Northwest Columbia Plateau PM_{10} Project

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

Title: ***Particle Sizing and the $PM_{2.5}$ to PM_{10} Emission Ratio of Eroded Sediment***

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Abstract of Research Findings
Windblown sediment and in-situ soil samples were collected from fields in summer fallow during seven major high wind events in eastern Washington. Dry aggregate size analysis indicated that the windblown sediment trapped nearer the soil surface was more characteristic of the parent soil. From 50-70% of the parent soil, 30-60% of surface creep, 25-35% of sediment trapped at a height of 0.1 m, and 10-20% of sediment trapped at a height of 1.5 m was composed of aggregates >45 µm in diameter. The geometric mean diameter of parent soil ranged from 30 to 55 µm and of sediment trapped at a height of 0.1 to 1.5 m above the soil surface ranged from 25 to 30 µm across high wind events. Observations suggest that suspension is the primary mode of transport of windblown sediment, but saltation of very small particles (45-100 µm in diameter) also occurs in this region. The $PM_{2.5}$ to PM_{10} emission ratio was assessed in a wind tunnel for five major soil types found across the Columbia Plateau. PM_{10} loss ranged from 0.05 to 0.1% of total sediment loss while $PM_{2.5}$ loss ranged from 0.01 to 0.05% of total sediment loss across soil types. The $PM_{2.5}$ to PM_{10} emission ratio varied with wind speed; at a wind speed of 18 m s-1, the emission ratio ranged from 0.2 for Athena silt loam to 0.5 for Warden sandy loam. These emission ratios are similar to the $PM_{2.5}$ to PM_{10} ratios of the in-situ soil.

Objectives
Saltation is often thought to be the driving mechanism for the emission of fine soil particles from agricultural soils during high winds. Indeed, the common method employed in simulating wind erosion and dust emissions from agricultural soils requires knowledge of the saltation activity at the soil surface. Saltation activity results in the direct emission of fine soil particles ($PM_{2.5}$ and PM_{10}) from the soil surface or abrading larger soil particles from which emanates the ejection of $PM_{2.5}$ and PM_{10}. Soils across the Columbia Plateau, however, are very unique compared to other regions of the United States where erosion occurs due to high winds. Soils of the Columbia Plateau are derived from loess and are predominately comprised of silt-size particles. To aid in simulating wind erosion processes in regions dominated by loess, knowledge must be acquired concerning the size of particles eroded from soils.

The Wind Erosion Prediction System has the capability to simulate PM_{10} emissions, but lacks the ability to simulate $PM_{2.5}$ emissions from agricultural soils. Estimating the emission of both $PM_{2.5}$ and PM_{10} is necessary for regional air quality modeling of these pollutants. An initial strategy to simulate $PM_{2.5}$ emissions from soil requires knowledge of the $PM_{2.5}$ to PM_{10} emission ratio. Indeed, knowing the fraction of PM_{10} that is comprised of $PM_{2.5}$ can simplify the algorithm used for estimating $PM_{2.5}$ emissions. However, no studies have examined the $PM_{2.5}$ to PM_{10} emission ratio for agricultural soil or whether this ratio will vary across soil types common to the Columbia Plateau.

The objectives of research in 2010 were to:

1. Examine the particle size of sediment eroded from agricultural fields during high wind events.
2. Ascertain the $PM_{2.5}$ to PM_{10} emission ratio for the major soil types found across the Columbia Plateau.

Methods and Materials

Research conducted in 2010 was aimed at examining the particle size of sediment eroded from agricultural fields during high wind events and ascertaining the $PM_{2.5}$ to PM_{10} emission ratio for the major soil types found across the Columbia Plateau. The following discuss methods used for these two objectives.

Particle Size

Agricultural fields in eastern Washington were instrumented to capture wind-blown sediment from 1999 to 2006. Observations of wind-blown sediment were made on a Ritzville silt loam except in 2005 when observations were made on a Shano silt loam. All fields were in the summer fallow phase of a winter wheat-summer fallow rotation. A nonerodible surface was maintained upwind of all field sites. Instrumentation was installed at the leeward position of the field sites to monitor horizontal soil flux and wind velocity.

Windblown sediment was trapped using creep and BSNE collectors. The creep collectors trapped sediment discharge below a height of 0.025 m. BSNE collectors were installed to trap sediment at heights of 0.1, 0.2, 0.5, 1.0 and 1.5 m. Collectors were cleaned and initialized prior to each high wind event. Sediment obtained from the collectors after a high wind event was air dried at 30°C prior to weighing and separating into • 10, 11- 32, 33-45, 46-100, and >100 µm diameter size fractions using a sonic sieve. The upper 30 mm of the soil profile at the field site was sampled prior to high wind events. Soil samples were air-dried and used to determine particle and aggregate size distribution of the parent soil. Particle size distribution was measured on dispersed parent soil using a Malvern Mastersizer laser diffractometer. Aggregate size distribution of the erodible parent soil fraction was determined by sieving the sample through a 2 mm screen to collect the erodible portion of the soil. The erodible portion was then weighed and separated into • 10, 11- 32, 33-45, 46-100, and >100 µm diameter size fractions using a sonic sieve.

$PM_{2.5}$ to PM_{10} emission ratio

Five major soils found across the Columbia Plateau were used in this study; the soil types include Warden sandy loam, Ritzville silt loam, Palouse silt loam, Athena silt loam, and Walla Walla silt loam. Soil samples were collected from the upper 3 cm layer of the soil profile and during the summer fallow phase of a winter wheat-summer fallow rotation for Warden sandy loam and Ritzville silt loam; during the spring barley phase of a continuous spring barley rotation for Palouse silt loam; during the chemical fallow phase of a no-tillage winter wheat-spring wheat-chemical fallow rotation for Athena silt loam; and during the summer fallow phase of a winter wheat-spring wheat-summer fallow rotation for the Walla Walla silt loam. The soil samples were air-dried and hand sieved through a 2-mm sieve to remove large aggregates, stone, and plant residue. Soil passing through 2-mm sieve was used for dispersed soil particle size analysis, nondispersed aggregate size analysis, and emissions testing in a wind tunnel.

Dispersed particle size was measured using a Malvern Mastersizer S laser diffractometer. Nondispersed soil aggregates 2000-840, 840-420, 420-00, 100-45, 45-32, and 32-10 µm in diameter were measured using a sonic sieve; $PM_{2.5}$ and PM_{10} fractions of the nondispersed samples were measured inside a rotating drum using DustTrak Aerosol Monitors.

Wind tunnel experiments were carried out inside a non-regulated climate control facility. Soil passing through the 2-mm sieve was placed in an aluminum tray (1 m long, 0.2 m wide, and 0.015 m deep). The tray was overfilled with soil and then leveled with a screed. Cutouts in the plywood floor of the wind tunnel were made 5 m downwind from the flow conditioning section so that the soil surface was flush with the tunnel floor.

Four replications of each soil were tested in the wind tunnel at three wind speeds of 11, 15, and 18 m s−1. Each soil was subjected to the wind for 5 min inside the wind tunnel as the erodible size material was depleted from the test surface within this time period.

Measurements made during the wind tunnels tests included: (i) loss of saltating and suspended sediment and surface creep and (ii) $PM_{2.5}$ and PM_{10} concentrations. Saltating and suspended sediment were measured using a vertically integrating isokinetic slot sampler. A 10x0.5-cm collection tray was attached to the downwind edge of the soil tray to catch surface creep. Total sediment loss was calculated by summing the masses caught by these two devices. $PM_{2.5}$ and PM_{10} concentrations were measured using DustTrak Aerosol Monitors. The $PM_{2.5}$ and PM_{10} measurements were made with aerosol inlets placed at 0.5, 2, and 5 cm above the soil surface at the downwind edge of the soil tray. Background $PM_{2.5}$ and PM_{10} concentrations were monitored for 1 min before each wind tunnel test. Wind speeds were measured using pitot tubes installed at heights corresponding to DustTrak inlet heights. Free stream velocity was measured with an additional pitot tube at a height of 1 m inside the wind tunnel.

The emission rate of $PM_{2.5}$ and PM_{10} (E) was calculated based on the following relationship:

$$E = \frac{1}{L} \int_0^{z_b} (C \times u \times dz)$$

where E is the $PM_{2.5}$ and PM_{10} emission rate (mg m−2 s−1), L is length of the eroding surface (m), zb is height at which $PM_{2.5}$ or PM_{10} concentrations reached background concentrations (m), C is $PM_{2.5}$ or PM_{10} concentration above background concentration (mg m−3), and u is wind speed at height z (m s−1). The equation was evaluated from the lowest sampling height to zb by plotting $PM_{2.5}$ or PM_{10} horizontal flux as a function of height. Sampling height was plotted as a function of $PM_{2.5}$ or PM_{10} concentration and fit with an exponential function to determine the height at which background concentration was achieved.

Results and Discussion

Particle Size

Windblown sediment trapped nearer to the soil surface was more characteristic of the parent soil. This is illustrated in Figure 1. Note that from 50-70% of the parent soil, 30-60% of surface creep, 25-35% of sediment trapped at a height of 0.1 m, and 10-20% of sediment trapped at a height of 1.5 m was composed of aggregates >45 µm in diameter. Very little of the sediment trapped above the soil surface was composed of particles >100 µm in diameter.

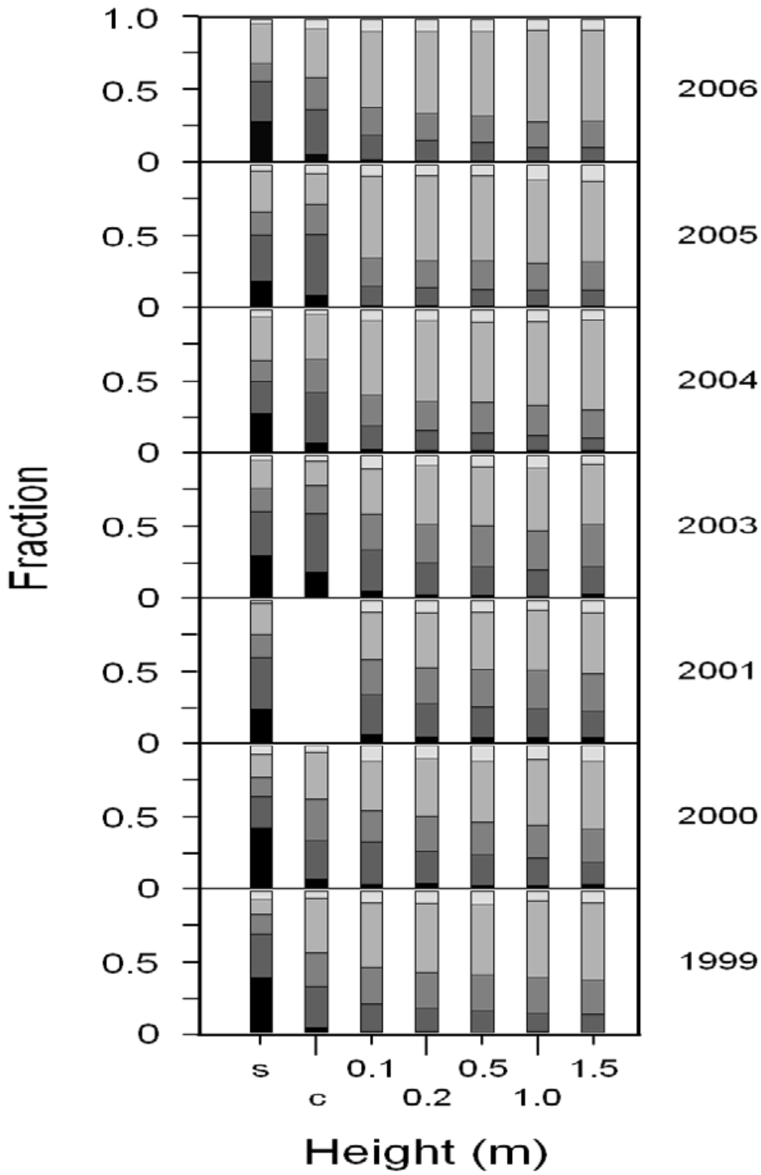

Figure 1. Fraction of soil (s) and windblown sediment trapped at the soil surface (c) and at various heights above the soil surface with a diameter • 10, 11-32, 33-45, 46-100, and >100µm (smaller particles are symbolized by lighter colors).

The proportion of coarse and fine particles comprising the windblown sediment appeared to respectively diminish and increase with height above the soil surface. This is illustrated for the 46-100 µm and 11-32 µm size fractions trapped at a height of 0.1 to 1.5 m in Figure 2. These trends are indicative of different transport processes; saltation for the 46-100 µm size fraction and suspension for the 11-32 µm size fraction.

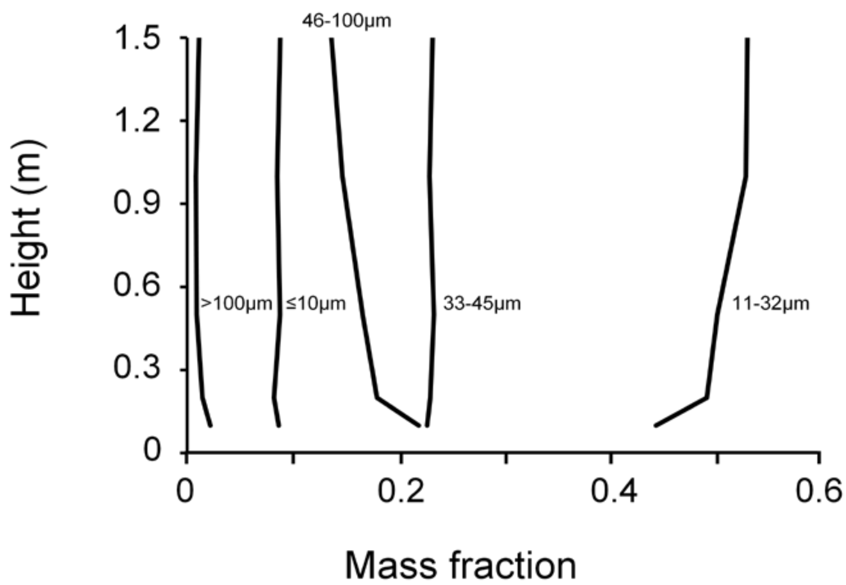

Figure 2. Particle size fraction of windblown sediment collected at 0.1 to 1.5 m above the soil surface.

Geometric mean diameter of windblown sediment varied with height as portrayed in Figure 3. The geometric mean diameter of parent soil ranged from 30 to 55 μm and for sediment trapped at a height of 0.1 to 1.5 m above the soil surface ranged from 25 to 30 μm across high wind events. Although only slightly apparent, the mean size of sediment decreased with height above the soil surface. The small decrease in size of sediment from a height of 0.2 to 1.5 m indicates more uniform mixing within this region of the atmosphere.

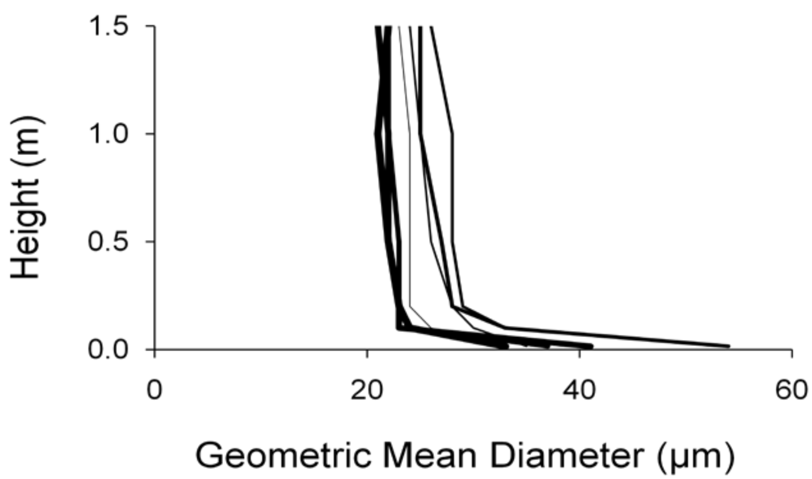

Figure 3. Geometric mean diameter of windblown sediment as a function of height above an eroding field. The thinnest line represents 1999 and the thickest line represents 2006.

$PM_{2.5}$ to PM_{10} emission ratio

Total sediment loss and $PM_{2.5}$ and PM_{10} emissions increased with an increase in wind speed (Table 1). Differences in emissions across soil types are more evident at higher wind speeds (Table 1).

The greatest loss of sediment, $PM_{2.5}$ and PM_{10} was observed for Warden sandy loam (Table 1). However, the $PM_{2.5}$ and PM_{10} fractions of both dispersed and nondispersed soil were similar to the other soil types examined in this study (Table 2 and 3). In comparison to other soils, the Warden soil contained more saltation-size aggregates and had a significantly greater sand fraction. The higher percentage of sand may serve as a saltating agent to break or abrade more mobile and immobile aggregates at high wind speeds. This abrading action could induce the release of more $PM_{2.5}$ and PM_{10} from the soil surface. Statistical analysis of loss of total sediment, $PM_{2.5}$ and PM_{10} flux, and $PM_{2.5}$ to PM_{10} emission ratios indicated similarity of Athena and Palouse soils as well as Ritzville and Walla Walla soils. In general, $PM_{2.5}$ and PM_{10} emissions measured in this study were either higher or similar for Athena and Palouse as compared with Ritzville and Walla Walla soils. This finding suggested that Athena and Palouse soils have a higher $PM_{2.5}$ and PM_{10} emission potential than Ritzville and Walla Walla soils.

Table 1. Total sediment, PM_{10}, and $PM_{2.5}$ loss at three wind speeds.

Wind speed (m s-1)	Soil type	Total sediment loss (g m-2)	PM_{10} flux (g m-2)	$PM_{2.5}$ flux (g m-2)	$PM_{2.5}$/ PM_{10} flux
	Warden	215	0.14	0.027	0.19
	Athena	17	0.02	0.006	0.29
11	Palouse	22	0.03	0.008	0.27
	Ritzville	26	0.02	0.004	0.20
	Walla Walla	12	0.01	0.002	0.25
	Warden	3634	3.81	1.29	0.33
	Athena	136	0.30	0.05	0.15
15	Palouse	112	0.55	0.06	0.11
	Ritzville	49	0.11	0.02	0.21
	Walla Walla	54	0.13	0.02	0.17
	Warden	8039	10.8	5.99	0.56
	Athena	222	0.9	0.17	0.20
18	Palouse	241	0.7	0.12	0.17
	Ritzville	153	0.4	0.09	0.23
	Walla Walla	113	0.4	0.08	0.20

Table 2. $PM_{2.5}$ and PM_{10} fraction based upon dispersed analysis.

Soil series	$PM_{2.5}$	PM_{10}	$PM_{2.5}$ /PM_{10}
Warden	0.11	0.17	0.62
Athena	0.19	0.39	0.50
Palouse	0.18	0.34	0.52
Ritzville	0.13	0.28	0.48
Walla Walla	0.20	0.39	0.51

Table 3. $PM_{2.5}$ and PM_{10} fraction based upon nondispersed analysis.

Soil series	PM_{10}	$PM_{2.5}$	$PM_{2.5}$ /PM_{10}
Warden	0.032	0.010	0.32
Athena	0.033	0.087	0.26
Palouse	0.038	0.014	0.36
Ritzville	0.046	0.015	0.32
Walla Walla	0.038	0.014	0.37

Publications and Presentations

Book Chapter

Sharratt, B. and R.S. Van Pelt. 2011. Wind erosion: Field measurements. Encyclopedia of Environmental Management. Taylor and Francis LLC (accepted September 2010).

Refereed Journal Articles

Feng, G., B. Sharratt, and F. Young. 2011. Soil properties governing wind erosion affected by cropping systems in the US Pacific Northwest. *Soil & Tillage Research* 111:168-174.

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Published Abstracts

Sharratt, B. 2010. Particle size of windblown loess within the Columbia Plateau, USA. [CD-ROM]. Soil Science Society of America annual meeting 31 Oct – 3 Nov., Long Beach, CA. ASA, CSSA, SSSA Agronomy Abstracts.

Feng, G. and B. Sharratt. 2010. Fine-dust entrainment potential from loessial soils in the US Pacific Northwest. Seventh International Conference on Aeolian Research, 5-9 July, Santa Rosa, Argentina.

Feng, G. and B. Sharratt. 2010. Evaluation and application of a soil erosion model on the Columbia Plateau, USA. Seventh International Conference on Aeolian Research, 5-9 July, Santa Rosa, Argentina.