

Wind Erosion and Air Quality Research in the Northwest U.S. Columbia Plateau: Organization and Progress

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INTRODUCTION

Controlling wind erosion and blowing dust has been an agricultural issue on the Columbia Plateau ever since farming began in the region some 120 years ago. This has been a particularly difficult problem because of the natural dustiness of the region due to its dry environments, scant vegetation, unpredictable high winds, and soils which contain substantial quantities of PM₁₀ size and smaller particulates. PM₁₀ refers to particles that are 10 microns (µm) in diameter (0.0004 inch, about 1/7 the diameter of a human hair). These minute particles, especially the very small size (e.g. PM_{2.5} and smaller), are now recognized as a serious health concern because they are readily inhaled and can accumulate in lung tissue and cause respiratory ailments. Soil dust is just one of many sources of fine particulates that become suspended and are transported in the atmosphere, but within the Columbia Plateau region it is often attributed to wind erosion of farm fields.

The potential impact of wind erosion from croplands on dust emissions and air quality has not been well defined. It is commonly observed, however, that regional air quality is usually at its worst during dust storm days. During these events, downwind concentrations of PM₁₀ can be 3 to 5 times the maximum allowable 24-hour average national air quality standard of 150 µg m⁻³. Use of traditional tillage practices in years of below normal precipitation can result in several exceedances per year of the national air quality standards.

Wind erosion is a very serious form of soil degradation and has permanently damaged the productive capacity for millions of cropland acres worldwide. If not controlled, the same fate awaits our Columbia Plateau farmlands and other erosion prone areas of the western U.S. Erosion reduces soil quality through the selective removal of plant nutrients and organic matter, and loss of fine particulates that can lead to soil compaction, poor soil tilth, and loss of crop

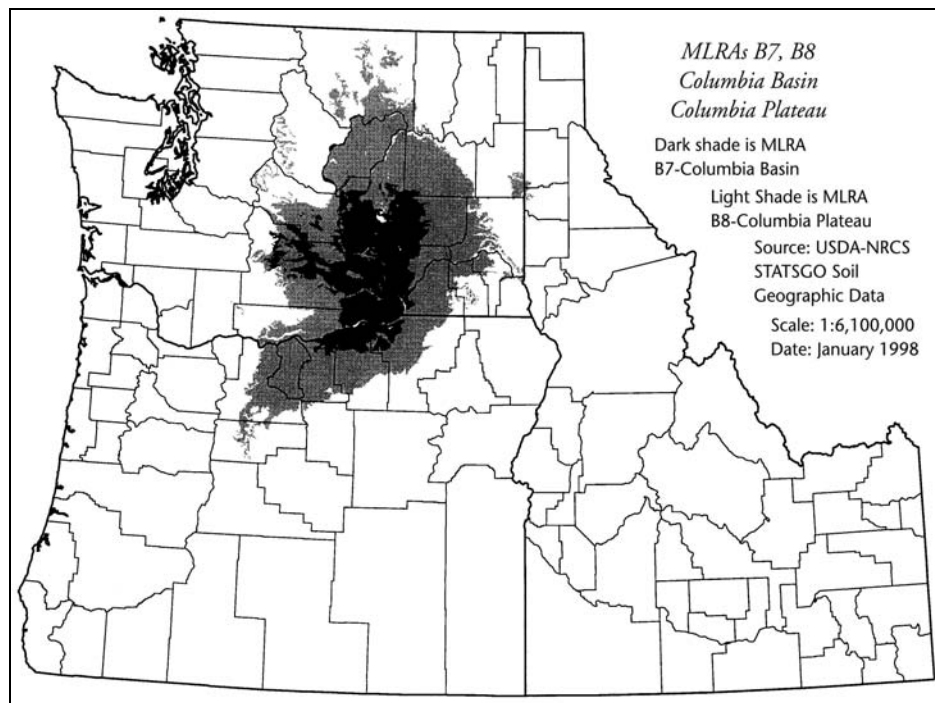


Figure 1. Pacific Northwest Major Land Resource Areas (MLRA) of significance for wind erosion and dust emissions in the Columbia Plateau.

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productivity. Once the topsoil is removed the remaining soil must be treated at significant cost to reclaim the loss in productivity (Lyles, 1997).

The Columbia Plateau and its irrigated counterpart, the Columbia Basin, are defined by the U.S. Department of Agriculture as Major Land Resource Areas (MLRA's) B7 and B8 (Fig. 1). Together these comprise a land area of about 30,000 square miles lying mostly in Central Washington and North Central Oregon. These mapping units make up the core of the cropland area with high farming density on lands that are most susceptible to wind erosion.

As the result of extensive wind erosion in the 1980's and associated heavy dust concentrations in urban regions, an extensive research project was planned and funded to define the regional conditions, prediction methods and enhanced control strategies. This project involved numerous individual projects conducted simultaneously and fully integrated to provide short-term answers. The guiding objectives of the project are shown in Appendix 1. This paper describes the major project category findings. Numerous other contributions have been summarized elsewhere (Saxton, 1995a, b, c; Papendick and Veseth, 1996; Papendick and Saxton, 1997; Papendick, 1998).

Wind Erosion Processes

To conduct effective wind erosion and dust emission research, it is necessary to review the known physics of wind entrainment of loose particles from agricultural surfaces (Saxton et al., 1996). The schematic shown in Fig. 2 illustrates the several simultaneous processes, which occur during wind erosion (Papendick, 1998). Each of these processes functions differently depending on the particle size and near-surface wind characteristics.

The wind velocity at which soil particles begin to move in the wind stream, the threshold velocity, of a soil that was roughened or covered with non-erodible materials (plants, anchored straw, stones, etc.) will be higher than that of the same soil having a bare, smooth, loose surface. The threshold velocity also depends on the inherent nature and properties of a given soil, i.e., its erodibility. Soil particles and aggregates less than 840 μm (0.84 mm, 0.033 inch) in size obtained by dry sieving the surface inch of soil are generally considered erodible by wind and their mass fraction has been used as an index of soil erodibility (Chepil, 1941). Wind speeds as low as 5-7 m s^{-1} (11-15 mph) at 3 m above the soil surface can initiate soil movement under highly erodible field conditions. Soil particles too large to enter the windstream, greater than about 500 μm , move along the soil surface during erosion by surface creep (Fig. 2). As medium size particles, 100 to 500 μm in diameter, are detached they may enter the wind stream momentarily but then are pulled back by gravity (Fig. 2). This causes them to impact other soil particles and set them in motion. These modes of transport, creep and saltation, are limited by the wind energy, thus may become nearly constant some distance downwind of a non-eroding surface.

As a result of saltation and direct wind forces, particulates 100 μm and less (more commonly 50 μm and

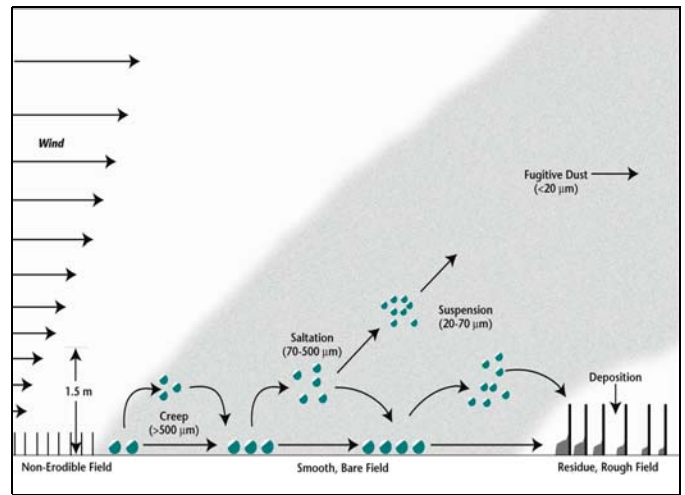


Figure 2. Schematic of the wind erosion and fugitive dust emission processes from agricultural fields.

less) in diameter are released and suspended in the wind stream where they are transported, often for great distances. Unlike saltation, the volume of the suspended load, which disperses into the atmosphere, is more commonly limited by available particulates from the soil surface than by available wind energy (Gillette, 1977).

The erodibility of a particular soil is defined as the maximum erosion possible (tons/acre/year) for a given wind energy. Erodibility varies considerably within and among soils as a result of variations in texture, organic matter content, and aggregate structure (Zobek, 1991). Generally, erodibility increases with increasing sand content, and decreases with increasing clay content and organic matter because these tend to form non-erodible aggregates. Because of changes in cloddiness and surface aggregate structure, soil erodibility can vary with season, cultivation, freezing, thawing, wetting, and drying. Tillage can often reduce the actual erodibility of medium- and fine-textured soils but may have little effect on deep sands.

Wind Erosion and Dust Emission Models

To achieve prediction capability for wind erosion and related suspended dust emissions in the Columbia Plateau, empirical models were developed from measured data within the study region. Existing models of wind erosion were not appropriate for short times (hourly and event), and did not have suspended dust components. Major variables were empirically combined as linear multipliers to develop a horizontal flux wind erosion equation such that (Saxton et al., 1998a,b):

$$Q_t = (W_t * EI * (e^{-0.05 SC} * e^{-0.52 K}) * WC)$$

where:

Q_t = eroded soil discharge per unit field width per time period ($\text{kg m}^{-1} \text{s}^{-1}$)

W_t = erosive wind energy per time period (g s^{-2})

EI = soil erodibility ($\text{kg m}^{-1} \text{s}^{-1}$) (g s^{-2})⁻¹

SC = surface cover index

K = surface roughness standard deviation (cm)

WC = soil moisture and crusting index

This equation represents the approximate equilibrium dust transport by creep and saltation for the wind energy and field surface condition of the specified event plus suspended material from a short distance up-wind. Our data were by instruments only moderately efficient for suspension size particles; and that caught would have originated from only a few meters up-wind, thus not representative of the whole field.

The vertical flux of PM₁₀ (F) emitted during an erosive period was assumed to be a function of horizontal mass flux, Q_t, the soil dustiness (D), and the wind velocity, (U) such that (Gillette and Passi, 1988):

$$F = f(Q_t, D, U)$$

Simultaneous measurements of PM10 concentrations and Q_t during wind erosion events were made to develop relationships between vertical dust flux and wind erosion (Stetler and Saxton, 1995, 1996). The suspended particulate filter mass of PM₁₀ measured at 1.5 and 2.5 m height (m_{1.5}, m_{2.5}) was correlated to the mass of dust available within the horizontal transport below 1.5 m height. The composite relationship to estimate vertical PM₁₀ flux and mass from a defined wind event, soil type and surface condition (Saxton, 1998a,b):

$$F = K_f u_* Q_T D \quad (\text{g m}^{-2} \text{s}^{-1})$$

where:

K _f = 0.26	(kg m ⁻¹)(m ³ s ⁻¹) ⁻¹
u _* = friction velocity	(m s ⁻¹)
Q _T = Horizontal flux,	(kg m ⁻¹)
D = dust coefficient	(g g ⁻¹)

The wind erosion and emissions model was interfaced as a sub-model with a meteorological-driven air quality transport-dispersion-deposition model to estimate atmospheric particulate concentrations on a regional scale during dust storm events (Claiborn et al., 1998). The emissions model integrated information on surface wind, soil characteristics, vegetation, management practices, and moisture conditions to calculate dust emissions for each

square kilometer as illustrated in Fig. 3. The regional air quality model provided spatial integration of the emissions, wind field, surface roughness and topography.

Farming Control Practices

Managing surface cover and soil roughness are the most practical approaches to reduce the potential of wind erosion and are often used in combination in the same field. Soil cover may consist of growing plants or crop residues, which protect erodible soil particles from the direct force of the wind.

Methods of wind erosion control are based on two principles: (1) reducing the direct force of wind on erodible soil particles and (2) modifying the soil surface to resist wind action or limit particle movement. Cover provided by plants and crop residues protect soil particles on the surface by absorbing a portion of the direct force of the wind transmitted to the soil. Cultural treatments, soil amendments and other techniques that increase the non-erodible fraction of the surface soil utilize the second principle of control. Soil modifications include using soil stabilizers that bind soil particles and maintain non-erodible aggregates or clods on the surface, and creating ridge roughness and soil cloddiness with tillage implements.

The effectiveness of soil cover and roughness to reduce wind erosion was determined using a portable wind tunnel (Pietersma et al., 1996; Horning et al., 1998; Fryrear, 1994, 1985). On field plots covering a range of flat residue and random roughness, measurements were made under typical tilled summer fallow conditions during the mid-dry season. Both random roughness and residue were estimated by visual comparisons with photographs of documented surface conditions.

Because bare fallow fields are highly susceptible to wind erosion, several control practices were investigated to modify the fallowing methods used in the dryland farming system of fallow-winter wheat. Reduced tillage, enhanced residue preservation, and direct seeding in a no-till system were evaluated (Schillinger and Bolton, 1996; Schillinger and Papendick, 1997).

Control Benefits

Managing eroded soil for the purpose of improving soil quality is an extremely slow and expensive process. It makes far more practical and economic sense to apply best management practices that will prevent wind erosion and soil quality decline than to attempt to reclaim soil after the damage is done. The cost of erosion from unprotected fields is often expressed in terms of reduced crop yields and crop quality, time and inputs to reclaim eroded land, and nutrients and organic matter lost with eroded soil. Estimates based on the loss of plant nutrients alone from wind erosion can be extremely high. Loss of the fine particulates can markedly accelerate the loss of soil nitrogen carried by them (Dormaar, 1987).

Large-scale implementation of control methods on Columbia Plateau croplands that are subject to wind erosion should significantly reduce windblown dust and improve region-wide air quality on dust storm days. The combined emission and transport-dispersion model was applied to

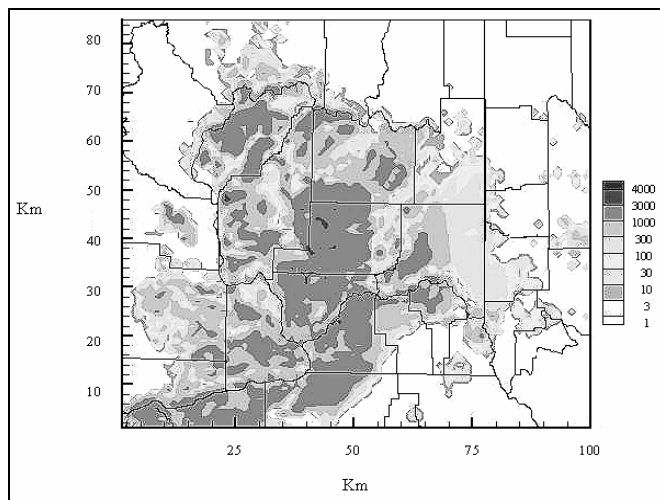


Figure 3. Predicted regional dust emissions for each square kilometer from a constant one-hour wind period illustrating spatial variation due to soils and cropping systems.

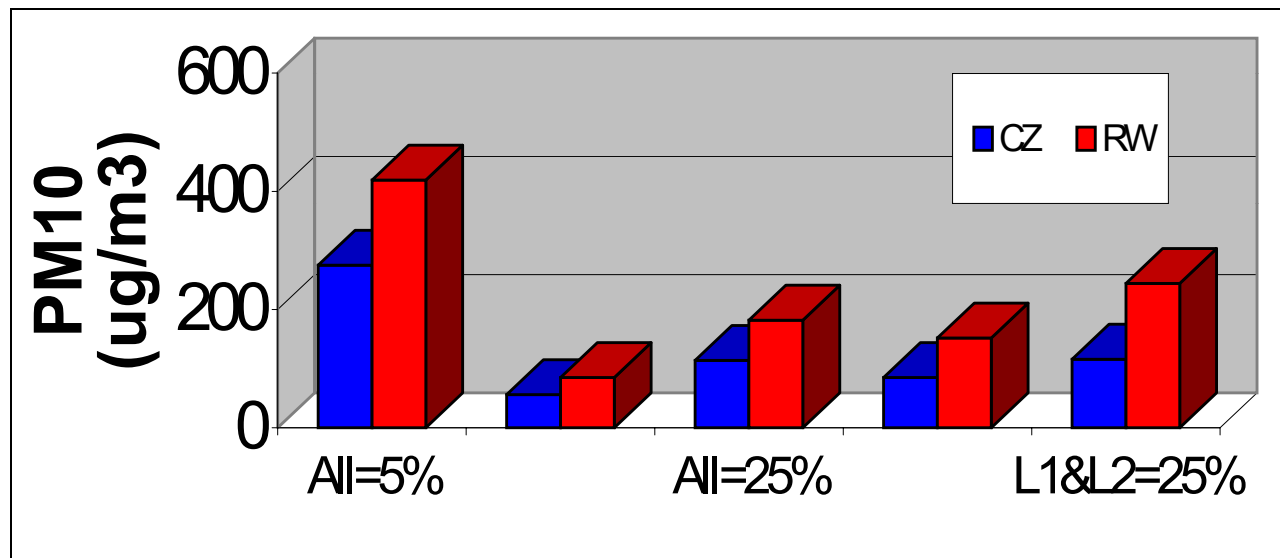


Figure 4. Estimated emission control by residue percentages on fallow fields for all or selected soil classes (L1 & L2) within the study region for two urban locations (CZ & RW).

evaluate the effectiveness of the proposed control strategies to reduce ambient PM concentrations. Figure 4 compares daily average PM-10 concentrations for base fallow (5% cover) with 1) 50% cover and 25% cover applied to all fallow land, and 2) 50% cover and 25% cover applied on just the L1 and L2 soil class croplands for two locations in Spokane, Crown Zellerbach (CZ) and Rockwood (RW).

SUMMARY

A regional wind erosion and air quality research project was developed for the Pacific Northwest Columbia Plateau of eastern Washington, northern Oregon and northern Idaho. Information was gathered to characterize soil, vegetation and climate variables. An empirical wind erosion and PM₁₀ dust flux model was developed from extensive field data. This model was included as the input to a regional GIS-based transport-dispersion prediction model, and preliminary trials show quite reasonable results when compared with downwind dust concentrations for several historic events. Dust concentration estimates made using the prediction models for several historic events with various potential control strategies demonstrated benefits useful for regional planning and policy decisions.

Enhanced field management control practices were developed and evaluated which would reduce wind erosion and associated dust emissions. As determined using a portable wind tunnel, enhanced surface cover and soil roughness are the most practical approaches to reduce the potential of wind erosion and are often used in combination in the same field. Through new farming systems and crop management, progress is being steadily made to implement effective conservation practices.

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Appendix 1. The Northwest Columbia Plateau Wind Erosion / Air Quality Project Abbreviated Objectives

1. Develop low and moderate resolution base data for the Columbia Plateau in GIS format necessary to describe major input variables such as climate, soil, vegetation and farming practices required to estimate agricultural wind erosion and PM₁₀ particulate emissions.
2. Establish the theory, quantification, and verification of simultaneous wind erosion and PM₁₀ fluxes on agricultural lands in the Columbia Plateau with data from several intensively instrumented agricultural field sites and a portable wind tunnel for calibration of the USDA National Wind Erosion Prediction System.
3. Obtain, test, and evaluate air mass transport-dispersion-deposition models suitable to predict PM₁₀ concentrations over the Columbia Plateau from spatially-distributed agricultural emission sources.
4. Develop a PM₁₀ air quality inventory for wind erosion events in the Columbia Plateau region and the probable urban impacts utilizing results and methods of objectives 1, 2, and 3.
5. Identify and test wind erosion and PM₁₀ emission control methods of alternative cropping systems (tillage, crops, rotation, weed control, etc.), and evaluate their effectiveness through descriptive measurements and portable wind tunnel tests.
6. Use data developed in objectives 1, 2 and 3 to appropriately reclassify suspect areas as Highly Erodible Lands (HEL) for control through the Food Security Act (FSA) assistance and develop strategy with USDA-SCS to set FSA criteria for on-farm compliance and assistance.
7. Determine the relative impact of human activity on suspended dust and PM₁₀ emission rates in the Columbia Plateau by determining erosion rates for non-anthropogenic and anthropogenic areas on a regional basis plus estimating pre-human erosion rates for soils during high wind events.
8. Develop an awareness and increased understanding by both rural and urban populations in the Columbia Plateau through educational materials, programs, and news media about wind erosion, PM₁₀ particulate emissions, and current and prospective control methods.
9. Better understand health impacts of particulate air pollution from several sources including agriculture.
10. Develop agricultural windblown dust best management practices and implementation policies including evaluating the profitability and social benefits of alternative farming systems for air quality control.
11. Develop a Columbia Plateau particulate air quality plan and modify local plans to achieve solutions to PM₁₀ problems throughout the Columbia Plateau.