EVALUATING A WOOD-STRAND MATERIAL FOR WIND EROSION CONTROL AND AIR QUALITY PROTECTION

By

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Abstract

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Wind erosion is a widespread problem in much of the western United States due to arid conditions and persistent winds. Fugitive dust from eroding land poses a risk to both environmental quality and human health. The Clean Air Act, established in 1971, was revised in 1987 to include ambient air quality standards for PM_{10} (particulate matter with mean aerodynamic diameter ≤ 10 μm) in the atmosphere. Agricultural straw has been widely used for erosion control, but there are numerous drawbacks to its use. Straw is a lightweight material and lacks stability during high-wind events. Also, there is growing concern over the introduction of noxious weeds to wildlands, chemical residues from pesticides, and health risks associated with dust particles liberated from the shattering of straw elements during the application process. A wood-based product has recently been developed as an alternative to agricultural straw for erosion control. The purpose of this study was to evaluate the efficacy of the wood-strand material in controlling wind erosion and fugitive dust emissions. A series of wind tunnel tests were conducted to compare wood strands to agricultural straw and bare soil in terms of total sediment loss, PM$_{10}$ vertical flux, and PM$_{10}$ loss. Results indicated that the types of wood strands tested are stable at wind speeds of up to 18 m s^{-1}, while wheat straw is only stable at speeds of up to 6.5 m s^{-1}. Wood strands reduced total sediment loss and PM$_{10}$ emissions by 90% as compared to bare soil. Wheat straw reduced total sediment loss and PM$_{10}$ emissions by up to 40% and 75%, respectively, as compared to bare soil.

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CHAPTER ONE

INTRODUCTION

Wind erosion is a global concern, affecting over one third of the Earth’s land surface (Chen and Fryrear, 1996). While arid environments such as the Sahara Desert in Africa, the Loess Plateau in China, and the desert southwest of the United States, are readily defined as key areas prone to wind erosion, semiarid and humid environments such as the ponderosa pine (*Pinus Ponderosa*) forests of the western U.S. and sandy soils along costal plains are also highly susceptible to wind erosion. The degree of susceptibility to wind erosion is mostly dependent upon land management (Whicker et al., 2006a).

Intense agricultural expansion and poor farming practices contributed to the Dust Bowl of the 1930’s in the U.S., which is probably the most well known example of wind erosion. Dust storms that occurred during this time carried material from the Great Plains states eastward to the Atlantic Ocean, depositing dust on ships’ decks hundreds of kilometers from shore (Worster, 1979). The U.S. Department of Agriculture (USDA) Soil Conservation Service (SCS), now the USDA Natural Resources Conservation Service (NRCS), was formed in response to the disaster in an effort to make information on sustainable agricultural practices available to farmers.

Wind erosion is not only a problem of the past, however, and dust sources are not limited to agricultural environments. Dust emissions from desertification of regions in Africa and China have been shown to affect global air quality (Garrison et al., 2003). Hundreds of million tons of dust from the Sahara and Sahel regions in Northern Africa are deposited in the Caribbean each year, affecting aquatic ecosystems, microbial processes, and human health (Garrison et al., 2003). Influxes of dust from the Takla Makan and Gobi deserts in China reach the Pacific Northwest of the U.S. each year (Garrison et al., 2003).

Regional air quality can be affected by local land management on shrublands, grasslands, and forested ecosystems. Forest fires, for example, can rapidly and drastically reduce the vegetative ground cover that protects the soil. Whicker et al. (2006b) found that severe forest fire initially increased dust emissions by an order of magnitude from a ponderosa pine forest in northern New Mexico and also reported increased dust emissions for several years following the fire. Breshears et al. (2003) reported that wind-driven soil transport was greater than water-driven soil transport in semiarid shrubland, grassland, and forest ecosystems.

Wind erosion is a global and regional concern which adversely affects both the environment and human health. Environmental implications include damage to plants and seedlings, contaminant transport, reduced productivity of soils due to nutrient loss, sediment loading in streams and lakes, and influences on global climate (Garrison et al., 2003; Riksen and De Graff, 2001; Shinn et al., 2000). Plants can be damaged by abrasion or buried from the mechanical action of the wind and storage capacity for plant-available water can be reduced by loss of topsoil (Riksen and De Graff, 2001).

The smallest particles are typically transported the farthest distances by wind. These small particles are the most chemically active portion of the soil and, thus, have the greatest potential to transport chemical compounds, microbes, and spores (Shinn et al., 2000). Fine-size particles may remain suspended in the atmosphere for long periods of time, affecting areas distant from the actual dust source. The influx of fugitive dust from Northern Africa has been suggested as the host to a variety of other compounds and microbes linked to coral reef decline in the Caribbean (Garrison et al., 2003). Increased production, use, and disposal of synthetic compounds into the environment may further elevate risks associated with dust transport due to adsorption processes. It has been suggested that emission of particulate matter (PM) and its sorbed constituents may play a role in global climate forcing (Charlson et al., 1992; Prospero and Lamb, 2003).

Implications of wind erosion on human health include decreased visibility on roadways and increased respiratory disease. Decreased visibility from suspended PM contributes to vehicle accidents on U.S. roadways each year (Cowherd et al., 1997; Day, 1993). Respiratory ailments from inhalation of the respirable soil size fraction have also been reported and increased atmospheric PM concentrations have been linked to decreased lung function and other respiratory ailments, including asthma incidence (Koren, 1995; Peden, 2001). PM_{10} (particles with an aerodynamic diameter of ≤ 10 μm) pose the greatest health risk because once respired, they are able to penetrate deep into the thoracic portion of the respiratory tract (US EPA, 2006b). Norton and Gunter (1999) investigated the correlation between quartz-rich PM and chronic obstructive pulmonary disease. Quartz has previously been identified as a human carcinogen by the International Agency for Research on Cancer (IARC Monograph, 1997).

Atmospheric PM has been regulated in the U.S. since 1971, when the U.S. EPA developed National Ambient Air Quality Standards (NAAQS) for total suspended particles (TSP's). The EPA revised the NAAQS in 1987, changing the regulated species from TSP to PM_{10} based upon findings from epidemiological and toxicological studies. The PM NAAQS were revised again in 1997 to include separate standards for the coarse (PM_{10}) and fine ($PM_{2.5}$) fractions of PM. The most recent revision occurred in December 2006 and established standards to regulate PM_{10} on a 24-h basis and $PM_{2.5}$ on both average annual and 24-h bases (Table 1) (U.S. EPA, 2006a).

Table 1. Current U.S. EPA National Ambient Air Quality Standards (NAAQS) for particulate matter in the atmosphere (U.S. EPA, 2006a).

	Averaging Time	
Regulated Species	Annual	24-h
PM_{10}	NA	150 µg m^{-3} †
$PM_{2.5}$	15.0 µg m^{-3}	35 µg m^{-3} ††

† Not to be exceeded more than once per year over a three-year average.
†† Three-year average of the 98th percentile of 24-h concentrations at each population-oriented monitor within an area must not exceed 35 µg m^{-3}.

Technically, wind erosion is the process by which particles are entrained, transported, and deposited by moving air. Particles are entrained either directly from wind energy incident at the soil surface or by impaction of other particles transported by the wind. The fluid and impact threshold velocities are the minimum velocities required to produce soil movement by direct action of the wind and by impaction of soil particles carried by the wind, respectively (Schwab et al., 1993). Wind speeds less than 5 m s^{-1} at a height of 0.3 meter are typically considered to be nonerosive for mineral soils (Schwab et al., 1993).

The three types of soil movement associated with wind erosion are saltation, suspension, and surface creep. Saltation is the process by which particles are lifted from the soil surface, but are too large to remain in suspension and return to the surface following distinct trajectories. Saltating particles may rebound or become embedded after impaction; however, their initial impact disturbs surrounding soil particles and can liberate nearby particles or abrade larger aggregates, producing more of the suspendible-size fraction. Suspended particles can remain in the atmosphere for extended periods of time. Particles in suspension typically represent 3–10 percent of the total eroding sediment (Chepil, 1945). The atmosphere has a large carrying capacity for soil transport and particularly for particle sizes less than 100 μm in diameter. It is estimated that the potential soil carrying capacity of the atmosphere is on the order of Gg km^{-3} (Schwab et al., 1993). Larger sand-sized particles roll along the soil surface in a process known as creep. Creep typically accounts for 7 to 25 percent of soil movement (Chepil, 1945). The amount of soil movement is dependent upon wind velocity, length of the eroding area, particle size, and particle gradation (Schwab et al., 1993). Variability in velocity and direction of wind produce cross-currents and eddies that can lift and transport soil. The rate of soil movement increases with the distance downwind from the leading edge of the eroding surface due to increased amounts of erosive particles carried by the wind which enhances abrasion and creates a gradual decrease in the surface roughness (Schwab et al., 1993).

A suspended particle is deposited when the gravitational force exceeds the forces holding the particle in the air. Deposition typically occurs when there is a decrease in wind velocity due to a wind barrier (e.g. vegetation, fences, ditches). Soil particles also play a role in raindrop formation and can be removed by precipitation when water droplets coalesce onto them.

Enhanced understanding of wind erosion mechanics has furthered development of wind erosion control technology and increased the ability to predict soil loss from wind-driven transport. A common model for estimating annual soil loss (E) from wind erosion is the wind erosion equation (Woodruff and Siddoway, 1965):

$$E = f(I, K, C, L, V) \qquad [1]$$

where E is the estimated annual average soil loss (Mg ha^{-1} yr^{-1}), I is the soil erodibility index (Mg ha^{-1} yr^{-1}), K is the ridge roughness factor, C is the climate factor, L is the unsheltered length of eroding land (m), and V is the vegetative cover factor.

Relationships were developed for the five soil loss parameters by Schwab et al. (1993) based on data from Woodruff and Siddoway (1965). The soil erodibility, I, is related to the soil aggregates greater than 0.84 mm in diameter and is described as:

$$I = 525e^{(-0.04F)} \tag{2}$$

where I is the soil erodibility index (Mg ha^{-1} yr^{-1}) and F is the percent dry soil fraction greater than 0.84 mm. Erodibility indices have been tabulated for various soil textures. Adjustments can be made to the erodibility index for location on windward slopes or knolls. Although erodibility is affected by surface crusting from wetting and drying of the soil as well as clod formation by tillage practices, these effects are not accounted for in the wind erosion equation.

The ridge roughness factor, K, represents the effect of ridges created from tillage on erosion rate. Ridges reduce erosion by absorbing and deflecting wind energy and trapping soil particles. If the surface is too rough, however, increased turbulence may exacerbate particle movement. The ridge roughness factor, K, can be calculated by the following regression equation:

$$K = 0.34 + \frac{12}{K_r + 18} + 6.2 \times 10^{-6} K_r^2 \tag{4}$$

where K is the roughness factor and K_r is ridge roughness (mm).

The following equation can be used to estimate ridge roughness:

$$K_r = 4\frac{h^2}{d} \qquad [3]$$

where K_r is ridge roughness (mm), h is ridge height (mm), and d is ridge spacing (mm). If ridges are normal to the predominant wind direction, K is assumed as 1.00 regardless of soil roughness.

The climate factor, C, is an indication of the effect climate has on the erosion rate. It includes wind speed and surface soil water content and is expressed as a percentage of the C factor for Garden City, Kansas, USA. Woodruff and Siddoway (1965) present methods of calculating the C factor.

The unsheltered length, L, is the unprotected distance in meters parallel to the prevailing wind direction. The vegetative cover factor, V, is a function of the type, amount, and orientation of vegetative material to its equivalent of small grain residue. The small grain equivalent is calculated as (Lyles and Allison, 1981):

$$V = aR_w^b \qquad [5]$$

where V is the vegetative cover factor expressed as the small grain equivalent (kg ha^{-1}), a and b are crop constants (tabulated in Lyles and Allison, 1981), and R_w is the quantity of residue to be converted to small grain equivalents (kg ha^{-1}).

The empirical wind erosion equation is the most commonly used predictive tool for agencies such as the USDA NRCS; however, development of a process-based model is underway. Researchers at the Wind Erosion Research Unit (WERU) in Manhatten, Kansas, USA have been leading development of the Wind Erosion Prediction System (WEPS). WEPS is a process-based, continuous, daily time-step model that simulates weather, field conditions, and erosion and is intended to significantly improve wind erosion prediction in the future. Furthermore, increased understanding of and ability to model underlying principles governing wind erosion processes will further enhance wind erosion control technology development.

Wind erosion control methods have largely been developed for use on agricultural lands and have included methods such as windbreaks, conservation tillage practices, soil water management techniques, and applied surface covers and soil tackifiers. A windbreak is a barrier for protection from wind and is often formed by planting rows of shrubs or trees, but can also be constructed from fences, vertical burlap, rock, or debris. Windbreaks are typically associated with wind protection for small areas such as gardens, buildings, orchards, and feed lots. A shelterbelt is a longer barrier than a windbreak and is usually intended for soil and water conservation and for protection of field crops or along roadways (Schwab et al., 1993). Windbreaks and shelterbelts reduce wind erosion by decreasing the unsheltered length, L, in the wind erosion equation. Wind tunnel tests conducted by Woodruff and Zingg (1952) indicated that the full protection for a windbreak is:

$$d = 17h(\frac{v_m}{v})\cos\theta \qquad [6]$$

where d is the distance of full protection, h is the height of barriers, v_m is the minimum wind velocity at 15-m height required to move the most erodible soil fraction, v is the actual wind velocity at 15-m height, and θ is the angle of deviation of prevailing wind direction from the perpendicular to the windbreak.

Windbreaks and shelterbelts are most effective when they are moderately dense from ground level to treetops. Windbreaks have been shown to be both cost-efficient and effective for wind erosion control. For example, Michels et al. (1998) found that windbreaks constructed in the Sahel region of Africa reduced soil loss by up to 77% compared to unsheltered controls and did not significantly impact grain yields. However; the results were dependent upon species used for the windbreak and would likely vary with climate, soil type, and growing crop to be protected (Michels et al., 1998). Schwab et al. (1993) indicated that selection of species and spacings should follow local recommendations.

Conservation tillage practices have been effective in reducing soil loss by maintaining roughness in the form of large clods and vegetative cover of the surface (Horning et al., 1998). Proper tillage produces a rough, cloddy surface with ridges normal to the prevailing wind direction which reduces the erosion rate by decreasing the soil erodibility index, I, and increasing the ridge roughness factor, K (Schwab et al., 1993). Additionally, remaining surface cover tacked into the soil from conservation tillage further reduces losses from wind erosion by reducing wind speed and trapping eroding soil. Schwab et al. (1993) indicated that the combined effect of straw residue and ridges was greater than either straw or ridges alone and that 1120 kg ha^{-1} of wheat straw residue reduced wind erosion by up to 88% as compared to bare soil.

Soil water conservation is a commonly used wind erosion control technique in arid and semiarid regions. Conserving soil water reduces wind erosion by increasing the threshold velocity of the soil due to the cohesive properties of water and effectively decreasing the erodibility index, I. Water is conserved by increasing infiltration, reducing evaporation, and preventing unnecessary plant growth. Soil water conservation techniques include mulching, tillage, crop rotation, and proper crop selection. Mulching and tillage practices reduce evaporation from the soil surface by increasing porosity at the surface, thus reducing the conductance of water vapor to the atmosphere (Schwab et al., 1993). The predominant cropping system employed on the Columbia Plateau of central Washington is a winter wheat-summer fallow rotation. This rotation is used to conserve soil water; however, the dry soil layer exposed during the fallow season is highly susceptible to wind erosion (Sharratt et al., 2006).

Surface covers and tackifiers are also commonly applied to exposed soil surfaces at construction sites, burned areas, and to supplement standing residues in agricultural fields. Applied surface covers are only effective in reducing wind erosion if they are stable during the wind events; therefore, lightweight materials, such as agricultural straw, often must be anchored into the soil. Wolf et al. (1984) reported that application of organic mulch materials increased infiltration, reduced erosion, and stimulated seedling development on steep slopes. The authors reported that straw was one of the most effective mulches, but only if tacked to the surface mechanically or with a liquid material due to its susceptibility to movement by wind. Another study conducted by Hipps et al. (1990) indicated that the rainfall-induced erosion reduction efficacy of straw in an orchard decreased over time due to dispersal of the straw by wind. Tackifiers, also referred to as spray-on adhesives and soil conditioning compounds, act to bind soil particles together and increase aggregate stability. Tackifiers have been shown to be effective on agricultural lands; however, application methods are intensive and can require special equipment (Lyles et al., 1969). Van Pelt and Zobeck (2004) investigated the effects of standing residue and polyacrylamide (PAM) on reducing wind erosion. The authors reported that cover cropping reduced soil loss by two to three orders of magnitude while surface application of PAM did not reduce soil loss at any application rate. Armbrust (1999) also investigated the effects of PAM on wind erosion and found that PAM reduced the amount of loose erodible material during laboratory testing, but did not reduce soil erodibility during field testing.

There are continuing efforts to evaluate and improve erosion control practices on agricultural lands. Less information is available, however, regarding wind erosion protection in non-agricultural areas, such as burned forest sites and semiarid shrublands and grasslands, although they have been shown to be important sources of dust emissions (Breshears et al., 2003). Control methods developed for use on agricultural lands may not always be feasible or equally effective on non-agricultural lands. For example, straw is often applied as a surface cover, but must be anchored into the soil to be effective (Hipps et al., 1990; Wolf et al., 1984), which poses a logistical problem for application over large areas and steep slopes, characteristic of burned forest sites where application of erosion control materials is often performed via helicopter. Additionally, ecologically sensitive areas such as forested habitats may not be suitable for application of traditional surface covers, such as agricultural straw, which may carry pesticides or non-native plant species (Robichaud et al., 2000). Thus, there exists a need for continued efforts in erosion control development.

CHAPTER TWO

A WOOD-STRAND MATERIAL FOR WIND EROSION CONTROL: EFFECTS ON TOTAL SEDIMENT LOSS, PM$_{10}$ VERTICAL FLUX, AND PM$_{10}$ LOSS

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ABSTRACT

Wind erosion is a widespread problem in much of the western United States due to arid conditions and persistent winds. Fugitive dust from eroding land poses a risk to both environmental quality and human health. The Clean Air Act, established in 1971, was revised in 1987 to include ambient air quality standards for PM_{10} (particulate matter with mean aerodynamic diameter ≤ 10 μm) in the atmosphere. Agricultural straw has been widely used for erosion control, but there are numerous drawbacks to its use. Straw is a lightweight material and lacks stability during high-wind events. Also, there is growing concern over the introduction of noxious weeds to wildlands, chemical residues from pesticides, and health risks associated with dust particles liberated from the shattering of straw elements during the application process. A wood-based product has recently been developed as an alternative to agricultural straw for erosion control. The purpose of this study was to evaluate the efficacy of the wood-strand material in controlling wind erosion and fugitive dust emissions. A series of wind tunnel tests were conducted to compare wood strands to agricultural straw and bare soil in terms of total sediment loss, PM_{10} vertical flux, and PM_{10} loss. Results indicated that the types of wood strands tested are stable at wind speeds of up to 18 m s^{-1}, while wheat straw is only stable at speeds of up to 6.5 m s^{-1}. Wood strands reduced total sediment loss and PM_{10} emissions by 90% as compared to bare soil. Wheat straw reduced total sediment loss and PM_{10} emissions by up to 40% and 75%, respectively, as compared to bare soil.

INTRODUCTION

Arid conditions and persistent winds, characteristic of much of the western United States, promote conditions conducive to wind erosion. Wind-blown dust liberated from construction sites, burned areas, and agricultural fields is a widespread problem with both human health and environmental implications. In 1987 the United States Environmental Protection Agency (U.S. EPA) began to regulate PM_{10} (particulate matter with mean aerodynamic diameter ≤ 10 μm) as a criteria pollutant. Since then, numerous epidemiological studies have shown a strong correlation between incidence of respiratory ailments such as asthma, and atmospheric PM_{10} (Dockery and Pope, 1994; Koren, 1995; Peden, 2001). Based upon these and other findings, National Ambient Air Quality Standards have been set regulating PM_{10} on a 24-h basis (U.S. EPA, 2006a). Aside from the health issues directly related to particulate matter, PM_{10} also represents the most chemically active portion of the soil, and thus, has the potential to transport heavy metals, pesticides, and microbes (Garrison et al., 2003; Whicker et al., 2006a). In addition to these potentially harmful compounds, PM_{10} may also transport nutrients necessary for plant growth, reducing soil productivity (VanPelt and Zobeck, 2007).

Once fine-sized particles are in suspension, they can remain in the atmosphere for long periods of time before being re-deposited. This long residence time allows the impacts of particulate matter to be realized in areas distant from the actual dust source. For instance, suspended particulates originating from dust storms in the Columbia Plateau region of the U.S. Pacific Northwest have been shown to affect air quality in eastern Washington and the Idaho Panhandle, with ambient PM_{10} concentrations exceeding air quality standards numerous times since monitoring began in 1985 (Sharratt and Lauer, 2006). Influxes of dust originating from events as far away as Asia have been measured on the Columbia Plateau (Vaughan et al., 2001) and it is estimated that hundreds of millions of tons of dust from Africa are deposited in the Caribbean each year (Moulin et al., 1997).

A common model for estimating annual soil loss (E) from wind erosion is (Woodruff and Siddoway, 1965):

$$E = f(I, K, C, L, V) \qquad [7]$$

where I is the soil erodibility index, K is the ridge roughness factor, C is the climate factor, L is the unsheltered length of eroding land, and V is the vegetative cover factor. A reduction in soil loss can be achieved by increasing vegetative cover, increasing surface roughness, decreasing unsheltered length (sometimes referred to as fetch length), or a combination of the three.

Traditional management practices for wind erosion control have included implementation of wind breaks, shelterbelts, irrigation, applied surface cover material, conservation tillage practices, and crop residue handling techniques. Newer approaches have also included the application of soil binding agents and stabilizers, such as polyacrylamides (Armbrust, 1999; Van Pelt and Zobeck, 2004). These techniques, in principle, apply to all land types; however, wind erosion research efforts have primarily focused on agricultural lands, and control technologies developed for agricultural lands may not be equally suitable or readily adaptable for use in other ecosystems such as grasslands, shrublands, and forests. Little information is available regarding wind erosion protection in non-agricultural lands although they have been shown to be important sources of dust emissions (Whicker et al., 2006a; Whicker et al., 2006b).

Perhaps the most widely used material for erosion control has been agricultural straw. Straw, however, may not be entirely effective in controlling wind erosion, as it is a lightweight material and lacks stability during high-wind events. Other drawbacks to the use of straw arise when application is on wildlands or forest ecosystems. One of these drawbacks is the concern over the introduction of noxious weeds and non-native species to forested areas (Robichaud et al., 2000). Straw itself carries fine dust particles which may be liberated when the straw elements are shattered, posing a health hazard to workers involved in the application process (Kullman et al., 2002). Straw is also a raw material for other potentially high-value uses such as energy production (Gorzell, 2001). Value-added products derived from straw may reduce the supply for erosion control.

Forest Concepts, LLC, Auburn, Washington, USA, has developed a wood-based straw analog made from the by-products of forest thinning and veneer manufacturing. The wood-strand materials (WoodStraw^{TM}) are heavier than straw, and thus, less likely to be blown away when exposed to high winds. Wood strands also have favorable mulching characteristics for decomposing into environment-friendly duff, offer long-term resistance to erosion, and do not introduce noxious weeds, pesticides, or non-native materials to wildlands (Forest Concepts, LLC, 2007). Additionally, the manufacturing of wood strands utilizes what were previously considered waste materials. The use of wood strands as an alternative material for water erosion control has previously been investigated. Foltz and Dooley (2003) and Yanosek et al. (2006)

reported that agricultural straw and wood strands were equally effective on two soil types in reducing rainfall-induced erosion by over 98% as compared to bare soil.

The current study was intended to evaluate wood strands in terms of wind erosion mitigation and air quality protection. Specific objectives of this study were: (1) to evaluate the effectiveness of wood strands in reducing total sediment loss, PM_{10} vertical flux, and PM_{10} loss compared to bare soil and soil covered with agricultural straw; and (2) to identify dimensional characteristics impacting the erosion reduction and dust reduction efficacy of the wood strands.

MATERIALS AND METHODS

Experimental Design

Wind tunnel experiments were performed at the United States Department of Agriculture-Agricultural Research Service (USDA-ARS) Palouse Conservation Field Station in Pullman, Washington. The experiments were carried out in a non-regulated climate facility using a portable wind tunnel (Pietersma et al., 1996) with a working section 1.0 m wide, 1.2 m tall, and 7.3 m long. Wind was generated by a 1.4-m diameter Joy Series 1000 axivane fan driven by a Ford industrial type gasoline engine. Thirteen available engine speeds and variable pitch fan blades yielded free stream velocities in the range of <2 to 20 m s^{-1}. A bell infuser and curvilinear guiding vanes were employed to ensure smooth, efficient transitions at the upwind and downwind edges of the fan, respectively. The flow was passed through a diffuser and honeycomb-screen combination to reduce turbulence. Sand-coated plywood (for fixed surface roughness) was used for the floor of the tunnel and allowed for establishment and stabilization of a boundary layer characteristic of a smooth, bare soil surface upwind of the test surface.

The experiment was a completely randomized design with 11 different treatment combinations of two surficial material types (agricultural straw or wood strands) and three coverages (0%, 50%, or 70%) (Table 2). Each treatment combination was replicated four times at three wind speeds. Surface treatments included a bare soil, soil covered with air-dried wheat straw at either 50 or 70 percent cover, and soil covered with air-dried wood strands of varying dimensions at either 50 or 70 percent cover. Treatments of wood strands included long strands (240 mm) at two thicknesses (4.8 mm and 2.5 mm) and a mixture of short (64 mm) and long strands at the same two thicknesses. Mixes were created on a 50:50 mass basis (long and short at designated thickness). All wood strands had a standard width of 4.5 mm. Forest Concepts, LLC produced the wood strands used in this experiment from Douglas fir (*Pseudotsuga menziesii*) clear wood blocks.

Table 2. Treatment combinations and average measured cover height.

Cover Type	% Cover	Dimensions[†]	Average Cover Height (cm)
Bare	0	-	-
Agricultural Straw	50	-	2.7
	70	-	3.3
Wood Strands	50	Long/Thick	2.5
		Mix/Thick	2.3
		Long/Thin	2.0
		Mix/Thin	1.3
	70	Long/Thick	3.3
		Mix/Thick	2.7
		Long/Thin	2.3
		Mix/Thin	1.8

[†] Long: 240 mm in length, short: 64 mm in length, thick: 4.8 mm in thickness, thin: 2.5 mm in thickness.

A Ritzville silt loam (coarse-silty, mixed, superactive, mesic Calcidic Haploxeroll) collected from the top 10 cm of the profile at a field site near Lind, Washington was selected for the study due to its high potential to erode and emit PM_{10} (Chandler et al., 2004). Prior to testing, the soil was air-dried and sieved to remove aggregates larger than 2 mm in diameter. Non-dispersed aggregate size analysis indicated that over 70% of the soil size fraction (< 2mm size fraction) was comprised of suspendible particles, or PM_{100} (particulate matter ≤ 100 µm in diameter), with nearly 4% of this fraction as PM_{10}. Aluminum trays (1 m long, 0.5 m wide, and 0.04 m deep) were filled with soil in three layers. After the addition of each soil layer, the sides of the trays were tapped to ensure even settling. Following the addition of the third layer, the trays were 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.

Cover treatments were applied by hand to the soil prior to transfer of trays to the tunnel. Pictures of the trays were taken before and after each wind tunnel test and actual percent cover was determined by a point count method using a 48-point grid overlay on the pictures. Average cover height was measured prior to each run.

Testing was performed at free stream velocities of 6.5, 11, and 18 m s^{-1}. The low wind speed, 6.5 m s^{-1}, was chosen because it is near threshold velocity (i.e. the minimum velocity at which wind begins to move soil particles) for the type of soil used in this study (Sharratt et al., 2006). The 18 m s^{-1} wind speed was chosen because it occurs at a frequency of at least once every two years in the Columbia Plateau region of the U.S. (Wantz and Sinclair, 1981). Each soil treatment was subjected to the wind for five minutes.

Measurements

Measurements made during the wind tunnels tests included: (1) loss of saltating and suspended sediment and surface creep to determine total sediment loss from the tray and (2) PM_{10} concentrations to assess the impact on air quality. Saltating and suspended sediment was measured using a vertically integrating isokinetic slot sampler (modified Bagnold type, Stetler et al., 1997) connected in series with a high efficiency cyclone and vacuum. A 10-cm wide 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_{10} concentrations were measured using TSI DustTrak^{TM} Aerosol Monitors (TSI, Inc., St. Paul, Minnesota). The DustTrak^{TM} is a constant-flow portable laser photometer capable of measuring particle sizes in the range of 0.1–10 µm. PM_{10} measurements were made at a frequency of 1 Hz with aerosol inlets placed at 0.5, 1, 2, 3, 4, and 10 cm above the cover surface at the downwind edge of the soil tray. These heights were chosen to measure concentrations within and above the boundary layer. Background PM_{10} concentrations were monitored with two additional aerosol monitors located at the upwind end of the tunnel. Wind speeds were measured at a frequency of 1 Hz and averaged over 60 seconds using pitot tubes connected to differential pressure transmitters (Series 606, Dwyer Instruments, Inc., Michigan City, Indiana) 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.

Ambient temperature, pressure, and relative humidity were monitored during testing, as these parameters affect particle suspension. In addition, soil water potential was measured using a dew point meter (WP4-T, Decagon Devices, Pullman, WA) prior to each wind tunnel run. Experiments were conducted across multiple days which were expected to result in varying ambient and soil conditions. Thus, each daily experimental plan included at least one bare soil (control) treatment to enable evaluation of any differences in results that might be attributable to varying experimental conditions.

PM_{10} Vertical Flux and Loss

Treatment effectiveness was assessed based on total sediment loss, vertical flux of PM_{10}, and PM_{10} loss. The wind velocity profile above the test surface was characterized in order to determine PM_{10} flux from the tray. When airflow encounters a change in surface conditions, such as the edge of the soil tray, the air begins to adjust to the new surface. An internal boundary layer with thickness, δ, develops and grows thicker with increasing fetch. Boundary layer thickness (δ) was approximated by (Munro and Oke, 1975):

$$\delta(x) = 0.1x^{(4/5)} z_0^{(1/5)} \qquad [8]$$

where x is the distance downwind from leading edge (m) and z_0 is the roughness parameter of new underlying surface (m).

Wind speed and PM_{10} concentrations were measured within and above the boundary layer. Airflow within the internal boundary layer was assumed to be fully adjusted to the new surface, and a logarithmic relationship was applied to characterize the wind velocity profile (Campbell and Norman, 1998):

$$U(z) = \frac{u^*}{k} \ln \frac{z-d}{z_0} \qquad [9]$$

where *U*(*z*) is mean wind speed at height z (m s^{-1}), *k* is the von Karman constant, taken as 0.4, u^* is friction velocity (m s^{-1}), z_0 is the roughness parameter (m), and *d* is zero plane displacement (m).

Friction velocity, u^*, is a characteristic velocity in a turbulent boundary layer and is defined as:

$$u^* = \sqrt{\frac{\tau_0}{\rho}} \qquad [10]$$

where u* is friction velocity (m s^{-1}), τ_0 is Reynold's stress (Pa), and ρ is air density (kg m^{-3}). Therefore, friction velocity is an indication of the shear stress at the surface. The roughness parameter (z_0) is directly related to height (*h*) of the roughness elements. Equation [9] allowed for direct calculation of u^* and z_0. The $\ln(z-d)$ was plotted as a function of mean wind speed, *U*(*z*), and fit with a linear trend of the form $y = mx + b$. Then, $u^* = k/m$ and $z_0 = \exp(b)$. Wind speed was measured at six heights above the soil surface; however, u^* was determined from best-fit linear regression based on three to four of these heights which fell within the boundary layer ($R^2 > 0.90$ in all cases). High degrees of linearity further ensured that measurements were made within the boundary layer.

The zero plane displacement, *d*, is an important parameter for rough surfaces and is an indication of the mean level at which momentum is absorbed by individual roughness elements. It was calculated as a function of roughness element height, *h*, by the following relationship (Stanhill, 1969):

$$\log_{10} d = 0.979 \log_{10} h - 0.154 \qquad [11]$$

where h is roughness element height (m) and d is zero plane displacement (m).

The vertical flux of PM_{10} represents the proportion of the total PM_{10} emitted from the surface that is transported vertically into the atmosphere and is directly proportional to friction velocity. Vertical flux of PM_{10} into the atmosphere was calculated as (Gillette, 1977):

$$F_v = -ku^* \frac{dC}{dz} \qquad [12]$$

where F_v is vertical flux of PM_{10} (mg m^{-2} s^{-1}), k is the von Karman constant, u^* is friction velocity (m s^{-1}), C is PM_{10} concentration above background concentration (mg m^{-3}), and z is height (m). Change in concentration with height was determined by plotting PM_{10} concentration against the natural log of height to generate a linear trend (Fig. 1) with slope = $dC/d(\ln z)$. Vertical flux was not constant over the entire five minutes of testing, likely due to the absence of saltating particles to continuously liberate PM_{10} from the surface. Since PM_{10} concentrations decreased rapidly within the first 60 seconds of testing (Fig. 2), vertical flux was only calculated for this portion of the test.

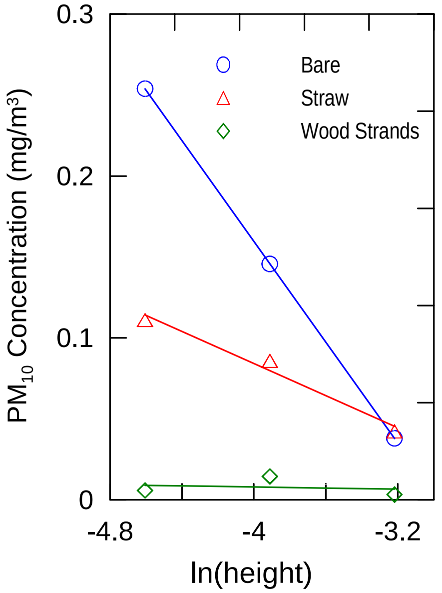

Figure 1. Composite trends of PM_{10} concentration versus natural log of height.

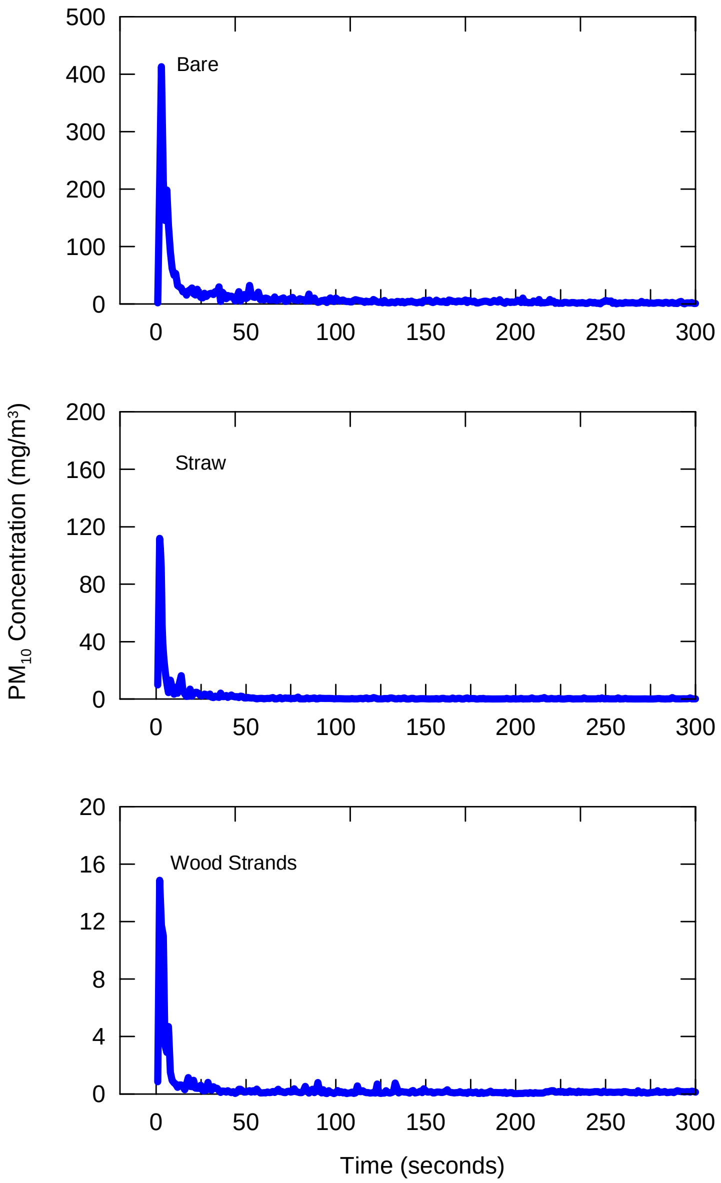

Figure 2. Representative time series of PM_{10} concentration measured above the surface of three different treatments at 11 m s^{-1}. Note scale difference in the three panels.

Friction velocity, the roughness parameter, and PM_{10} vertical flux were not calculated for the straw treatments at 11 or 18 m s^{-1} due to straw mobility and measurement constraints. Calculation of these parameters required that wind speed and PM_{10} measurements be made within the boundary layer. The bottom of the boundary layer was approximated based on average height of the cover material (e.g., for a straw treatment, the lowest sampling height was

0.5 cm above the average cover height for that treatment). Once the straw was blown away, the instrumentation was no longer within the boundary layer, prohibiting calculation of friction velocity, and thus calculation of vertical flux.

The emission rate of PM_{10}, E, was calculated based on the following relationship (Houser and Nickling, 2001; Shao et al., 1993):

$$E = \frac{1}{L}\int_{0}^{z_b} Cudz \qquad [13]$$

where E is PM_{10} emission rate (mg m^{-2} s^{-1}), L is length of the eroding surface (m), z_b *is* height at which PM_{10} concentrations reached background concentrations (m), C is PM_{10} concentration above background concentration (mg m^{-3}), u is wind speed at height z (m s^{-1}).

Equation [13] was evaluated from the lowest sampling height to z_b by plotting PM_{10} horizontal flux as a function of height (Fig. 3). The PM_{10} emission rate was determined by integrating this function from the lowest sampling height up to the height at which PM_{10} concentrations reached background concentrations and then dividing by tray length. Sampling height was plotted as a function of PM_{10} concentration and fit with a logarithmic function to determine the height at which background concentration was achieved.

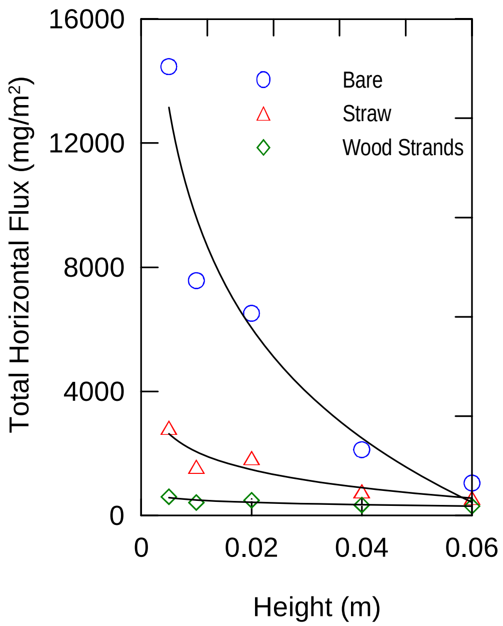

Figure 3. Composite trends of total PM_{10} horizontal flux with height. Total flux is for the five minute time period.

In some cases, peak PM_{10} concentrations at the lower sampling heights exceeded the DustTrak capabilities during the first few seconds of testing (no longer than five seconds). This was of particular concern for bare and straw treatments at 18 m s^{-1}. Peak PM_{10} concentrations were estimated in these instances to obtain better estimates of PM_{10} loss. Peak PM_{10} concentration estimates were made by fitting the reliable data points before and after the exceedance with linear and power functions, respectively and then extrapolating backward and forward in time.

Statistical Analyses

Statistical analyses were performed on total sediment loss, friction velocity, the roughness parameter, PM_{10} vertical flux, and PM_{10} loss using the mixed-model analysis of variance (ANOVA) (Littell et al., 1996). Analyses were made across wind speeds, with wind speed treated as a continuous variable. Three-way ANOVA's were conducted with *treatment*, *percent cover*, and *wind speed* as the main treatment effects. *Percent cover* was nested within *treatment* in the model statement, thus interactions of *treatment* and *percent cover* were not included in the model; all other interactions were included. Multiple pairwise comparisons were made using Tukey's procedure. Two-way ANOVA's were also performed within wind speed groups for a more in-depth investigation when significant interactions were identified in the three-way ANOVA. All results are reported at the $\alpha = 0.05$ level of significance.

Residuals from the mixed model were not normally distributed in all cases; transformations were performed on the data in those instances to satisfy the normality assumption necessary for the ANOVA. Log transformations were performed on friction velocity, total sediment loss, and PM_{10} loss data for all ANOVA's. Square-root transformations were performed on the roughness parameter data for two-way ANOVA's at 6.5 and 11 m s^{-1}; no transformation was necessary at the 18 m/s wind speed. Log and square-root transformations were performed on PM_{10} vertical flux data for the three-way and two-way ANOVA's, respectively.

Straw treatments were not considered in the analysis of friction velocity, the roughness parameter, or PM_{10} vertical flux at the 11 or 18 m s^{-1} wind speed due to previously mentioned measurement constraints. A within-wind speed evaluation was conducted to investigate differences in friction velocity, the roughness parameter, and vertical flux among treatments. All three treatments were examined at the 6.5 m s^{-1} wind speed and the bare and wood strand treatments were compared at the 11 and 18 m s^{-1} speeds.

RESULTS

Trends in PM_{10} concentration over time were characterized by a rapid increase to a peak concentration within the first 3–5 seconds of testing, followed by a rapid decay over the next 60–90 seconds (Fig. 2). The trends observed in this study were similar to the conceptual trend reported in Houser and Nickling (2001) and Loosemore and Hunt (2000) for nonabraded dust resuspension.

Overall, there was little total sediment or PM_{10} loss at 6.5 m s^{-1}, and increasing amounts at 11 and 18 m s^{-1} (Fig. 4). Differences in treatment efficacy became more evident at higher wind speeds, with wood strands consistently outperforming straw in suppressing soil and PM_{10} loss (Fig. 4). There were also differences in cover stability among wind speeds. Straw was only semi-stable at 6.5 m s^{-1}, with some movement from the upwind edge to the middle of the tray during the first few seconds of testing. The straw then appeared to become intertwined and re-stabilize, resulting in little loss of straw elements from the tray. The straw was not stable at 11 or 18 m s^{-1}, being completely blown from the test tray within the first few seconds of testing. Wood strands were stable at all wind speeds, although some reorientation of the wood strands occurred at 18 m s^{-1}.

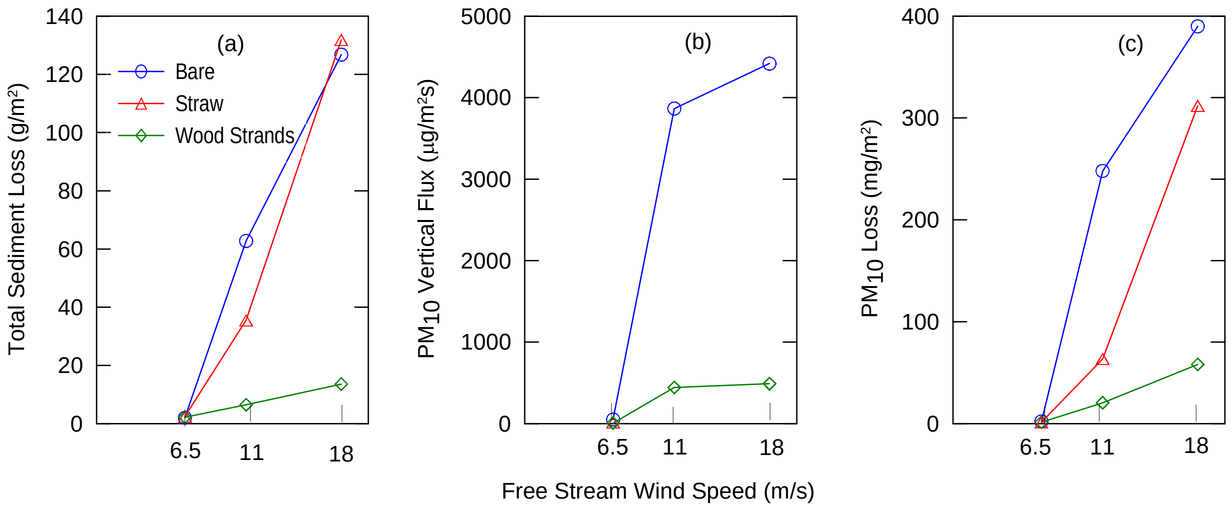

Figure 4. Average measured soil and PM_{10} loss and PM_{10} flux from the test tray at three wind speeds. PM_{10} vertical flux was not calculated for the 11 and 18 m s^{-1} wind speeds.

Soil water potential ranged from −135 MPa to −51.8 MPa, and was not significantly different among the treatments to warrant its use as a covariate. This is in accordance with McKeena-Neuman and Nickling (1989) who found little variation in threshold velocity to initiate soil movement at water potentials < -10 MPa. A paired *t*-test indicated that applied covers were not statistically different from the intended covers of 50 or 70%, so these nominal values were used in statistical testing and in all subsequent discussion. No statistically significant differences were found in measured loss or flux among wood strand blends. With the exception of PM_{10} vertical flux, no significant differences were found due to percent cover of straw or wood strands. Consequently, results will be discussed only in terms of the three treatments (bare, straw, and wood strands), except for the discussion on vertical flux, which will also include relevant information about material coverage.

Total Sediment Loss

A three-way ANOVA indicated a significant difference in total sediment loss due to *wind speed* and the *wind speed*treatment* interaction. Two-way ANOVA's performed at each wind speed indicated no significant differences among treatments at the 6.5 m s^{-1} wind speed. Two-way ANOVA's at 11 and 18 m s^{-1} indicated significant differences in total sediment loss due to *treatment*, with wood strands reducing sediment loss more than the bare and straw treatments. Tukey's procedure indicated no differences in total sediment loss among treatments at the 6.5 m s^{-1} wind speed, but grouped total sediment loss from the bare and straw treatments into a group statistically different from that of the wood strands at 11 and 18 m s^{-1} (Table 3).

Table 3. Average total sediment and PM_{10} loss for three wind speeds.[†]

Wind Speed (m s^{-1})	Treatment		
	Bare	Straw	Wood Strands
		Total Sediment Loss (g m^{-2})	
6.5	1.96^a	2.37^a	2.15^a
11	62.7^a	35.5^a	6.45^b
18	126^a	131^a	13.6^b
		PM_{10} Loss (mg m^{-2})	
6.5	2.06^a	1.24^{ab}	1.22^b
11	248^a	63.6^b	20.4^c
18	390^a	312^a	58.0^b

[†] a, b, and c superscripts denote groupings of significant mean values within a wind speed.

Friction Velocity, the Roughness Parameter, and PM_{10} Vertical Flux

Friction velocity, the roughness parameter, and vertical flux were not calculated for straw treatments at the 11 or 18 m s^{-1} wind speeds. A two-way ANOVA indicated no significant differences in friction velocity or the roughness parameter at the 6.5 m s^{-1} wind speed. Two-way ANOVA's indicated differences in both friction velocity and the roughness parameter among treatments at the 11 and 18 m s^{-1} wind speeds. Tukey's procedure yielded identical groupings for the friction velocity and roughness parameter data, with all three treatments grouped together at the 6.5 m s^{-1} wind speed and the bare and wood strand treatments separated into different groups at the 11 and 18 m s^{-1} wind speeds.

A three-way ANOVA identified *wind speed* and *percent cover* as significant effects and *wind speed*treatment* and *wind speed*percent cover* as significant interactions. A two-way ANOVA identified a significant difference in vertical flux due to *treatment* at 6.5 m s^{-1}. Tukey's method grouped the straw and wood strands together in a group having a statistically lower vertical flux (average flux 12.9 and 5.67 μg m^{-}2 s^{-1}, respectively) than the bare treatment (average flux 49 μg m^{-}2 s^{-1}). Tukey's method also indicated that the bare treatment was different from wood strands at 50 and 70 percent cover, but was different from the straw only when it was applied at 70 percent cover. Two-way ANOVA's indicated significant differences due to *treatment* for both the 11 and 18 m s^{-1} tests. In both cases Tukey's procedure identified wood strands at 50 and 70 percent cover as being different from the bare treatment. Additionally, a two-way ANOVA with *wind speed* and *percent cover* as the main effects indicated no significant difference between the 11 and 18 m s^{-1} wind speed for the wood strand treatment.

PM$_{10}$ Loss

A three-way ANOVA indicated significant differences in PM$_{10}$ loss due to *wind speed*, with Tukey's method separating the bare and straw treatments into a group statistically different than the wood strands. Two-way ANOVA's were performed on the transformed data to further investigate trends within wind speeds. Two-way ANOVA's indicated *treatment* as a significant effect at all three wind speeds. Tukey's procedure grouped the bare and wood strand treatments into separate groups, with the straw treatment overlapping into both groups at the 6.5 m s^{-1} wind speed (Table 3). Tukey's procedure separated the treatments into three groups at the 11 m s^{-1} wind speed and grouped the bare and straw treatments into a group different from the wood strands at the 18 m s^{-1} wind speed (Table 3).

DISCUSSION

Total Sediment Loss

The lack of differences among treatments at the 6.5 m s^{-1} wind speed was attributed to the small amount of total sediment loss observed at this wind speed (Table 3). Differences among treatments became evident at 11 m s^{-1}; at this wind speed the wood strands were effective in reducing total sediment loss compared to the straw and bare treatments (Fig. 4a). The straw appears to be effective at 11 m s^{-1}, with an average total sediment loss of about half of that from the bare treatment (Fig. 4a); however, due to the variability of the data, total sediment loss from the straw treatment was not significantly different from the bare treatment. This trend did not continue at the 18 m s^{-1} wind speed, at which the straw was not an improvement over the bare, but the wood strands continued to reduce total sediment loss (Figure 4a).

Examination of the soil loss ratios (SLR's) provides a more detailed look at the effectiveness of cover treatments in reducing soil loss (Table 4). SLR's, calculated as the soil loss from the treatment divided by soil loss from the bare soil, were greater than one at the 6.5 m s^{-1} wind speed. This was not unexpected, however, as there was no significant difference in soil loss among the three treatments, and the overall mean sediment loss for the three treatments was relatively low (2.2 g m^{-2}, Table 3). SLR's at 11 m s^{-1} indicated that straw reduced total sediment loss by about 60% and wood strands by about 90% as compared to bare soil. The effectiveness of the straw in reducing soil loss was not maintained at 18 m s^{-1}, with a SLR greater than one, while wood strands continued to maintain a reduction in total sediment loss by about 90%. The diminishing effectiveness of straw in reducing soil loss at 18 m s^{-1} was due to the instability of the straw at this wind speed. The large SLR for the straw treatment at 18 m s^{-1} was attributed to the differences in surface creep between the bare and straw treatments at this wind speed (Table 5). As the straw was being blown from the tray, scouring of the soil surface carried larger particles as surface creep, thus producing a larger mean total sediment loss than from the bare treatment.

Table 4. Total sediment and PM_{10} loss ratios for straw and wood strand treatments at three wind speeds.

Wind Speed (m s^{-1})		Loss Ratio[†]	
	Loss	Straw	Wood Straw
6.5	Total Sediment	1.21	1.10
	PM_{10}	0.61	0.60
11	Total Sediment	0.57	0.11
	PM_{10}	0.25	0.08
18	Total Sediment	1.04	0.11
	PM_{10}	0.80	0.15

[†] Soil loss ratios were calculated as the total sediment or PM_{10} loss from the treatment divided by total sediment or PM_{10} loss from the bare soil.

Table 5. Average sediment lost as creep, saltation, and suspension at three wind speeds.

Process	Wind Speed ($m\ s^{-1}$)	Sediment Loss ($g\ m^{-2}$)		
		Bare	Straw	Wood Strands
Creep	6.5	0.01	0.01	0.02
	11	1.40	3.33	0.02
	18	2.82	6.22	0.17
Saltation and Suspension	6.5	1.95	2.36	2.13
	11	61.3	32.1	6.43
	18	124	126	13.4

Although straw was not stable at the 11 or 18 m s^{-1} wind speeds, straw did reduce average total sediment loss as compared to the bare soil at 11m s^{-1}. One possible explanation for observing a reduction in soil loss at this wind speed is that there was a slight delay in the straw transport at 11 m s^{-1} compared to the nearly instantaneous loss of straw at 18 m s^{-1}. Straw elements were then able to absorb some of the initial momentum from the wind at 11 m s^{-1}, offering some protection to the soil surface during start-up of the wind tunnel.

Friction Velocity, the Roughness Parameter, and PM_{10} Vertical Flux

Friction velocity and the roughness parameter did not differ among the treatments at 6.5 m s^{-1} (Table 6). Friction velocity and the roughness parameter were different between the bare and wood strand treatments at 11 and 18 m s^{-1}, indicating differences in the surface roughness, and thus differences in friction at the wind-soil interface among the two treatments.

Table 6. Average friction velocity and roughness parameter for three surfaces at three wind speeds.[†]

Wind Speed (m s^{-1})	Bare	Straw[††]	Wood Strands
		Friction Velocity (m s^{-1})	
6.5	0.40^{a}	0.33^{a}	0.48^{a}
11	0.55^{a}	NA	0.90^{b}
18	0.34^{a}	NA	0.64^{b}
		Roughness Parameter (m)	
6.5	9.69×10^{-4a}	1.21×10^{-3a}	2.36×10^{-3a}
11	9.56×10^{-4a}	NA	3.18×10^{-3b}
18	1.62×10^{-5a}	NA	4.36×10^{-4b}

[†] a and b superscripts denote groupings of significant mean values within a wind speed.
[††] Friction velocity and the roughness parameter were not calculated for straw at 11 or 18 m s^{-1}.

Vertical flux is a function of both friction velocity and change in PM_{10} concentration with height as shown in Eq [12]. The dominant variable in this case, however, was the concentration gradient, which varied by orders of magnitude among the treatments. Unlike total sediment loss, there was a significant difference in PM_{10} vertical flux among the treatments at 6.5 m s^{-1}, with the straw and the wood strands being equally effective and resulting in significantly less vertical flux than the bare soil treatment. Vertical flux was also affected by percent cover of material applied. There were differences in flux between the bare and wood strands at both 50 and 70 percent cover; however, the straw was only effective in reducing vertical flux when applied at 70 percent cover. Although overall soil loss at the 6.5 m s^{-1} wind speed was low, these differences in PM_{10} vertical flux have implications for air quality, as the amount of PM_{10} emitted into the atmosphere can be reduced from a bare soil even at wind speeds near the threshold velocity of the soil. Vertical PM_{10} emissions from the bare soil were reduced by application of straw or wood strands on the surface, even at wind speeds near threshold velocity. The wood strands were equally effective in reducing vertical flux compared to the bare soil when applied at 50 or

70 percent cover at the 11 and 18 m s^{-1} wind speeds. The reduction in vertical flux between the bare soil and wood strand treatments was large at 11 and 18 m s^{-1}, and wood strand effectiveness in reducing vertical flux increased from 11 to 18 m s^{-1} (Figure 4b).

PM_{10} Loss

Little PM_{10} was lost from the three treatments at the 6.5 m s^{-1} wind speed (Fig. 4c). Although differences in PM_{10} vertical flux were found among all three treatments at 6.5 m s^{-1}, the lack of differences in PM_{10} loss is not surprising as loss was calculated for the entire five minute period. Vertical flux was determined for the initial 60 second period due to diminished emissions of PM_{10} with time (Fig. 2).

Wood strands and wheat straw both significantly reduced PM_{10} loss as compared to the bare soil at the 11 m s^{-1} wind speed, although the wood strands reduced loss significantly further than the straw (Fig. 4c). The straw became ineffective in reducing loss from a bare soil surface at the 18 m s^{-1} wind speed, while wood strands continued to reduce PM_{10} loss. The straw's diminishing effectiveness can be explained by the same reasoning as for the total sediment loss; that is, delayed movement of straw at the lower 11 m s^{-1} wind speed may have provided some initial protection to the bare soil surface, whereas instantaneous movement of straw at 18 m s^{-1} immediately exposed the soil surface to the forces of the wind.

Wood Strand Properties

The range of wood strand dimensions tested in this study was equally effective in reducing wind erosion. In terms of erosion reduction potential, wood strands were considerably more stable than straw, especially at the 18 m s^{-1} wind speed. Lack of differences in total sediment and PM_{10} loss between 50 and 70 percent cover of the wood strands suggests that lower coverages than those tested in this study may also be effective. Wood strands may be less stable on the soil surface at a lower percent cover, however, as material stability may be a function of cover due to material layering and interweaving. Layering increased with increasing percent cover because the wood strands did not evenly cover the ground surface, but rather lay on top of one another as more strands were applied. Layering thus disproportionately increased both depth of cover and effective surface roughness. Layering also appeared to increase wood strand stability by promoting interweaving of the materials.

CONCLUSIONS

Wood strands appear to be a viable wind erosion control alternative to agricultural straw. Wood strands reduced sediment loss and PM_{10} emissions from bare soil surfaces at wind speeds of up to 18 m s^{-1}, whereas agricultural straw only reduced sediment losses at the 11 m s^{-1} wind speed. Wood strands were more stable at higher wind speeds than the straw. Wood strand effectiveness was not affected by the range of dimensional characteristics tested in this study. Additional testing of wood strands at lower percent covers may be necessary to further investigate the cover-stability relationship of the wood strands. Wind tunnel testing with saltating agents used as abraders may also be of interest to explore the ability of the wood strands to prevent saltating grains from liberating erodible material from the soil surface. Further field-scale research may provide more insight into the erosion reduction efficacy of wood strands versus agricultural straw, as microtopography will also play a role in the performance of cover elements in the field.

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APPENDIX

Table A. Parameters measured for each treatment prior to and during wind tunnel testing. Dashes indicate missing data or parameters not measured for a particular treatment. "B" = bare, "S" = straw, "NL" = narrow, long wood strands, "NM" = narrow, mixture of long and short wood strands, "CL" = thick, long wood strands, "CM" = thick, mixture of long and short wood strands.

Treatment	Wind Speed (m/s)	Target Cover (%)	Measured Cover (%)	Cover Height (cm)	Matric Potential (MPa)	Creep (g/m^2)	Saltation and Suspension (g/m^2)	Background PM_{10} Concentration (mg/m^3)	Wind Speed (m/s)					
									Height Above Cover Surface (cm)					
									0.5	1	2	3	4	10
B	6.5	0	-	-	-64.75	0.00	2.13	0.05	2.21	2.78	3.09	3.40	3.56	4.20
B	6.5	0	-	-	-76.12	0.00	0.98	0.04	2.33	2.54	3.11	3.61	3.65	4.36
B	6.5	0	-	-	-69.24	0.00	6.00	0.12	2.30	2.94	3.05	3.52	3.76	4.16
B	6.5	0	-	-	-71.4	0.00	1.33	0.10	2.62	2.85	2.94	3.47	3.90	4.13
B	6.5	0	-	-	-77.76	0.00	0.53	0.08	2.13	2.89	3.32	3.73	4.15	4.31
B	6.5	0	-	-	-75.96	0.10	2.13	0.08	2.23	2.58	3.05	3.47	3.82	4.16
B	6.5	0	-	-	-74.57	0.00	1.24	0.07	2.22	2.91	3.14	3.49	3.82	4.08
B	6.5	0	-	-	-64.24	0.00	1.24	0.07	2.29	2.35	2.99	3.55	3.92	3.97
S	6.5	50	-	3.5	-84.79	0.00	2.62	0.04	3.44	3.32	3.15	3.56	3.60	4.11
S	6.5	50	-	3.0	-79.95	0.00	1.78	0.04	3.49	3.29	3.43	4.15	4.26	4.05
S	6.5	50	-	3.0	-61.56	0.00	0.89	0.07	2.65	2.57	2.69	3.45	3.69	4.14
S	6.5	50	-	2.0	-59.25	0.00	0.93	0.07	2.87	2.44	2.73	3.12	3.60	3.93
S	6.5	70	-	4.0	-67.54	0.00	3.78	0.05	3.85	4.08	3.80	4.38	4.28	4.19
S	6.5	70	-	3.0	-97	0.10	7.96	0.05	2.18	2.01	2.48	2.62	3.32	4.15
S	6.5	70	-	3.0	-76.78	0.00	0.18	0.08	3.37	3.11	3.60	3.80	4.03	4.13
S	6.5	70	-	3.5	-59.09	0.00	0.76	0.07	2.85	2.85	3.55	3.76	3.90	3.94
NL	6.5	50	-	1.5	-72.17	0.00	11.11	0.05	3.21	3.09	3.26	3.99	4.05	4.09
NL	6.5	50	-	1.5	-72.94	0.00	3.87	0.12	3.02	2.88	3.21	3.48	3.91	4.22
NL	6.5	50	-	2.0	-75.96	0.00	0.09	0.08	2.41	2.99	3.31	3.74	3.99	4.31
NL	6.5	50	-	-	-73.67	0.00	0.22	0.07	3.23	3.11	3.17	3.41	3.71	4.23
NM	6.5	50	-	1.5	-67.52	0.10	1.11	0.12	2.77	2.79	2.82	3.30	3.71	4.09
NM	6.5	50	-	1.5	-72.89	0.10	5.56	0.12	3.18	3.03	3.48	3.96	4.08	4.42
NM	6.5	50	-	1.5	-76.22	0.00	0.44	0.08	2.76	2.83	3.02	3.61	3.97	4.31
NM	6.5	50	-	1.5	-75.23	0.00	5.29	0.08	3.28	3.17	2.92	3.50	4.03	4.31
CL	6.5	50	-	2.5	-67.15	0.00	1.69	0.12	3.82	3.48	3.56	4.08	4.21	4.25
CL	6.5	50	-	2.5	-81.36	0.00	1.42	0.10	3.65	3.67	3.46	3.94	4.23	4.31
CL	6.5	50	-	2.5	-74.71	0.10	0.84	0.08	3.75	3.49	3.49	3.85	4.20	4.22

Treatment	Wind Speed (m/s)	Target Cover (%)	Measured Cover (%)	Cover Height (cm)	Matric Potential (MPa)	Creep (g/m^2)	Saltation and Suspension (g/m^2)	Background PM$_{10}$ Concentration (mg/m^3)	Wind Speed (m/s) Height Above Cover Surface (cm)					
									0.5	1	2	3	4	10
CL	6.5	50	-	2.5	-75.13	0.00	1.60	0.08	4.00	3.80	3.63	4.00	4.13	4.14
CM	6.5	50	-	2.0	-81.09	0.10	7.91	0.05	2.66	2.45	3.08	3.47	3.83	4.13
CM	6.5	50	-	2.5	-76.37	0.00	1.02	0.04	3.02	2.40	2.65	2.81	3.71	4.32
CM	6.5	50	-	2.0	-79.02	0.00	2.04	0.12	3.56	3.44	3.28	3.64	4.19	4.22
CM	6.5	50	-	2.5	-73.55	0.00	1.07	0.07	3.86	3.52	3.69	4.07	4.20	4.23
NL	6.5	70	-	2.5	-83.89	0.10	7.24	0.05	2.32	2.15	2.69	3.09	3.23	4.12
NL	6.5	70	-	3.0	-83.36	0.00	0.67	0.10	3.71	3.24	3.32	3.79	3.95	4.31
NL	6.5	70	-	2.0	-74.27	0.00	1.33	0.07	2.94	2.79	3.26	3.80	4.12	4.22
NL	6.5	70	-	2.0	-55.19	0.00	0.93	0.07	2.49	2.18	2.60	3.32	3.96	4.00
NM	6.5	70	-	2.0	-75.2	0.00	1.51	0.04	2.98	2.95	3.30	3.85	4.03	4.06
NM	6.5	70	-	1.5	-77.23	0.00	0.98	0.10	2.98	2.92	3.03	3.33	3.77	4.43
NM	6.5	70	-	1.5	-76.33	0.00	0.00	0.08	2.73	2.67	2.93	3.24	3.43	4.21
NM	6.5	70	-	1.5	-76.13	0.00	1.87	0.08	2.85	2.37	2.55	3.19	3.83	4.10
CL	6.5	70	-	3.0	-68.24	0.00	1.64	0.04	3.61	3.79	3.36	3.89	3.98	4.33
CL	6.5	70	-	3.0	-70.88	0.00	1.60	0.10	3.36	3.12	2.55	3.16	3.43	4.28
CL	6.5	70	-	4.0	-80.83	0.00	0.58	0.10	3.66	3.27	3.05	3.60	3.90	4.28
CL	6.5	70	-	4.0	-63.6	0.00	0.58	0.07	3.34	3.18	3.49	3.86	4.14	4.06
CM	6.5	70	-	2.5	-75.63	0.00	0.40	0.08	3.12	3.26	3.39	3.89	4.06	4.24
CM	6.5	70	-	2.5	-77.14	0.00	0.18	0.08	2.37	2.62	3.11	3.79	4.13	4.26
CM	6.5	70	-	3.0	-73.28	0.00	1.87	0.07	3.32	3.35	3.31	3.60	3.81	4.26
CM	6.5	70	-	2.5	-74.33	0.00	1.64	0.07	2.82	2.43	2.63	3.26	3.55	4.28
B	11	0	-	-	-76.12	0.60	57.93	0.05	5.47	4.65	4.14	5.25	5.45	7.44
B	11	0	-	-	-70.14	0.70	52.88	0.07	4.27	4.81	5.23	6.12	6.70	6.99
B	11	0	-	-	-55.32	3.80	58.56	0.18	4.44	5.00	5.28	5.82	6.43	6.80
B	11	0	-	-	-87.45	0.50	71.54	0.07	3.76	4.05	4.92	6.15	6.37	6.86
B	11	0	-	-	-63.14	0.20	54.42	0.08	2.28	3.85	5.39	5.99	6.45	6.79
B	11	0	-	-	-75.81	1.00	92.84	0.08	4.37	4.63	4.96	5.46	6.28	6.88
B	11	0	-	-	-80.03	1.70	73.65	0.05	4.25	4.55	4.92	5.50	6.25	6.66
B	11	0	-	-	-90.7	2.70	28.88	0.06	4.12	4.76	4.86	5.83	6.49	6.61
S	11	50	-	4.0	-55.59	1.40	36.98	0.18	7.94	6.45	6.37	5.65	6.63	6.23
S	11	50	-	2.5	-64.8	3.40	26.91	0.08	2.33	3.98	-	5.64	4.01	7.08

Treatment	Wind Speed (m/s)	Target Cover (%)	Measured Cover (%)	Cover Height (cm)	Matric Potential (MPa)	Creep (g/m^2)	Saltation and Suspension (g/m^2)	Background PM_{10} Concentration (mg/m^3)	Wind Speed (m/s)					
									Height Above Cover Surface (cm)					
									0.5	1	2	3	4	10
S	11	50	-	3.0	-72.51	5.90	44.56	0.07	3.71	4.39	6.58	6.11	8.07	6.34
S	11	50	-	2.5	-84.28	2.90	19.33	0.06	1.75	1.18	3.72	3.71	-	6.93
S	11	70	-	3.5	-79.81	2.80	46.81	0.07	5.85	5.25	2.30	8.36	8.39	8.53
S	11	70	-	4.0	-62.47	4.10	33.47	0.18	8.22	7.60	6.38	8.32	8.16	7.95
S	11	70	-	3.5	-80.02	3.20	23.33	0.06	5.89	5.70	6.53	7.21	8.59	6.94
S	11	70	-	3.0	-82.26	2.90	25.65	0.06	4.22	2.62	3.23	7.00	4.23	7.19
NL	11	50	-	2.5	-69.14	0.00	5.05	0.07	6.08	5.88	5.71	6.51	7.01	7.19
NL	11	50	-	2.0	-78.62	0.00	13.16	0.07	4.95	5.13	5.06	6.48	6.84	7.17
NL	11	50	-	2.5	-68.4	0.00	7.37	0.07	5.97	5.59	6.19	6.54	6.91	7.16
NL	11	50	-	2.5	-76.12	0.00	2.81	0.05	5.87	6.32	6.27	6.12	6.79	6.76
NM	11	50	-	1.5	-72.71	0.10	7.72	0.05	4.93	5.82	5.85	6.25	6.80	7.02
NM	11	50	-	1.5	-67.2	0.00	8.91	0.05	6.15	5.98	5.60	6.56	6.87	7.16
NM	11	50	-	1.5	-82.53	0.00	5.26	0.07	4.43	4.75	4.95	5.87	6.58	6.76
NM	11	50	-	1.5	-84.68	0.10	2.77	0.07	4.20	3.27	4.40	6.50	7.03	7.05
CL	11	50	-	2.5	-70.61	0.10	9.72	0.05	4.92	4.91	5.00	6.45	6.76	7.05
CL	11	50	-	2.5	-80.68	0.00	4.42	0.07	4.90	5.17	4.81	6.02	6.61	7.05
CL	11	50	-	3.0	-81.57	0.10	3.75	0.07	5.80	5.89	5.84	6.54	7.04	6.96
CL	11	50	-	2.5	-81.12	0.00	8.39	0.05	5.25	5.54	5.15	5.93	6.07	6.89
CM	11	50	-	2.5	-70.5	0.00	9.75	0.05	5.30	5.47	5.64	6.59	6.91	7.17
CM	11	50	-	2.5	-59.48	0.00	3.75	0.18	5.51	5.45	6.16	6.47	7.06	6.76
CM	11	50	-	2.5	-64.12	0.10	3.89	0.08	5.64	5.60	5.50	6.24	6.71	6.69
CM	11	50	-	2.5	-60.54	0.00	5.54	0.08	4.92	4.07	5.10	5.49	5.89	6.74
NL	11	70	-	2.5	-64.67	0.00	2.98	0.18	5.97	5.36	3.76	5.85	6.02	6.91
NL	11	70	-	2.0	-61.02	0.00	3.05	0.08	3.83	4.32	4.72	5.86	6.20	6.70
NL	11	70	-	3.0	-77.2	0.00	6.14	0.08	6.20	6.42	6.33	6.31	7.01	6.67
NL	11	70	-	2.5	-76.97	0.00	6.53	0.08	4.80	5.27	5.14	5.67	5.96	6.78
NM	11	70	-	2.5	-67.3	0.00	2.07	0.08	5.51	4.46	6.13	6.10	6.83	6.72
NM	11	70	-	2.0	-72.51	0.10	13.51	0.08	4.22	4.66	4.60	5.66	5.98	6.56
NM	11	70	-	2.0	-73.99	0.00	13.82	0.08	4.16	4.30	5.21	5.98	6.31	6.76
NM	11	70	-	2.5	-78.13	0.00	4.98	0.06	5.13	4.93	4.98	6.10	6.66	6.78
CL	11	70	-	3.5	-51.81	0.00	8.42	0.18	5.17	4.77	4.60	6.56	6.99	6.93

Treatment	Wind Speed (m/s)	Target Cover (%)	Measured Cover (%)	Cover Height (cm)	Matric Potential (MPa)	Creep (g/m^2)	Saltation and Suspension (g/m^2)	Background PM$_{10}$ Concentration (mg/m^3)	Wind Speed (m/s)					
									Height Above Cover Surface (cm)					
									0.5	1	2	3	4	10
CL	11	70	-	3.5	-78.95	0.00	2.18	0.07	5.64	4.87	5.57	6.51	6.64	7.02
CL	11	70	-	3.5	-72.92	0.00	5.26	0.05	5.42	6.01	6.10	6.56	6.99	6.87
CL	11	70	-	3.5	-76.2	0.00	4.32	0.05	5.07	5.59	4.88	5.91	6.08	6.71
CM	11	70	-	3.0	-71.67	0.00	15.96	0.05	4.39	5.50	4.90	6.11	6.41	7.31
CM	11	70	-	3.0	-71.9	0.00	4.25	0.07	5.17	5.18	4.97	5.93	6.36	7.02
CM	11	70	-	3.0	-86.23	0.00	5.23	0.05	5.23	5.23	5.55	6.26	6.48	6.95
CM	11	70	-	2.5	-78.82	0.00	4.77	0.06	4.97	5.44	5.17	5.90	6.55	6.97
B	18	0	-	-	-87	3.81	110.67	0.23	5.57	6.66	7.24	-	7.48	-
B	18	0	-	-	-62.96	0.48	46.22	0.06	6.18	7.45	7.98	-	0.00	-
B	18	0	-	-	-96.97	1.41	147.56	0.11	6.06	7.19	7.62	-	7.78	-
B	18	0	-	-	-116.27	4.9	128.89	0.10	5.28	6.64	7.48	-	7.65	-
B	18	0	-	-	-93.34	0.95	105.78	0.23	6.00	7.00	7.31	-	7.74	-
B	18	0	-	-	-129.13	3.52	184.44	0.13	6.26	7.52	7.83	-	8.04	-
B	18	0	-	-	-129.35	2.87	136.44	0.45	5.84	7.08	7.25	-	7.46	-
B	18	0	-	-	-130.04	4.58	131.56	0.30	5.40	6.67	7.40	-	9.97	-
S	18	50	46.5	2.0	-62.82	5.99	39.11	0.06	4.01	2.06	7.78	-	8.04	-
S	18	50	47.2	2.0	-130.22	5.91	149.33	0.45	4.14	7.41	7.46	-	8.75	-
S	18	50	48.6	2.0	-132.82	5.09	120.00	0.45	7.42	7.52	8.05	-	6.87	-
S	18	50	50.0	2.5	-113.67	4.76	98.22	0.30	8.89	9.28	9.12	-	10.87	-
S	18	70	68.8	3.5	-59.64	2.45	36.00	0.06	4.41	4.77	5.42	-	10.71	-
S	18	70	69.4	2.5	-92.26	4.4	147.56	0.11	1.79	9.82	9.08	-	9.67	-
S	18	70	68.1	3.0	-115.73	13.4	333.33	0.10	5.55	3.00	5.82		9.70	-
S	18	70	68.1	3.0	-131.46	7.74	81.33	0.30	2.89	8.56	8.90		9.38	-
NL	18	50	52.1	2.0	-61.43	0.16	4.44	0.06	5.06	6.09	7.38		8.34	-
NL	18	50	47.9	2.0	-113.32	0.2	17.78	0.10	6.81	7.61	8.41		8.57	-
NL	18	50	50.0	1.5	-109.63	0.15	14.22	0.23	6.04	6.94	8.09		8.49	-
NL	18	50	52.8	1.5	-135.81	0.64	8.89	0.13	6.21	7.17	8.27		8.86	-
NM	18	50	48.3	1.0	-66.34	0.17	7.11	0.06	5.98	7.47	8.11		8.89	-
NM	18	50	49.0	1.0	-107.52	0.27	16.89	0.23	5.92	6.76	7.85		8.13	-
NM	18	50	50.7	1.0	-132.2	0.1	13.33	0.30	3.84	4.91	6.42		7.59	-
NM	18	50	52.8	1.0	-130.87	0.21	13.33	0.30	5.06	6.14	7.36		5.17	-

Treatment	Wind Speed (m/s)	Target Cover (%)	Measured Cover (%)	Cover Height (cm)	Matric Potential (MPa)	Creep (g/m^2)	Saltation and Suspension (g/m^2)	Background PM$_{10}$ Concentration (mg/m^3)	Wind Speed (m/s)					
									Height Above Cover Surface (cm)					
									0.5	1	2	3	4	10
CL	18	50	49.3	2.5	-88.07	0.26	14.67	0.23	6.18	6.67	7.52		8.03	-
CL	18	50	49.3	2.5	-101.99	0.06	12.89	0.11	6.38	7.40	7.91		8.51	-
CL	18	50	54.9	2.5	-111.4	0.45	12.89	0.23	5.76	6.09	7.42		8.16	-
CL	18	50	52.1	2.5	-132.74	0.29	12.44	0.30	4.37	5.59	6.13		7.46	-
CM	18	50	55.2	2.5	-87.43	0.1	5.33	0.23	7.23	7.85	8.06		8.35	-
CM	18	50	46.2	2.0	-67.6	0.17	7.11	0.06	7.02	7.58	8.47		8.86	-
CM	18	50	50.0	2.0	-111.54	0.4	17.78	0.10	6.90	7.88	8.31		8.84	-
CM	18	50	54.2	2.0	-129.61	0	100.89	0.13	6.15	7.23	8.04		8.93	-
NL	18	70	67.4	2.0	-86.97	0.06	4.89	0.23	5.67	6.85	7.44		7.95	-
NL	18	70	66.3	2.5	-88.7	0.12	6.22	0.23	6.76	7.24	8.45		8.65	-
NL	18	70	66.7	2.0	-100.41	0.14	7.11	0.11	6.43	7.63	7.88		8.27	-
NL	18	70	75.0	2.0	-129.92	0.07	10.22	0.13	5.61	6.91	7.66		8.62	-
NM	18	70	70.5	1.5	-123.19	0.1	17.78	0.10	4.73	5.97	6.66		7.81	-
NM	18	70	65.3	1.5	-108.75	0.05	11.11	0.23	5.62	6.55	7.64		7.93	-
NM	18	70	70.1	2.0	-126.85	0.04	11.56	0.13	3.84	4.91	6.42		7.59	-
NM	18	70	71.5	1.5	-125.84	0.05	4.00	0.30	4.99	6.13	7.16		8.12	-
CL	18	70	66.7	3.0	-93.13	0.05	10.22	0.11	4.04	5.24	6.02		6.97	-
CL	18	70	66.0	3.0	-112.08	0.28	0.89	0.23	5.22	5.86	5.78		6.72	-
CL	18	70	66.0	3.0	-131.51	0	8.89	0.13	4.74	5.67	6.66		6.22	-
CL	18	70	67.4	3.0	-128.07	0.28	20.89	0.45	4.59	5.74	6.01		7.11	-
CM	18	70	63.9	3.0	-87.61	-	5.78	0.23	6.04	7.35	7.61		8.30	-
CM	18	70	66.0	2.5	-95.88	0.31	12.89	0.11	5.17	6.48	7.20		7.89	-
CM	18	70	66.0	2.5	-120.89	0.1	8.89	0.10	5.35	6.92	7.18		7.65	-
CM	18	70	70.1	2.5	-131.02	0.04	8.00	0.30	5.75	6.52	7.79		8.58	-

Table B. Measured and corrected PM_{10} concentrations over time at several heights above the soil surface. Data shown here are for a bare treatment at 6.5 m/s. Concentrations are reported in mg/m^3. “Raw” = measured concentration, “clean” = corrected concentration, and “ND” indicates missing data. Remaining data can be found in the attached CD under “appendix_b.”

	Bare-1											
	0.5 cm		1 cm		2 cm		3 cm		4 cm		10 cm	
Time (s)	raw	clean	raw	clean	raw	clean	raw	clean	raw	clean	raw	clean
1	0.006	0.006	0.012	0.012	0.002	0.002	0.084	0.084	0.02	0.02	0.003	0.003
2	0.017	0.017	0.096	0.096	0.078	0.078	0.237	0.237	0.219	0.219	0.01	0.01
3	0.759	0.759	0.313	0.313	0.751	0.751	0.615	0.615	0.117	0.117	0.061	0.061
4	12.142	12.142	7.925	7.925	2.407	2.407	0.16	0.16	0.152	0.152	0.043	0.043
5	5.011	5.011	2.582	2.582	0.448	0.448	0.166	0.166	0.058	0.058	0.052	0.052
6	15.228	15.228	0.853	0.853	0.698	0.698	0.542	0.542	0.127	0.127	0.117	0.117
7	1.116	1.116	0.416	0.416	0.111	0.111	0.242	0.242	0.118	0.118	0.07	0.07
8	1.245	1.245	0.422	0.422	0.178	0.178	0.101	0.101	0.08	0.08	0.063	0.063
9	0.479	0.479	0.282	0.282	0.151	0.151	0.094	0.094	0.07	0.07	0.051	0.051
10	3.733	3.733	0.707	0.707	0.273	0.273	0.08	0.08	0.055	0.055	0.025	0.025
11	0.367	0.367	0.198	0.198	0.156	0.156	0.035	0.035	0.057	0.057	0.033	0.033
12	0.318	0.318	0.326	0.326	0.334	0.334	0.05	0.05	0.038	0.038	0.055	0.055
13	0.199	0.199	0.149	0.149	0.221	0.221	0.104	0.104	0.063	0.063	0.052	0.052
14	0.254	0.254	0.17	0.17	0.172	0.172	0.06	0.06	0.063	0.063	0.056	0.056
15	2.55	2.55	0.603	0.603	0.138	0.138	0.078	0.078	0.057	0.057	0.051	0.051
16	0.368	0.368	0.721	0.721	0.787	0.787	0.075	0.075	0.107	0.107	0.054	0.054
17	0.965	0.965	0.218	0.218	0.085	0.085	0.118	0.118	0.052	0.052	0.055	0.055
18	1.071	1.071	0.111	0.111	0.063	0.063	0.074	0.074	0.079	0.079	0.033	0.033
19	0.412	0.412	0.156	0.156	0.122	0.122	0.057	0.057	0.036	0.036	0.05	0.05
20	0.404	0.404	0.07	0.07	0.056	0.056	0.069	0.069	0.054	0.054	0.061	0.061
21	0.085	0.085	0.094	0.094	0.044	0.044	0.057	0.057	0.088	0.088	0.05	0.05
22	0.113	0.113	0.085	0.085	0.074	0.074	0.065	0.065	0.116	0.116	0.062	0.062
23	0.091	0.091	0.093	0.093	0.062	0.062	0.095	0.095	0.081	0.081	0.05	0.05
24	0.152	0.152	0.128	0.128	0.096	0.096	0.09	0.09	0.053	0.053	0.044	0.044
25	0.129	0.129	0.18	0.18	0.056	0.056	0.068	0.068	0.051	0.051	0.043	0.043
26	0.177	0.177	0.096	0.096	0.046	0.046	0.046	0.046	0.053	0.053	0.062	0.062
27	0.092	0.092	0.133	0.133	0.085	0.085	0.054	0.054	0.047	0.047	0.048	0.048
28	0.077	0.077	0.075	0.075	0.053	0.053	0.064	0.064	0.054	0.054	0.049	0.049
29	0.072	0.072	0.077	0.077	0.066	0.066	0.046	0.046	0.093	0.093	0.054	0.054
30	0.06	0.0600	0.09	0.09	0.052	0.052	0.065	0.065	0.061	0.061	0.045	0.045
31	0.185	0.1850	0.222	0.222	0.058	0.058	0.053	0.053	0.05	0.05	0.043	0.043
32	0.095	0.0950	0.107	0.107	0.096	0.096	0.049	0.049	0.045	0.045	0.071	0.071
33	0.231	0.2310	0.056	0.056	0.058	0.058	0.044	0.044	0.069	0.069	0.05	0.05
34	0.934	0.9340	0.076	0.076	0.052	0.052	0.096	0.096	0.057	0.057	0.048	0.048
35	0.094	0.0940	0.103	0.103	0.112	0.112	0.054	0.054	0.057	0.057	0.062	0.062
36	0.543	0.5430	0.352	0.352	0.09	0.09	0.059	0.059	0.067	0.067	0.056	0.056
37	1.273	1.2730	0.135	0.135	0.084	0.084	0.065	0.065	0.061	0.061	0.069	0.069
38	0.128	0.1280	0.112	0.112	0.081	0.081	0.068	0.068	0.055	0.055	0.062	0.062
39	0.092	0.0920	0.107	0.107	0.059	0.059	0.06	0.06	0.061	0.061	0.063	0.063
40	0.071	0.0710	0.089	0.089	0.142	0.142	0.054	0.054	0.076	0.076	0.07	0.07
41	0.874	0.8740	0.161	0.161	0.095	0.095	0.054	0.054	0.063	0.063	0.057	0.057
42	0.152	0.1520	0.098	0.098	0.078	0.078	0.07	0.07	0.053	0.053	0.053	0.053

	Bare-1											
	0.5 cm		1 cm		2 cm		3 cm		4 cm		10 cm	
Time (s)	raw	clean	raw	clean	raw	clean	raw	clean	raw	clean	raw	clean
43	0.12	0.1200	0.081	0.081	0.066	0.066	0.057	0.057	0.063	0.063	0.085	0.085
44	0.057	0.0570	0.071	0.071	0.072	0.072	0.075	0.075	0.07	0.07	0.074	0.074
45	0.064	0.0640	0.078	0.078	0.066	0.066	0.077	0.077	0.076	0.076	0.056	0.056
46	0.254	0.2540	0.128	0.128	0.101	0.101	0.073	0.073	0.087	0.087	0.063	0.063
47	0.092	0.0920	0.095	0.095	0.07	0.07	0.087	0.087	0.064	0.064	0.073	0.073
48	0.146	0.1460	0.089	0.089	0.164	0.164	0.085	0.085	0.078	0.078	0.065	0.065
49	0.099	0.0990	0.1	0.1	0.068	0.068	0.109	0.109	0.094	0.094	0.092	0.092
50	0.078	0.0780	0.148	0.148	0.148	0.148	0.103	0.103	0.064	0.064	0.083	0.083
51	0.105	0.1050	0.148	0.148	0.115	0.115	0.067	0.067	0.078	0.078	0.063	0.063
52	0.089	0.0890	0.088	0.088	0.096	0.096	0.07	0.07	0.066	0.066	0.043	0.043
53	0.157	0.1570	0.09	0.09	0.066	0.066	0.057	0.057	0.046	0.046	0.039	0.039
54	0.928	0.1165	0.068	0.068	0.048	0.048	0.019	0.019	0.022	0.022	0.038	0.038
55	0.076	0.0760	0.062	0.062	0.034	0.034	0.025	0.025	0.042	0.042	0.046	0.046
56	0.065	0.0650	0.042	0.042	0.024	0.024	0.049	0.049	0.045	0.045	0.05	0.05
57	0.06	0.0600	0.056	0.056	0.068	0.068	0.044	0.044	0.054	0.054	0.042	0.042
58	0.064	0.0640	0.058	0.058	0.053	0.053	0.056	0.056	0.039	0.039	0.036	0.036
59	0.073	0.0730	0.07	0.07	0.056	0.056	0.029	0.029	0.052	0.052	0.071	0.071
60	0.052	0.0520	0.052	0.052	0.029	0.029	0.084	0.084	0.072	0.072	0.05	0.05
61	0.047	0.0470	0.073	0.073	0.071	0.071	0.057	0.057	0.053	0.053	0.043	0.043
62	0.081	0.0810	0.101	0.101	0.058	0.058	0.044	0.044	0.058	0.058	0.064	0.064
63	0.055	0.0550	0.087	0.087	0.046	0.046	0.07	0.07	0.07	0.07	0.063	0.063
64	0.055	0.0550	0.081	0.081	0.063	0.063	0.077	0.077	0.107	0.107	0.06	0.06
65	0.073	0.0730	0.086	0.086	0.083	0.083	0.074	0.074	0.065	0.065	0.061	0.061
66	0.089	0.0890	0.07	0.07	0.054	0.054	0.06	0.06	0.068	0.068	0.047	0.047
67	0.071	0.0710	0.076	0.076	0.062	0.062	0.049	0.049	0.042	0.042	0.018	0.018
68	0.081	0.0810	0.067	0.067	0.068	0.068	0.024	0.024	0.017	0.017	0.027	0.027
69	0.077	0.0770	0.085	0.085	0.019	0.019	0.029	0.029	0.032	0.032	0.045	0.045
70	0.026	0.0260	0.029	0.029	0.037	0.037	0.049	0.049	0.038	0.038	0.038	0.038
71	0.058	0.0580	0.06	0.06	0.05	0.05	0.04	0.04	0.053	0.053	0.037	0.037
72	0.264	0.0495	0.062	0.062	0.051	0.051	0.037	0.037	0.041	0.041	0.039	0.039
73	0.041	0.0410	0.067	0.067	0.038	0.038	0.051	0.051	0.045	0.045	0.035	0.035
74	0.086	0.0860	0.049	0.049	0.04	0.04	0.046	0.046	0.034	0.034	0.072	0.072
75	0.063	0.0630	0.053	0.053	0.033	0.033	0.052	0.052	0.087	0.087	0.07	0.07
76	0.086	0.0860	0.121	0.121	0.08	0.08	0.079	0.079	0.096	0.096	0.071	0.071
77	0.072	0.0720	0.095	0.095	0.081	0.081	0.074	0.074	0.099	0.099	0.054	0.054
78	0.104	0.1040	0.097	0.097	0.088	0.088	0.076	0.076	0.052	0.052	0.038	0.038
79	0.08	0.0800	0.122	0.122	0.064	0.064	0.021	0.021	0.013	0.013	0.02	0.02
80	0.064	0.0640	0.08	0.08	0.032	0.032	0.013	0.013	0.029	0.029	0.017	0.017
81	0.027	0.0270	0.04	0.04	0.049	0.049	0.026	0.026	0.018	0.018	0.039	0.039
82	0.028	0.0280	0.034	0.034	0.021	0.021	0.046	0.046	0.061	0.061	0.022	0.022
83	0.022	0.0220	0.036	0.036	0.03	0.03	0.02	0.02	0.017	0.017	0.022	0.022
84	0.089	0.0890	0.059	0.059	0.026	0.026	0.014	0.014	0.032	0.032	0.032	0.032
85	0.096	0.0960	0.027	0.027	0.019	0.019	0.023	0.023	0.037	0.037	0.048	0.048
86	0.043	0.0430	0.036	0.036	0.027	0.027	0.03	0.03	0.058	0.058	0.058	0.058
87	0.033	0.0330	0.097	0.097	0.037	0.037	0.047	0.047	0.086	0.086	0.038	0.038
88	0.115	0.1150	0.077	0.077	0.095	0.095	0.076	0.076	0.056	0.056	0.028	0.028
89	0.102	0.1020	0.122	0.122	0.063	0.063	0.036	0.036	0.031	0.031	0.025	0.025

	Bare-1											
	0.5 cm		1 cm		2 cm		3 cm		4 cm		10 cm	
Time (s)	raw	clean	raw	clean	raw	clean	raw	clean	raw	clean	raw	clean
90	0.115	0.1150	0.061	0.061	0.032	0.032	0.027	0.027	0.025	0.025	0.024	0.024
91	0.073	0.0730	0.039	0.039	0.069	0.069	0.017	0.017	0.029	0.029	0.041	0.041
92	0.056	0.0560	0.033	0.033	0.026	0.026	0.048	0.048	0.06	0.06	0.049	0.049
93	0.034	0.0340	0.031	0.031	0.046	0.046	0.109	0.109	0.113	0.113	0.06	0.06
94	0.056	0.0560	0.111	0.111	0.087	0.087	0.053	0.053	0.058	0.058	0.043	0.043
95	0.124	0.1240	0.077	0.077	0.08	0.08	0.059	0.059	0.058	0.058	0.053	0.053
96	0.078	0.0780	0.055	0.055	0.046	0.046	0.045	0.045	0.107	0.107	0.048	0.048
97	0.11	0.1100	0.102	0.102	0.038	0.038	0.036	0.036	0.045	0.045	0.026	0.026
98	0.071	0.0710	0.041	0.041	0.059	0.059	0.029	0.029	0.05	0.05	0.064	0.064
99	0.05	0.0500	0.071	0.071	0.033	0.033	0.044	0.044	0.053	0.053	0.066	0.066
100	0.046	0.0460	0.043	0.043	0.06	0.06	0.094	0.094	0.06	0.06	0.061	0.061
101	0.057	0.0570	0.059	0.059	0.074	0.074	0.07	0.07	0.053	0.053	0.082	0.082
102	0.083	0.0830	0.097	0.097	0.062	0.062	0.07	0.07	0.08	0.08	0.067	0.067
103	0.086	0.0860	0.088	0.088	0.066	0.066	0.076	0.076	0.089	0.089	0.069	0.069
104	0.126	0.1260	0.124	0.124	0.086	0.086	0.061	0.061	0.057	0.057	0.044	0.044
105	0.091	0.0910	0.085	0.085	0.085	0.085	0.045	0.045	0.043	0.043	0.042	0.042
106	0.16	0.1600	0.068	0.068	0.053	0.053	0.034	0.034	0.05	0.05	0.04	0.04
107	0.051	0.0510	0.072	0.072	0.071	0.071	0.054	0.054	0.041	0.041	0.061	0.061
108	0.043	0.0430	0.054	0.054	0.036	0.036	0.062	0.062	0.057	0.057	0.069	0.069
109	0.056	0.0560	0.065	0.065	0.066	0.066	0.062	0.062	0.053	0.053	0.031	0.031
110	0.075	0.0750	0.07	0.07	0.059	0.059	0.046	0.046	0.035	0.035	0.052	0.052
111	1.878	0.0675	0.061	0.061	0.045	0.045	0.046	0.046	0.049	0.049	0.07	0.07
112	0.06	0.0600	0.052	0.052	0.037	0.037	0.059	0.059	0.06	0.06	0.06	0.06
113	0.062	0.0620	0.065	0.065	0.08	0.08	0.076	0.076	0.06	0.06	0.078	0.078
114	0.171	0.1710	0.068	0.068	0.076	0.076	0.053	0.053	0.049	0.049	0.067	0.067
115	0.096	0.0960	0.081	0.081	0.047	0.047	0.056	0.056	0.073	0.073	0.059	0.059
116	0.068	0.0680	0.052	0.052	0.067	0.067	0.051	0.051	0.065	0.065	0.072	0.072
117	0.088	0.0880	0.076	0.076	0.047	0.047	0.066	0.066	0.064	0.064	0.062	0.062
118	0.06	0.0600	0.079	0.079	0.063	0.063	0.057	0.057	0.065	0.065	0.082	0.082
119	0.074	0.0740	0.075	0.075	0.064	0.064	0.086	0.086	0.077	0.077	0.075	0.075
120	0.105	0.1050	0.068	0.068	0.076	0.076	0.096	0.096	0.101	0.101	0.083	0.083
121	0.085	0.0850	0.093	0.093	0.095	0.095	0.079	0.079	0.084	0.084	0.073	0.073
122	0.268	0.2680	0.097	0.097	0.088	0.088	0.078	0.078	0.078	0.078	0.091	0.091
123	0.188	0.1880	0.109	0.109	0.088	0.088	0.082	0.082	0.1	0.1	0.12	0.12
124	0.14	0.1400	0.101	0.101	0.081	0.081	0.115	0.115	0.109	0.109	0.117	0.117
125	0.102	0.1020	0.107	0.107	0.146	0.146	0.129	0.129	0.127	0.127	0.274	0.274
126	0.147	0.1470	0.124	0.124	0.141	0.141	0.208	0.208	0.253	0.253	0.211	0.211
127	0.147	0.1470	0.137	0.137	0.181	0.181	0.124	0.124	0.166	0.166	0.111	0.111
128	0.394	0.3940	0.171	0.171	0.223	0.223	0.22	0.22	0.111	0.111	0.071	0.071
129	0.178	0.1780	0.137	0.137	0.376	0.376	0.099	0.099	0.082	0.082	0.081	0.081
130	0.206	0.2060	0.203	0.203	0.085	0.085	0.064	0.064	0.045	0.045	0.047	0.047
131	0.111	0.1110	0.071	0.071	0.045	0.045	0.045	0.045	0.043	0.043	0.035	0.035
132	0.064	0.0640	0.133	0.133	0.041	0.041	0.046	0.046	0.04	0.04	0.025	0.025
133	0.079	0.0790	0.057	0.057	0.044	0.044	0.027	0.027	0.027	0.027	0.024	0.024
134	0.047	0.0470	0.042	0.042	0.026	0.026	0.031	0.031	0.036	0.036	0.04	0.04
135	0.032	0.0320	0.054	0.054	0.014	0.014	0.041	0.041	0.045	0.045	0.041	0.041
136	0.031	0.0310	0.035	0.035	0.049	0.049	0.059	0.059	0.036	0.036	0.033	0.033

	Bare-1											
	0.5 cm		1 cm		2 cm		3 cm		4 cm		10 cm	
Time (s)	raw	clean	raw	clean	raw	clean	raw	clean	raw	clean	raw	clean
137	0.066	0.0660	0.081	0.081	0.067	0.067	0.03	0.03	0.046	0.046	0.041	0.041
138	0.064	0.0640	0.046	0.046	0.028	0.028	0.036	0.036	0.036	0.036	0.036	0.036
139	0.047	0.0470	0.083	0.083	0.062	0.062	0.044	0.044	0.048	0.048	0.039	0.039
140	0.05	0.0500	0.048	0.048	0.031	0.031	0.042	0.042	0.044	0.044	0.046	0.046
141	0.043	0.0430	0.054	0.054	0.046	0.046	0.038	0.038	0.057	0.057	0.052	0.052
142	0.05	0.0500	0.067	0.067	0.041	0.041	0.06	0.06	0.045	0.045	0.053	0.053
143	0.054	0.0540	0.061	0.061	0.053	0.053	0.058	0.058	0.048	0.048	0.031	0.031
144	0.064	0.0640	0.06	0.06	0.05	0.05	0.031	0.031	0.026	0.026	0.023	0.023
145	0.067	0.0670	0.06	0.06	0.035	0.035	0.024	0.024	0.017	0.017	0.018	0.018
146	0.031	0.0310	0.035	0.035	0.031	0.031	0.015	0.015	0.015	0.015	0.009	0.009
147	0.025	0.0250	0.045	0.045	0.028	0.028	0.021	0.021	0.011	0.011	0.004	0.004
148	0.02	0.0200	0.026	0.026	0.023	0.023	0.003	0.003	0.006	0.006	0.007	0.007
149	0.01	0.0100	0.017	0.017	0.004	0.004	0.003	0.003	0.008	0.008	0.008	0.008
150	0.023	0.0230	0.013	0.013	0.006	0.006	0.006	0.006	0.013	0.013	0.022	0.022
151	0.008	0.0080	0.013	0.013	0.025	0.025	0.024	0.024	0.027	0.027	0.032	0.032
152	0.023	0.0230	0.098	0.098	0.019	0.019	0.035	0.035	0.03	0.03	0.031	0.031
153	0.026	0.0260	0.03	0.03	0.04	0.04	0.039	0.039	0.032	0.032	0.029	0.029
154	0.038	0.0380	0.045	0.045	0.024	0.024	0.033	0.033	0.032	0.032	0.02	0.02
155	0.039	0.0390	0.041	0.041	0.03	0.03	0.012	0.012	0.02	0.02	0.036	0.036
156	0.036	0.0360	0.063	0.063	0.014	0.014	0.026	0.026	0.04	0.04	0.043	0.043
157	0.021	0.0210	0.029	0.029	0.029	0.029	0.051	0.051	0.037	0.037	0.022	0.022
158	0.047	0.0470	0.046	0.046	0.043	0.043	0.032	0.032	0.043	0.043	0.018	0.018
159	0.048	0.0480	0.054	0.054	0.046	0.046	0.018	0.018	0.023	0.023	0.021	0.021
160	0.027	0.0270	0.032	0.032	0.016	0.016	0.018	0.018	0.021	0.021	0.019	0.019
161	0.052	0.0520	0.034	0.034	0.02	0.02	0.016	0.016	0.025	0.025	0.027	0.027
162	0.029	0.0290	1.559	0.033	0.02	0.02	0.033	0.033	0.027	0.027	0.021	0.021
163	0.025	0.0250	0.032	0.032	0.027	0.027	0.024	0.024	0.023	0.023	0.027	0.027
164	0.035	0.0350	0.043	0.043	0.022	0.022	0.025	0.025	0.048	0.048	0.019	0.019
165	0.033	0.0330	0.09	0.09	0.038	0.038	0.02	0.02	0.012	0.012	0.009	0.009
166	0.034	0.0340	0.032	0.032	0.019	0.019	0.006	0.006	0.012	0.012	0.01	0.01
167	0.02	0.0200	0.021	0.021	0.008	0.008	0.011	0.011	0.009	0.009	0.021	0.021
168	0.014	0.0140	0.018	0.018	0.012	0.012	0.013	0.013	0.02	0.02	0.024	0.024
169	0.011	0.0110	0.018	0.018	0.015	0.015	0.021	0.021	0.019	0.019	0.008	0.008
170	0.024	0.0240	0.034	0.034	0.023	0.023	0.009	0.009	0.009	0.009	0.021	0.021
171	0.024	0.0240	0.028	0.028	0.008	0.008	0.013	0.013	0.018	0.018	0.027	0.027
172	0.01	0.0100	0.016	0.016	0.013	0.013	0.027	0.027	0.022	0.022	0.019	0.019
173	0.023	0.0230	0.028	0.028	0.03	0.03	0.018	0.018	0.015	0.015	0.017	0.017
174	0.023	0.0230	0.03	0.03	0.021	0.021	0.012	0.012	0.019	0.019	0.013	0.013
175	0.026	0.0260	0.026	0.026	0.017	0.017	0.013	0.013	0.012	0.012	0.016	0.016
176	0.024	0.0240	0.024	0.024	0.021	0.021	0.01	0.01	0.012	0.012	0.017	0.017
177	0.017	0.0170	0.019	0.019	0.009	0.009	0.012	0.012	0.019	0.019	0.026	0.026
178	0.014	0.0140	0.035	0.035	0.015	0.015	0.021	0.021	0.032	0.032	0.188	0.188
179	0.019	0.0190	0.027	0.027	0.022	0.022	0.031	0.031	0.028	0.028	0.025	0.025
180	0.034	0.0340	0.041	0.041	0.031	0.031	0.022	0.022	0.028	0.028	0.049	0.049
181	0.03	0.0300	0.062	0.062	0.328	0.042	0.043	0.043	0.056	0.056	0.121	0.121
182	0.043	0.0430	0.039	0.039	0.053	0.053	0.069	0.069	0.085	0.085	0.096	0.096
183	0.09	0.0900	0.074	0.074	0.083	0.083	0.094	0.094	0.114	0.114	0.093	0.093

	Bare-1											
	0.5 cm		1 cm		2 cm		3 cm		4 cm		10 cm	
Time (s)	raw	clean	raw	clean	raw	clean	raw	clean	raw	clean	raw	clean
184	0.092	0.0920	0.085	0.085	0.12	0.12	0.099	0.099	0.085	0.085	0.07	0.07
185	0.11	0.1100	0.129	0.129	0.142	0.142	0.085	0.085	0.062	0.062	0.054	0.054
186	0.114	0.1140	0.108	0.108	0.097	0.097	0.061	0.061	0.045	0.045	0.03	0.03
187	0.077	0.0770	0.076	0.076	0.052	0.052	0.03	0.03	0.021	0.021	0.037	0.037
188	0.046	0.0460	0.048	0.048	0.031	0.031	0.032	0.032	0.043	0.043	0.049	0.049
189	0.034	0.0340	0.032	0.032	0.049	0.049	0.043	0.043	0.051	0.051	0.048	0.048
190	0.031	0.0310	0.068	0.068	0.042	0.042	0.05	0.05	0.109	0.109	0.105	0.105
191	0.053	0.0530	0.056	0.056	0.061	0.061	0.074	0.074	0.073	0.073	0.061	0.061
192	0.07	0.0700	0.072	0.072	0.082	0.082	0.068	0.068	0.068	0.068	0.054	0.054
193	0.082	0.0820	0.112	0.112	0.068	0.068	0.049	0.049	0.053	0.053	0.067	0.067
194	0.067	0.0670	0.075	0.075	0.127	0.127	0.062	0.062	0.056	0.056	0.066	0.066
195	0.061	0.0610	0.063	0.063	0.085	0.085	0.067	0.067	0.079	0.079	0.069	0.069
196	0.074	0.0740	0.087	0.087	0.087	0.087	0.075	0.075	0.074	0.074	0.05	0.05
197	0.075	0.0750	0.086	0.086	0.094	0.094	0.06	0.06	0.034	0.034	0.031	0.031
198	0.204	0.0840	0.096	0.096	0.06	0.06	0.043	0.043	0.03	0.03	0.045	0.045
199	0.093	0.0930	0.075	0.075	0.04	0.04	0.047	0.047	0.044	0.044	0.03	0.03
200	0.058	0.0580	0.053	0.053	0.04	0.04	0.037	0.037	0.024	0.024	0.029	0.029
201	0.058	0.0580	0.061	0.061	0.13	0.13	0.034	0.034	0.055	0.055	0.049	0.049
202	0.042	0.0420	0.04	0.04	0.032	0.032	0.047	0.047	0.051	0.051	0.05	0.05
203	0.047	0.0470	0.083	0.083	0.051	0.051	0.051	0.051	0.049	0.049	0.032	0.032
204	0.072	0.0720	0.062	0.062	0.056	0.056	0.035	0.035	0.056	0.056	0.036	0.036
205	0.063	0.0630	0.102	0.102	0.044	0.044	0.035	0.035	0.038	0.038	0.044	0.044
206	0.044	0.0440	0.056	0.056	0.036	0.036	0.049	0.049	0.059	0.059	0.051	0.051
207	0.048	0.0480	0.052	0.052	0.042	0.042	0.068	0.068	0.053	0.053	0.035	0.035
208	0.053	0.0530	0.07	0.07	0.048	0.048	0.031	0.031	0.03	0.03	0.017	0.017
209	0.063	0.0630	0.062	0.062	0.037	0.037	0.016	0.016	0.021	0.021	0.026	0.026
210	0.037	0.0370	0.038	0.038	0.019	0.019	0.026	0.026	0.028	0.028	0.042	0.042
211	0.025	0.0250	0.033	0.033	0.024	0.024	0.052	0.052	0.051	0.051	0.049	0.049
212	0.033	0.0330	0.039	0.039	0.045	0.045	0.055	0.055	0.065	0.065	0.065	0.065
213	0.044	0.0440	0.059	0.059	0.051	0.051	0.065	0.065	0.059	0.059	0.087	0.087
214	0.118	0.1180	0.085	0.085	0.073	0.073	0.097	0.097	0.081	0.081	0.061	0.061
215	0.21	0.2100	0.079	0.079	0.092	0.092	0.059	0.059	0.051	0.051	0.047	0.047
216	0.087	0.0870	0.094	0.094	0.06	0.06	0.042	0.042	0.033	0.033	0.041	0.041
217	0.055	0.0550	0.058	0.058	0.056	0.056	0.049	0.049	0.042	0.042	0.061	0.061
218	0.041	0.0410	0.044	0.044	0.038	0.038	0.059	0.059	0.065	0.065	0.069	0.069
219	0.054	0.0540	0.049	0.049	0.054	0.054	0.07	0.07	0.071	0.071	0.058	0.058
220	0.068	0.0680	0.084	0.084	0.061	0.061	0.054	0.054	0.056	0.056	0.059	0.059
221	0.072	0.0720	0.072	0.072	0.43	0.061	0.055	0.055	0.056	0.056	0.053	0.053
222	0.069	0.0690	0.075	0.075	0.061	0.061	0.048	0.048	0.051	0.051	0.039	0.039
223	0.06	0.0600	0.058	0.058	0.043	0.043	0.035	0.035	0.047	0.047	0.045	0.045
224	0.069	0.0690	0.055	0.055	0.035	0.035	0.045	0.045	0.035	0.035	0.027	0.027
225	0.043	0.0430	0.049	0.049	0.043	0.043	0.029	0.029	0.025	0.025	0.016	0.016
226	0.041	0.0410	0.054	0.054	0.035	0.035	0.013	0.013	0.019	0.019	0.011	0.011
227	0.026	0.0260	0.032	0.032	0.019	0.019	0.009	0.009	0.011	0.011	0.01	0.01
228	0.03	0.0300	0.024	0.024	0.011	0.011	0.006	0.006	0.01	0.01	0.019	0.019
229	0.016	0.0160	0.032	0.032	0.007	0.007	0.044	0.044	0.054	0.054	0.024	0.024
230	0.023	0.0230	0.019	0.019	0.013	0.013	0.022	0.022	0.03	0.03	0.023	0.023

	Bare-1											
	0.5 cm		1 cm		2 cm		3 cm		4 cm		10 cm	
Time (s)	raw	clean	raw	clean	raw	clean	raw	clean	raw	clean	raw	clean
231	0.032	0.0320	0.09	0.09	0.027	0.027	0.023	0.023	0.015	0.015	0.01	0.01
232	0.347	0.0255	0.064	0.064	0.024	0.024	0.009	0.009	0.01	0.01	0.022	0.022
233	0.019	0.0190	0.03	0.03	0.011	0.011	0.015	0.015	0.032	0.032	0.026	0.026
234	0.013	0.0130	0.046	0.046	0.012	0.012	0.028	0.028	0.031	0.031	0.047	0.047
235	0.053	0.0530	0.059	0.059	0.031	0.031	0.045	0.045	0.041	0.041	0.065	0.065
236	0.113	0.1130	0.046	0.046	0.052	0.052	0.047	0.047	0.052	0.052	0.048	0.048
237	0.051	0.0510	0.053	0.053	0.044	0.044	0.053	0.053	0.055	0.055	0.057	0.057
238	0.066	0.0660	0.068	0.068	0.054	0.054	0.063	0.063	0.058	0.058	0.045	0.045
239	0.052	0.0520	0.059	0.059	0.048	0.048	0.048	0.048	0.05	0.05	0.053	0.053
240	0.065	0.0650	0.063	0.063	0.053	0.053	0.055	0.055	0.068	0.068	0.067	0.067
241	0.074	0.0740	0.061	0.061	0.051	0.051	0.064	0.064	0.072	0.072	0.075	0.075
242	0.068	0.0680	0.08	0.08	0.058	0.058	0.083	0.083	0.079	0.079	0.041	0.041
243	0.068	0.0680	0.105	0.105	0.099	0.099	0.06	0.06	0.045	0.045	0.025	0.025
244	0.089	0.0890	0.083	0.083	0.152	0.152	0.03	0.03	0.026	0.026	0.028	0.028
245	0.052	0.0520	0.047	0.047	0.025	0.025	0.028	0.028	0.026	0.026	0.019	0.019
246	0.037	0.0370	0.034	0.034	0.025	0.025	0.022	0.022	0.017	0.017	0.017	0.017
247	0.037	0.0370	0.037	0.037	0.025	0.025	0.018	0.018	0.025	0.025	0.043	0.043
248	0.027	0.0270	0.029	0.029	0.017	0.017	0.044	0.044	0.043	0.043	0.048	0.048
249	0.02	0.0200	0.034	0.034	0.035	0.035	0.045	0.045	0.047	0.047	0.044	0.044
250	0.061	0.0610	0.064	0.064	0.048	0.048	0.048	0.048	0.057	0.057	0.038	0.038
251	0.054	0.0540	0.057	0.057	0.041	0.041	0.04	0.04	0.037	0.037	0.052	0.052
252	0.068	0.0680	0.057	0.057	0.047	0.047	0.046	0.046	0.054	0.054	0.058	0.058
253	0.035	0.0350	0.047	0.047	0.044	0.044	0.052	0.052	0.057	0.057	0.074	0.074
254	0.061	0.0610	0.065	0.065	0.058	0.058	0.075	0.075	0.078	0.078	0.092	0.092
255	0.057	0.0570	0.069	0.069	0.088	0.088	0.09	0.09	0.096	0.096	0.074	0.074
256	0.097	0.0970	0.115	0.115	0.096	0.096	0.09	0.09	0.175	0.175	0.051	0.051
257	0.1	0.1000	0.105	0.105	0.133	0.133	0.058	0.058	0.057	0.057	0.047	0.047
258	0.083	0.0830	0.093	0.093	0.054	0.054	0.053	0.053	0.065	0.065	0.079	0.079
259	0.069	0.0690	0.064	0.064	0.053	0.053	0.091	0.091	0.077	0.077	0.036	0.036
260	0.057	0.0570	0.077	0.077	0.077	0.077	0.046	0.046	0.021	0.021	0.045	0.045
261	0.091	0.0910	0.097	0.097	0.065	0.065	0.018	0.018	0.044	0.044	0.061	0.061
262	0.044	0.0440	0.034	0.034	0.016	0.016	0.054	0.054	0.07	0.07	0.064	0.064
263	0.035	0.0350	0.059	0.059	0.058	0.058	0.06	0.06	0.071	0.071	0.081	0.081
264	0.075	0.0750	0.075	0.075	0.06	0.06	0.066	0.066	0.086	0.086	0.088	0.088
265	0.069	0.0690	0.079	0.079	0.08	0.08	0.097	0.097	0.084	0.084	0.088	0.088
266	0.093	0.0930	0.098	0.098	0.123	0.123	0.094	0.094	0.108	0.108	0.115	0.115
267	0.11	0.1100	0.097	0.097	0.099	0.099	0.118	0.118	0.107	0.107	0.085	0.085
268	0.103	0.1030	0.11	0.11	0.142	0.142	0.093	0.093	0.078	0.078	0.067	0.067
269	0.134	0.1340	0.13	0.13	0.155	0.155	0.072	0.072	0.069	0.069	0.058	0.058
270	0.097	0.0970	0.09	0.09	0.069	0.069	0.058	0.058	0.064	0.064	0.071	0.071
271	0.086	0.0860	0.08	0.08	0.054	0.054	0.073	0.073	0.076	0.076	0.072	0.072
272	0.068	0.0680	0.064	0.064	0.068	0.068	0.079	0.079	0.073	0.073	0.067	0.067
273	0.147	0.1470	0.089	0.089	0.089	0.089	0.072	0.072	0.078	0.078	0.079	0.079
274	0.078	0.0780	0.111	0.111	0.07	0.07	0.105	0.105	0.082	0.082	0.047	0.047
275	0.096	0.0960	0.304	0.304	0.099	0.099	0.063	0.063	0.077	0.077	0.058	0.058
276	0.112	0.1120	0.087	0.087	0.062	0.062	0.056	0.056	0.072	0.072	0.053	0.053
277	0.049	0.0490	0.06	0.06	0.054	0.054	0.073	0.073	0.058	0.058	0.05	0.05

	Bare-1											
	0.5 cm		1 cm		2 cm		3 cm		4 cm		10 cm	
Time (s)	raw	clean	raw	clean	raw	clean	raw	clean	raw	clean	raw	clean
278	0.075	0.0750	0.074	0.074	0.064	0.064	0.049	0.049	0.062	0.062	0.038	0.038
279	0.082	0.0820	0.061	0.061	0.052	0.052	0.035	0.035	0.045	0.045	0.063	0.063
280	0.06	0.0600	0.143	0.143	0.038	0.038	0.072	0.072	0.057	0.057	0.058	0.058
281	0.071	0.0710	0.047	0.047	0.078	0.078	0.059	0.059	0.07	0.07	0.048	0.048
282	0.102	0.1020	0.089	0.089	0.071	0.071	0.043	0.043	0.05	0.05	0.042	0.042
283	0.125	0.1250	0.064	0.064	0.046	0.046	0.055	0.055	0.04	0.04	0.042	0.042
284	0.054	0.0540	0.06	0.06	0.053	0.053	0.044	0.044	0.047	0.047	0.036	0.036
285	0.051	0.0510	0.063	0.063	0.048	0.048	0.047	0.047	0.043	0.043	0.036	0.036
286	0.074	0.0740	0.053	0.053	0.042	0.042	0.041	0.041	0.039	0.039	0.025	0.025
287	0.05	0.0500	0.053	0.053	0.046	0.046	0.032	0.032	0.027	0.027	0.034	0.034
288	0.042	0.0420	0.056	0.056	0.023	0.023	0.028	0.028	0.047	0.047	0.065	0.065
289	0.032	0.0320	0.049	0.049	0.028	0.028	0.068	0.068	0.07	0.07	0.054	0.054
290	0.046	0.0460	0.056	0.056	0.084	0.084	0.063	0.063	0.053	0.053	0.07	0.07
291	0.075	0.0750	0.075	0.075	0.07	0.07	0.057	0.057	0.079	0.079	0.069	0.069
292	0.069	0.0690	0.063	0.063	0.053	0.053	0.077	0.077	0.052	0.052	0.038	0.038
293	0.072	0.0720	0.079	0.079	0.083	0.083	0.04	0.04	0.037	0.037	0.028	0.028
294	0.057	0.0570	0.068	0.068	0.041	0.041	0.038	0.038	0.03	0.03	0.04	0.04
295	0.418	0.0500	0.049	0.049	0.033	0.033	0.037	0.037	0.038	0.038	0.049	0.049
296	0.043	0.0430	0.041	0.041	0.035	0.035	0.047	0.047	0.041	0.041	0.041	0.041
297	0.039	0.0390	0.046	0.046	0.054	0.054	0.03	0.03	0.046	0.046	0.039	0.039
298	0.064	0.0640	0.057	0.057	0.037	0.037	0.052	0.052	0.055	0.055	0.042	0.042
299	0.04	0.0400	0.048	0.048	0.04	0.04	0.035	0.035	0.03	0.03	0.037	0.037
300	0.04	0.0400	0.048	0.048	0.04	0.04	0.035	0.035	0.03	0.03	0.037	0.037