and absorbance at 2930 to
2870 cm$^{-1}$, which marks the presence of easily degradable aliphatic–CH (Calderón et
al., 2011a) (Table 2, Fig. 5). Additionally, there was higher absorbance for clays t in
fine dust, in agreement with the particle size data. Previous studies have linked clays
to the physical protection of SOM due to the ability of clays to adsorb SOM (Sorensen, 1972; Ladd et al., 1985; Feller and Beare, 1997; Hassink, 1997). Thus, the loss of clays could, indirectly, adversely affect soil quality by limiting the protection of SOM. Because the heating of clay in samples can lead to artifacts due to clay dehydroxylation on the MidIR clay bands (Reeves, 2012), we focused our attention on two main areas of interest when analyzing ashed-subtracted spectra for the wind eroded sediments; between 3500-2800 cm\(^{-1}\) and 1750-1500 cm\(^{-1}\) where clay has a reduced effect on the spectra (Fig. 5). All samples had subtracted absorbance peaks located at the same wavenumbers (1550, 1660, 2930, and 3400 cm\(^{-1}\)), although, the level of absorbance varied, indicating quantitative differences. According to Janik et al. (2007), absorbance at 1550 cm\(^{-1}\) corresponds to proteins due to the amide II band in SOM (Table 2). Absorbance at this band was lower for saltation-size material when compared to fine dust in the F-W\(_{ct}\) treatment. The same trend occurred for absorbance at 1660 cm\(^{-1}\) which is due to a combined band from proteins, lignin and humic acids, all of which absorb between 1660 and 1610 cm\(^{-1}\). Our current results for a sandy and low organic matter content, semiarid soil coincide with results from an organic soil (Histosol) evaluated by Gardner et al., (2012), with similar differences in the wind eroded sediments collected. Thus, the similar distribution of SOM chemical composition traveling in wind eroded sediments of different size from these different studies/soils could be of ecological significance. These results suggest that depending on the severity of wind erosion events and the particle size distribution of the sediments, there will be not only different impacts on the soil source-SOM quantity but also on the SOM quality. This could affect nutrient pools for crop growth, the soil physical properties necessary for roots to thrive, and the soil's capacity to be a
source/sink for atmospheric CO₂ which is important for soil C sequestration potential (Lal, 2004).

3.4. MidIR spectra of wind eroded sediments showed distinctions of soil management history

The significant differences that we found in soil C and N contents among different cropping systems and tillage prompted also the question whether there were differences in the MidIR spectra of the wind eroded sediments that could reflect the soil management history. As observed for the source soil, a slightly higher peak can be observed at 2930 cm⁻¹ for the fine dust (Fig. 6a, lower spectra) and the saltation size-material (Fig. 6b, lower spectra) under F-Wnt than F-Wct. This indicates higher quantities of aliphatic CH in the wind eroded sediments derived from no-till when compared to conventional tillage. The ash subtractions improved the resolution between crop rotations. The ashed subtraction of the saltation sized material (Fig. 6b, lower spectra) showed a more pronounced peak at 3400 and 2930 cm⁻¹ for F-Wnt when compared to F-Wct. The broad band at 3400 cm⁻¹, which is higher on the nt saltation sized spectrum relative to the ct, is due to OH and NH stretching, which has been found in organic materials such as casein and starch but is absent in clays and silicates (Calderón et al., 2013). One of the most obvious differences due to cropping intensity was a sharp protein/humic acid peak at 1660 cm⁻¹ (as well as the protein amide) in the ashed spectra for F-W-Cnt than F-Wnt in both wind eroded sediments (Fig 6a or b, lower spectra). Trends in these wind eroded sediments reflect the soil
management history due to tillage, but more research is needed in order to elucidate
trends for different soils and cropping systems.

3.5. MidIR band ratio analysis

All band ratios including 3305/1874, 2926/1874, 1651/1874, 1552/1874,
1435/1874, and 1240/1874 cm\(^{-1}\) were significantly higher on the dust spectra than the
saltation size spectra according to a studentized T-test (p<0.05) (Table 5 a). This
agrees with the higher C content of the dusts (Table 4), and shows that the band ratios
are sensitive to quantitative changes in C. Absorbance at 1874 cm\(^{-1}\) is a mineral band
that has been shown to correlate negatively with soil C in the same soils used in this
study, while absorbance at 2926 cm\(^{-1}\) correlates positively with soil C. (Calderón et al.,
2011b). The ratio of 1620/2926 cm\(^{-1}\), hypothesized to be a good index for the
decomposability of SOM (Demyan et al., 2012), was significantly higher in the saltation
size sediment.

The band ratio analysis was also sensitive to crop rotation effects on the un-
ashed dust and saltation size spectra (Table 5 b). Within the fine dusts, tilled
treatments tended to have higher ratios overall than the nt, with the F-W-C nt and F-W
nt having higher ratios than the F-W ct. This is consistent with the sediment C and N
content (Table 4). All ratios with 1874 cm\(^{-1}\) as denominator were significantly different.
The ratio of 1620/2926 cm\(^{-1}\), however, was similar between the rotations, suggesting
that the band ratio differences may be explained by changes in C quantity, and not C
quality. The results of the ratio analysis for the saltation size sediments are very
similar to that of the fine dusts (Table 5 b and c). One important difference is that the
saltation size sediments have a significant difference between treatments in the $1620/2926 \text{ cm}^{-1}$ ratio. This suggests that crop rotations affect the chemistry of the organic matter lost via saltation in these soils.

4. Summary and Conclusions

Although MidIR spectroscopy provides a semiquantitative estimate of C sources, it is of ecological significance that this technique distinguished the C types and minerals more predominantly transported in fine dust (35 $\mu$m mean dia.) vs. saltation-size material (175 $\mu$m mean dia.) as generated during simulated wind erosion processes. The fine dust fraction was characterized by strong clay and silicate absorption, as well as aliphatic C chemical compounds associated with labile SOM. The saltation-size material fraction showed lower clay absorption than fine dust, while it showed greater absorption for silicates. The differences in C distribution within wind eroded sediments of different particle size distribution found in our study can have important implications for soil and air quality as smaller particulates are capable of being transported long distances from their source by the wind. With this study, it has been elucidated that the types of C sources transported in fine dust can cause potential impacts over large areas during their relatively long distance travel as the sediments remain suspended. This is because dust-sized eroded sediments, like the fine dust, can travel up to thousands of kilometers while this is not the case for the saltation size sediment (Pye, 1987). Therefore, the aliphatic C sources and clay traveling in fine dust can act as an ecological input, where they can ultimately become deposited into downwind terrestrial or marine systems and contribute to other soils’ fertility (e.g., McTainsh and Strong, 2007; Van Pelt and Zobeck, 2007). On the other
hand, the loss of labile C sources via transport of fine dust will have negative impacts on the functioning of the soil source. Since the transport distance of fine dust is determined principally by particle size, information on differences in organic matter quality by size class will be relevant to predictions of the erosion and deposition of this material throughout the environment.

MidIR is sensitive to small changes in SOM due to important molecular moieties associated with proteins, aromatics, biochars, and carbohydrates (Calderón et al., 2013). Our study also demonstrates the suitability of MidIR as an effective tool in comparing the characteristics of wind eroded sediments. Compared to enzyme assays, which have been also used for dust properties characterization (Acosta-Martínez and Zobeck, 2007), less sample is required by MidIR and the sample can be reused for different analyses when more than one assay and number of samples are required to provide information of C cycling by the assessments of enzyme activities. The MidIR spectra of both wind eroded sediments (fine dust and saltation-size material) reflected the soil type and chemical composition (i.e., texture, SOM) and its management history. Tilling or lack thereof, affected the composition of the two particle sizes differently. For both types of sediments, MidIR spectral ratios indicated that not results in greater absorbance of labile, proteinaceous, and aromatic bands relative to ct. These results appear to indicate that conventional tilling exposes the soil by preferentially creating smaller particle sizes (fine dust) making a greater composition of soil, both organic and mineral, available for erosion. Conversely, not tilling allows for more aggregation which can protect the more stable SOC.

Our findings provide another insight into the impacts of wind erosion on the soil quality and functioning that have not been explored. Further studies are needed to
better determine (quantify) the chemical composition of SOM carried in different sized-
wind eroded sediments for different soils. Additionally, more studies determining the
erosion potential of different soils are needed.
**Figure captions**

Fig. 1. Layout of the wind tunnel.

Fig. 2. Mid infrared spectra of the ashed and un-ashed source soils at three temperatures (top), and subtractive spectra of the un-ashed minus ashed soils (bottom).

Fig. 3. MidIR spectra of the whole soil (a) and the subtracted spectra, neat minus ashed (b). All three management practices are shown.

Fig. 4. Subtractive spectra of the un-ashed source soils.

Fig. 5. Subtracted spectra (un-ashed minus ashed) of fine dust and saltation-size material sizes generated from soil under different cropping intensity and tillage regimes: F-W<sub>ct</sub> (a) F-W<sub>nt</sub> (b) and F-W-C<sub>nt</sub> (c).

Fig. 6. MidIR spectra (top) and the subtracted spectra, neat minus ashed (bottom) for the fine dust (a) and saltation-size material (b) from soil under different cropping intensity and tillage regimes: F-W<sub>ct</sub>, F-W<sub>nt</sub>, and F-W-C<sub>nt</sub>. 

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Cox, R. J., Peterson, H. L., Young, J., Cusik, C., and Espinoza, E. O. 2000. The


Ladd, J.N., Amato, M., Oades, J.M., 1985. Decomposition of plant material in
Australian soils. III. Residual organic and microbial biomass C and N from isotope-
labeled legume material and soil organic matter, decomposing under field

Geomorphology 89, 39-54.

Matějková, Š., Šimon, T., 2012. Application of FTIR spectroscopy for evaluation of 18
hydrophobic/hydrophilic organic components in arable soil. Plant Soil Env. 58,
192–195.

Movasaghi, Z., Rehman, S., Rehman, I.U., 2008. Fourier transform infrared (FTIR)


Pandey, K. 1999. A Study of Chemical Structure of Soft and Hardwood and Wood

Pimentel, D., Harvey, C., Resosudarmo, P., Sinclair, K., Kurz, D., McNair, M., Crist, S.,
costs of soil erosion and conservation benefits. Sci. 267, 1117-1123.


Reeves III, J.B., 2012. Mid-infrared spectral interpretation of soils: Is it practical or
accurate? Geoderma. 189, 508-513.

Aggregation and Aggregate Carbon in a Forested Southeastern Coastal Plain

Simon, T. 2007. Quantitative and qualitative characterization of soil organic matter in
the long-term fallow experiment with different fertilization and tillage. Archives of

Sorensen, L. H., 1972. Stabilization of newly formed amino acid metabolites in soil by

Sundquist, B., 2010. Chapter 9—Food supply from soil. In topsoil loss and
degradation—causes, effects and implications. Available online:


Zobeck, T.M., Fryrear, D.W., 1986. Chemical and physical characteristics of windblown sediment II. Chemical characteristics and total soil and nutrient discharge. Trans. ASAE 29, 1037–1041.
Table 1 - Selected chemical properties of the soil (0-5 cm) used to generate different wind eroded sediments under different cropping intensities (CI) and tillage (nt=no-tillage; ct=conventional tillage).

<table>
<thead>
<tr>
<th>Soil Properties</th>
<th>50% CI rotation</th>
<th>67% CI rotation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F-W ct</td>
<td>F-W nt</td>
</tr>
<tr>
<td>C (g Kg⁻¹ soil)</td>
<td>7.6 b</td>
<td>13.7a</td>
</tr>
<tr>
<td>N (g Kg⁻¹ soil)</td>
<td>0.73b</td>
<td>1.43a</td>
</tr>
<tr>
<td>pH</td>
<td>6.10a</td>
<td>6.43a</td>
</tr>
</tbody>
</table>

Different letters for the same soil property indicate significant differences (P < 0.05) among these cropping systems. The CI is determined by the ratio of the number of crop(s) harvested divided by the number of years of the rotation with each entity assigned a value of one.

Table 2 - Assignments for the mid infrared absorbance bands relevant to this study.

<table>
<thead>
<tr>
<th>wn (cm⁻¹)</th>
<th>Assignment (δ is bending, and ν is stretching)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3700 - 3200</td>
<td>vO-H and v N-H&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>3630</td>
<td>ν O-H in clays&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>2930-2870</td>
<td>νC-H&lt;sup&gt;c,d&lt;/sup&gt;</td>
</tr>
<tr>
<td>2000-1790</td>
<td>Quartz overtones&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>1600-1670</td>
<td>Amide I, or phenyl ring ν C=C&lt;sup&gt;a&lt;/sup&gt;, ν C=O of amide groups and nucleic acids, carboxyl&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>1480-1560</td>
<td>Amide II ν C-N and δ C-N-H&lt;sup&gt;a,c&lt;/sup&gt;, Aromatic ν C-H. ν C=N, or ν C=C&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>1280 - 1200</td>
<td>Carboxylic acid ν C-O, ester, phenol ν C-O&lt;sup&gt;a&lt;/sup&gt;.</td>
</tr>
<tr>
<td>1220-1320</td>
<td>Amide III band&lt;sup&gt;a&lt;/sup&gt;, C-H overtones, Carboxylic acid ν C-O, OH deformation, ester, phenol ν C-O.</td>
</tr>
<tr>
<td>1250-1050</td>
<td>Quartz band&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>1000-1170</td>
<td>ν C-O in carbohydrates, nucleic acids, proteins&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>1050</td>
<td>δ C-O in carbohydrates&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a</sup> Movasaghi et al., (2008);<sup>b</sup> Nguyen et al., (1991);<sup>c</sup> Haberhauer and Gerzabek (1999);<sup>d</sup> Janik et al., (2007)
Table 3 - Diameter and particle size distribution of the wind eroded sediments evaluated.

<table>
<thead>
<tr>
<th>Type of wind</th>
<th>Mean Diameter</th>
<th>STD Dev Diameter</th>
<th>Median Diameter</th>
<th>Sand</th>
<th>Silt</th>
<th>Clay</th>
</tr>
</thead>
<tbody>
<tr>
<td>eroded sediment</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fine Dust</td>
<td>35</td>
<td>29.7</td>
<td>26.4</td>
<td>0</td>
<td>3.3</td>
<td>22.3</td>
</tr>
<tr>
<td>Saltation Material</td>
<td>175.3</td>
<td>118.1</td>
<td>160.9</td>
<td>17.5</td>
<td>35.1</td>
<td>27.7</td>
</tr>
</tbody>
</table>

The particle size distribution of the saltation size material represents an average of 4 samples collected during Run 1, when no abrader was introduced into the tunnel.

Table 4 - C and N contents in different sized wind eroded sediments from different soil management histories.

<table>
<thead>
<tr>
<th></th>
<th>Fine Dust</th>
<th>Saltation Sized-material</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F-W_{ct}</td>
<td>F-W_{nt}</td>
</tr>
<tr>
<td></td>
<td>(g kg^{-1})</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>9.38b</td>
<td>11.53b</td>
</tr>
<tr>
<td>N</td>
<td>1.01b</td>
<td>1.21b</td>
</tr>
</tbody>
</table>

Different letter suffixes indicate significant differences within a row.
Table 5 - Band ratios of the fine dusts and saltation size sediments showing sample type or crop rotation effects.

a) Comparison between fine dusts and saltation size spectra, all rotations averaged:

<table>
<thead>
<tr>
<th>Sample type</th>
<th>3305/</th>
<th>1686/</th>
<th>1651/</th>
<th>1630/</th>
<th>1350/</th>
<th>1325/</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fine dust</td>
<td>1874</td>
<td>1874</td>
<td>1874</td>
<td>1874</td>
<td>1874</td>
<td>1874</td>
</tr>
<tr>
<td>Saltation size</td>
<td>0.52</td>
<td>1.16a</td>
<td>1.41a</td>
<td>1.6a</td>
<td>3.02b</td>
<td>2.77b</td>
</tr>
</tbody>
</table>

b) Fine dust crop rotation comparison:

<table>
<thead>
<tr>
<th>Tillage Rotation</th>
<th>3305/</th>
<th>1686/</th>
<th>1651/</th>
<th>1630/</th>
<th>1350/</th>
<th>1325/</th>
</tr>
</thead>
<tbody>
<tr>
<td>F-W</td>
<td>1874</td>
<td>1874</td>
<td>1874</td>
<td>1874</td>
<td>1874</td>
<td>1874</td>
</tr>
<tr>
<td>ct</td>
<td>0.47b</td>
<td>1.15</td>
<td>1.36</td>
<td>1.66</td>
<td>2.33a</td>
<td>2.56a</td>
</tr>
<tr>
<td>nt</td>
<td>0.54a</td>
<td>1.12</td>
<td>1.47</td>
<td>1.64</td>
<td>2.32ab</td>
<td>2.46ab</td>
</tr>
<tr>
<td>F-W-C</td>
<td>0.56a</td>
<td>1.17</td>
<td>1.51</td>
<td>1.75</td>
<td>2.17b</td>
<td>2.40b</td>
</tr>
</tbody>
</table>

(c) Saltation size sediments crop rotation comparison:

<table>
<thead>
<tr>
<th>Tillage Rotation</th>
<th>3305/</th>
<th>1686/</th>
<th>1651/</th>
<th>1630/</th>
<th>1350/</th>
<th>1325/</th>
</tr>
</thead>
<tbody>
<tr>
<td>F-W</td>
<td>1874</td>
<td>1874</td>
<td>1874</td>
<td>1874</td>
<td>1874</td>
<td>1874</td>
</tr>
<tr>
<td>ct</td>
<td>0.48b</td>
<td>1.53a</td>
<td>0.90b</td>
<td>1.60a</td>
<td>8.79</td>
<td>5.88</td>
</tr>
<tr>
<td>nt</td>
<td>0.58ab</td>
<td>1.49a</td>
<td>1.27a</td>
<td>1.51a</td>
<td>10.35</td>
<td>6.64</td>
</tr>
<tr>
<td>F-W-C</td>
<td>0.66a</td>
<td>1.27b</td>
<td>1.25a</td>
<td>1.25b</td>
<td>8.35</td>
<td>5.46</td>
</tr>
</tbody>
</table>

Numbers within a column not sharing a letter suffix are significantly different according to a studentized T-test (p<0.05).

Rotations are fallow-wheat (F-W), and fallow-wheat-corn (F-W-C). Tillage is conventional (ct), or no-till (nt).

n=18 for the fine dust, n=22 for the saltation size sediments.
n=6 for the fine dust F-W ct, n=7 for the fine dust F-W nt, n=4 for the fine dust F-W-C nt.
n=7 for the saltation sized F-W ct, n=8 for the saltation sized F-W nt, n=7 for the saltation sized F-W-C nt.
Figure 1
Figure 2
Figure 3
Figure 4
Figure 5
Figure 6