Northwest Columbia Plateau PM$_{10}$ Project

Objective 2: Measurement and Prediction of Wind Erosion and Dust Emissions

Title: PM$_{10}$ Flux from Conventional and Conservation Tillage Systems

Personnel: Principal Investigator: Brenton Sharratt, USDA-ARS soil scientist; Co-investigators: Guanglong Feng, WSU research associate; Robert Barry, USDA-ARS research technician; Randy Kulm, wheat grower.

Abstract of Research Findings

The frequency and type of tillage operation during the fallow cycle of the conventional winter wheat – summer fallow rotation in the low precipitation zone of the Columbia Plateau can influence the physical properties and thus the erodibility of soils. In support of ascertaining the influence of tillage on wind erosion and dust emissions, the following activities were undertaken in 2005: determining the efficiency of the Big Spring Number Eight (BSNE) airborne particle collector in catching suspension-size material and PM$_{10}$ during high wind events, ascertaining loss of PM$_{10}$ from conventional fallow in 2003 and 2004 using high-volume PM$_{10}$ sampler and BSNE collector data, and establishing a field site in 2005 to collect emissions data from adjoining fields maintained with conventional tillage and conservation tillage practices. For Ritzville silt loam, the BSNE collector traps 60% of the suspension-size material and from 10 to 25% of PM$_{10}$ over a range in wind speed of 5 to 18 m s$^{-1}$. Based upon this sampling efficiency, loss of soil and PM$_{10}$ approached 2320 kg ha$^{-1}$ and 210 kg ha$^{-1}$ from a fallow field during a single high wind event over two years (2003 and 2004). Conservation tillage appeared to suppress erosion and emission of PM$_{10}$ from a fallow field during several high wind events in 2005. Loss of soil during a singular event ranged from 22 kg ha$^{-1}$ for conservation tillage to 190 kg ha$^{-1}$ for conventional tillage.

Objective

Conservation tillage and cropping systems are sought in the low precipitation zone of the Columbia Plateau that will reduce windblown dust and PM$_{10}$ emissions from agricultural soils. Past studies related to tillage and cropping systems in the region have focused specifically on agronomic characteristics (e.g. yield, crop cover) of those systems with little attention given to characterizing the physical state of the soil of those systems. In addition, there have been no field observations made of PM$_{10}$ emissions from different tillage or cropping systems.

The objective of this research was to:

1. Establish experimental plots that differ with respect to tillage management. One plot was managed using conventional tillage and the other plot was managed using conservation tillage.
1. Monitor wind erosion and dust emissions from these plots and collect soil, crop, and weather data necessary to validate the Wind Erosion Prediction System (WEPS) over a range in management systems.

**Methods and Materials**

Several activities were undertaken in 2005 in support of ascertaining the influence of tillage on PM$_{10}$ emissions. These activities included calibrating BSNE airborne particle collectors for suspension-size material and PM$_{10}$, ascertaining the loss of PM$_{10}$ from conventional fallow in 2003 and 2004 using high-volume PM$_{10}$ sampler and BSNE collector data, and establishing a field site in 2005 to collect emissions data from adjoining fields managed using conventional tillage and conservation tillage practices. These activities are described in greater detail as follows:

1. **Calibration of BSNE airborne particle collectors for suspension-size material and PM$_{10}$**: PM$_{10}$ concentration profiles extending from the soil surface to the height of the PM$_{10}$ plume are needed for estimating PM$_{10}$ horizontal flux and loss from a field during high wind events. Instrumentation used in the field to measure PM$_{10}$ concentration included high-volume PM$_{10}$ samplers. These samplers are deployed in the field at heights of 1.5 to 6 m. The physical size of the high-volume samplers limits the use of these samplers below a height of 1.5 m. Thus, other methods are required to obtain PM$_{10}$ concentrations below a height of 1.5 m.

BSNE airborne collectors are used to measure horizontal soil flux from 0.1-m to 1.5-m height. These collectors are designed to passively, but isokinetically, sample the airstream. Due to the design of the collector (the collector has a 60 mesh screen with ~200 µm openings that filters the aerosol as air passes through the collector), these instruments are less than 100% efficient in trapping suspended particulates and PM$_{10}$. Therefore, we investigated the efficiency of the BSNE collector in trapping suspended particulates and PM$_{10}$.

The catch efficiency of the BSNE collector for suspended particulates and PM$_{10}$ was determined at wind speeds of 5, 10 and 18 m s$^{-1}$ in a wind tunnel. A BSNE collector was mounted at a height of 0.6 m inside the wind tunnel. Wind speed at a height of 0.6 m inside the tunnel and near the opening of the collector was monitored using a pitot tube. A 50 mm extension was placed on the front of the BSNE collector. A funnel protruded through the top of the wind tunnel and into the top of the extension, thus allowing soil to be introduced into the BSNE collector via the funnel. A 150 µm screen was positioned inside the funnel to control the rate at which soil entered the BSNE collector. The funnel was capped as soil was added to the BSNE collector to prevent suspended particles from escaping the top of the funnel.

Ritzville silt loam was used to determine the catch efficiency of the BSNE collector as this soil was the dominate soil type at the field site near Washtucna, Washington in 2003 and 2004. A bulk sample of Ritzville silt loam was sieved through a 125 µm screen to obtain suspension-size material; this size fraction was further analyzed using a sonic sieve apparatus to determine the PM$_{10}$ fraction. Approximately 5 g of suspension-size Ritzville silt loam was added to the funnel and thus entered the BSNE collector. Catch efficiency was determined by dividing the amount of suspension-size material or PM$_{10}$ trapped inside the collector by the amount that entered the BSNE collector.
2. Loss of soil and PM$_{10}$ from conventional fallow in 2003 and 2004:  Loss of soil and PM$_{10}$ from conventional fallow during high wind events was determined by subtracting the horizontal flux measured at the leeward position in the field from the horizontal flux at the windward position in the field located near Washtucna, Washington. Although soil horizontal flux and PM$_{10}$ concentration data were collected in 2003 and 2004, further experimentation was required to determine the catch efficiency of the BSNE collector for suspended participates and PM$_{10}$ prior to assessing loss.

The catch efficiency of the BSNE collector for suspended particulates was used to correct the measured catch of the BSNE collector (the BSNE is less than 100% efficient in trapping suspended sediment). The vertical distribution of saltating and suspended sediment captured by the BSNE collectors at each field position was described using the following equation:

$$ q = az^{-b} $$

where $q$ is sediment catch (kg m$^{-2}$) corrected based upon catch efficiency of the BNSE collector, $z$ is height (m) of the opening of the BSNE collector above the soil surface, and $a$ and $b$ are fitted parameters. Saltating and suspended sediment flux was then determined by integrating the above equation from 0.025 to 5 m (approximate height where integrated flux for all high wind events approached maximum value). Loss of soil from the field was computed by subtracting the sediment flux at the leeward position from that at the windward position in the field and dividing by the length of the field.

Loss of PM$_{10}$ from the field was assessed by subtracting horizontal PM$_{10}$ flux at the windward position from that at the leeward position in the field and dividing by the length of the field. Horizontal PM$_{10}$ flux at each field position was determined by:

$$ PM_{10} \text{flux} = \int [C_z \times u_z \times t] dz $$

where PM$_{10}$ flux is in µg m$^{-1}$, $C_z$ is PM$_{10}$ concentration at height $z$ (µg m$^{-3}$), $u_z$ is wind speed at height $z$ (m s$^{-1}$), and $t$ is duration of the high wind event (s). PM$_{10}$ concentration below a height of 1.5 m was determined using BSNE sediment catch and correcting for the catch efficiency of the BSNE collector. The integral was evaluated from 0.025 m to the height of the PM$_{10}$ plume. Plume height was obtained by extrapolating the PM$_{10}$ concentration profiles (3 and 5 m heights in 2003 and 1.5, 3, and 6 m heights in 2004) at the windward and leeward positions in the field; plume height was the height where the profiles intercepted.

3. Emission of PM$_{10}$ from conventional and conservation tillage in 2005:  The field site used to monitor soil loss and PM$_{10}$ emissions in 2005 was located 10-km SSW of Lind, Washington. The experimental site was in winter wheat in 2004. Half of the site (2-ha) was managed using conventional tillage practices that included spring disking, incorporation of fertilizer, and two rodweedings during the fallow period. The other half of the site was managed using conservation tillage practices that included using an undercutter V-sweep (0.8 m wide) implement in the spring followed by two rodweedings during the fallow period. The field adjacent to our experimental site was in winter wheat; this field created a non erodible boundary that minimized the influx of airborne and eroded sediment.
Crop residue and soil physical properties required as input to WEPS were periodically measured on each experimental plot throughout the 2005 season. Crop residue cover and biomass, stubble density and biomass, stubble height, near-surface soil water content, particle size distribution, aggregate size distribution, and roughness were determined after each tillage operation or high wind event.

Soil loss from the conventional tillage and conservation tillage plots were assessed by measuring the influx and efflux of soil from the experimental plots. High-volume air samplers, E-samplers, and BNSE airborne sediment collectors were deployed at the windward and leeward positions in each plot to assess sediment moving into the plots from the non-erodible boundary (wheat field) and that leaving each plot. High-volume samplers and E-samplers were positioned at a height of 1.5, 3, and 6 m above the soil surface. A creep collector was placed in each plot to measure surface creep and BSNE collectors were positioned at a height of 0.1, 0.2, 0.5, 1.0 and 1.5 m above the soil surface to assess saltation and suspension.

Results and Discussion
Several activities were undertaken in 2005 to determine loss of soil and PM$_{10}$ from agricultural fields during high wind events within the low precipitation zone of the Columbia Plateau. These activities included:

1. Calibration of BSNE airborne particle collectors for suspension-size material and PM$_{10}$: PM$_{10}$ concentration profiles were determined using BSNE collector and high volume sampler data. PM$_{10}$ concentrations to a height of 1.5 m above the surface of an eroding Ritzville silt loam in 2003 and 2004 near Washutucna, Washington was determined from BSNE sediment catch according to the equation:

\[
C_z = \frac{M_z}{u_z \cdot f \cdot S \cdot t}
\]

where $C_z$ is PM$_{10}$ concentration at height $z$, $M_z$ is the PM$_{10}$ mass in the BSNE collector at height $z$, $u_z$ is wind velocity at height $z$, $S$ is the area of BSNE opening, $t$ is the duration of the high wind event, and $f$ is the PM$_{10}$ catch efficiency of BSNE collectors. The PM$_{10}$ catch efficiency of the BSNE collector for Ritzville silt loam ranged from 10% at a wind velocity of 18 m s$^{-1}$ to 25% at a wind velocity of 5 m s$^{-1}$ (Fig. 1). While our efficiencies are smaller than those reported (~40%) by other investigators, differences in particle size, particle shape, and wind speed among studies can affect the efficiency of BSNE collectors.

Horizontal soil flux is dependent upon the efficiency of the BSNE collector to trap suspension-size material. Thus, the catch efficiency of the collector was determined for suspended Ritzville sediment. The catch efficiency of the collector for suspension-size material ranged from 55 to 65% at wind speeds of 5 to 18 m s$^{-1}$ (Fig. 1). We assumed that the catch efficiency of the BSNE collector for suspended sediment was 60% since a progressive increase in catch efficiency was not apparent with a reduction in wind speed.
2. Loss of soil and PM$_{10}$ from conventional fallow in 2003 and 2004: Loss of soil and PM$_{10}$ from a field managed in summer fallow near Washtucna, Washington was assessed for four high wind events in 2003 and two events in 2004. Soil loss, based upon the catch efficiency of BSNE collector, ranged from 4 g m$^{-2}$ or 40 kg ha$^{-1}$ for the 12-22 September 2003 high wind event to 232 g m$^{-2}$ or 2320 kg ha$^{-1}$ for the 27-29 October 2003 event (Table 1).

Loss of PM$_{10}$ between the windward and leeward positions in the field ranged from 0.5 g m$^{-2}$ or 5 kg ha$^{-1}$ for the 12-22 September 2003 and 15-27 October 2003 events to 21 g m$^{-2}$ or 210 kg ha$^{-1}$ for the 27-29 October 2003 event (Table 1). Assuming that near-surface bulk density is 1 Mg m$^{-3}$, loss of PM$_{10}$ for the 27-29 October 2003 event would constitute 2.1% of the mass in the uppermost 1 mm of the soil profile. This percentage was greater than that found in the parent soil (0.9% PM$_{10}$) before the high wind event. The differences between PM$_{10}$ content of the parent soil and PM$_{10}$ loss is due to breakage or abrasion of aggregates or incorrectly specifying the depth to which the soil is influenced by wind erosion processes.

Fig. 1. Efficiency of BSNE collector to catch suspension-size material (PM$_{100}$) and PM$_{10}$ at different wind speeds.
Table 1. Loss of soil and PM$_{10}$ from a fallow field during high wind events in 2003 and 2004 near Washtucna, Washington.

<table>
<thead>
<tr>
<th>Year</th>
<th>Day</th>
<th>Soil loss</th>
<th>PM$_{10}$ loss</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>----------</td>
<td>----------------</td>
</tr>
<tr>
<td>2003</td>
<td>12-22 Sep</td>
<td>43</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>3-15 Oct</td>
<td>118</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>15-27 Oct</td>
<td>44</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>27-29 Oct</td>
<td>2317</td>
<td>212</td>
</tr>
<tr>
<td>2004</td>
<td>6-23 Aug</td>
<td>138</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>23 Aug – 9 Sep</td>
<td>1604</td>
<td>163</td>
</tr>
</tbody>
</table>

3. Emission of PM$_{10}$ from conventional and conservation tillage in 2005: Multiple equipment failures were experienced during the 2005 field season that precluded obtaining continuous PM$_{10}$ emission data. For example, the generator that powers the high-volume PM$_{10}$ samplers required periodic repair due to breakage of the fuel filter and failure of the starter. In addition, failure of high-volume sampler and E-sampler motors required replacement.

Conservation tillage by undercutting the soil with a wide V-blade implement appeared to suppress erosion and dust emissions from the soil surface during high wind events in comparison to conventional tillage by diskling. The horizontal flux of suspended sediment was markedly reduced by an order of magnitude near the soil surface as indicated for the 7-23 June 2005 high wind event in Fig. 2.
Fig. 2. Horizontal soil flux as a function of height above soil surface in conventional (disk) and conservation (undercut) tillage. Measurements were made during the 7-23 June 2005 high wind event.

Loss of soil from the field site during this event ranged from 22 kg ha\(^{-1}\) for conservation tillage to 190 kg ha\(^{-1}\) for conventional tillage (Table 2). A reduction of soil loss using conservation tillage was also apparent during a high wind event earlier in the season (12 May – 7 Jun). However, these losses do not account for the sampling inefficiency of the BSNE for Shano loam, the predominant soil type at the field site. Thus, any further analysis will require the determination of the BSNE catch efficiency for Shano loam suspension-size material and PM\(_{10}\).

Table 2. Loss of soil from conventional and conservation tillage during high wind events in 2005 near Lind, Washington.

<table>
<thead>
<tr>
<th>Day</th>
<th>Soil loss</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Conventional</td>
</tr>
<tr>
<td>12 May – 7 Jun</td>
<td>88</td>
</tr>
<tr>
<td>7-23 Jun</td>
<td>190</td>
</tr>
</tbody>
</table>
Publications and Presentations

Refereed Journal Articles

Published Abstracts

Conference Proceedings