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Validation of the Wind Erosion Prediction System (WEPS) Erosion Submodel on Small Cropland Fields

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Abstract

The Global Change and Terrestrial Ecosystems Soil Erosion Network has conducted a model validation exercise for water erosion models. This paper reports on part of a project to conduct a similar exercise for wind erosion models. Soil loss measurements for selected storm events obtained over several years from an eroding field are compared to predictions from the Wind Erosion Prediction System (WEPS) erosion submodel for the same events. The field data were collected from a small (2.5 hectare), circular, cropland field at Big Spring, TX. with samplers arranged in vertical clusters to sample horizontal soil discharge passing a point . Weather data including wind speed, wind direction, solar radiation, relative humidity, air temperature, and rainfall also were collected on-site. Temporal field site characteristics that were measured periodically included surface roughness, plant/residue cover, and dry aggregate size distribution. A power-law curve was fitted to the measured point-discharge data in each erosion event to estimate soil leaving the field at a downwind distance of 180 m. The WEPS erosion submodel was used to calculate the threshold erosion friction velocity based on surface conditions and then simulate soil loss during periods when the speed exceeded that threshold. Measured and simulated erosion values were in reasonable agreement ($R^2 = 0.65$). Uncertainties in the input data as well as additional techniques to improve the predictions are discussed.

Keywords. Wind erosion, Model, Dust.

Introduction

Wind erosion models are used for a variety of purposes including estimating the on-site and off-site consequences of wind erosion, as well as for designing erosion control measures. Because of their widespread use, it is imperative to validate the performance of erosion prediction models. The Global Change and Terrestrial Ecosystems Soil Erosion Network has conducted a model validation exercise for water erosion models. A project has been initiated to conduct a similar exercise for wind erosion models. Data on selected storm events collected during the last decade by ARS scientists (Fryrear et al., 1991) were distributed to participating scientists for model validation tests. More than half the data (24 storm events) selected for the validation tests were collected at the Big Spring, TX location, and the remainder came from locations in other states. This paper presents the results of simulating the Big Spring daily erosion events using the Wind Erosion Prediction System (WEPS) erosion submodel. Simulations of the other locations will be presented in a later report.

The WEPS is a process-based, daily time-step model that simulates weather and field conditions (Wagner, 1996). The erosion submodel determines when friction velocity exceeds the threshold and then simulates soil loss and deposition over the simulation region on a sub-hourly basis (Hagen, Wagner, and Skidmore, 1999). During erosion, the submodel individually simulates the saltation/creep and suspension components of wind-eroded soil. This approach was used because the saltation/creep component has a defined transport capacity, whereas the suspension component generally continues to increase over the entire length of eroding fields. Individual processes simulated include entrainment of loose material and abrasion of clods/crusts.

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Field Site Preparation and Instrumentation

The Big Spring site was a 2.5-ha, tilled, circular area located within a larger field that did not erode. The circular site pattern was selected to permit collection of erosion data regardless of wind direction with a minimum number of samplers (Fryrear et al., 1991).

Soil sediment samplers (Fryrear, 1986) were arranged in vertical clusters to sample the horizontal soil discharge passing a point. A typical cluster consisted of five samplers located at 0.05, 0.10, 0.20, 0.5, and 1.0 m above the soil surface. Thirteen clusters were placed within each circular field site. Six clusters were located at 60-degree intervals on each of two concentric circles with radii of 60 and 95 m, and the remaining cluster was located at the center of the site. A meteorological tower also was located near the center of each site and instrumented to record wind speed, wind direction, air temperature, solar radiation, rainfall, and relative humidity.

Data Analyses Procedures

The horizontal soil flux (kg m^{-2}) trapped by the catchers in each cluster was integrated to a height of 2 m to determine the soil discharge (kg/m) at each cluster location. The wind direction and upwind distance to the edge of the field also were calculated for each cluster. In our analyses, we fitted the measured point-discharge data to empirical equations to estimate the soil discharge at 180 m downwind. The discharge for each storm then was divided by 180 to provide an estimate of soil loss per unit area for a 180 m long, 1 m wide, strip of field. The empirical equation providing the best fit to most of the cluster data was of the form:

$$q = a + bX^c \qquad \textbf{(1)}$$

where q is the downwind horizontal discharge (kg m^{-1}), X is the downwind distance from nonerodible boundary, and a, b, c are empirical coefficients. However, the measured cluster data exhibited significant scatter with downwind distance, which likely was caused by changing wind directions and nonuniform surface conditions during storms.

Wind statistics provided for each daily storm included the maximum speed, average speed, and a wind factor (Fryrear, Saleh, and Bilbro, 1998). We used these statistics to calculate three parameters (scale, shape, and zero intercept) for a Weibull cumulative distribution of the wind speed data for each storm day. Using the Weibull distribution, a synthetic distribution of subhourly wind speeds was generated that was symmetric about the maximum daily wind speed. These subhourly wind speeds then were used to drive the erosion submodel.

The field surface conditions used in the storm simulations are listed in Table 1. Unfortunately, several of the field surface parameters needed for WEPS were not measured and had to be estimated. Crust cover fraction was estimated from cumulative rainfall since last tillage operation, except in 1996, when the field was assumed to be crusted as a result of unreported factors. The aggregate and crust dry stabilities were assigned average values based on the soil texture. The surface soil was assumed to be air dry during the erosion events.

Results and Discussion

The average storm soil loss extrapolated from the cluster measurements was 1.01 kg m^{-2}, and the average predicted soil loss was 0.93 kg m^{-2} (Table 1). The estimated crust cover fraction significantly influenced the predicted soil loss. For example, if the crust cover was assumed to be zero for the three storms in 1996, the total predicted soil loss would be 1.98 kg m^{-2}. The predicted soil loss fit the measured soil loss with a coefficient of determination (R^2) equal to 0.65 (Fig. 1).

Table 1. Field surface conditions for selected erosion events and measured and predicted soil losses for these events at Big Spring, TX

Storm Date	Flat Cover (fraction)	Aggregate <0.84 mm (fraction)	Crust Cover (fraction)	Crust & Aggregate Stability Ln(J/kg)	Random Roughness (mm)	Ridge Height (mm)	Measured Soil loss (kg/m^2)	Pred. Soil loss (kg/m^2)
4-22-89	0.00	0.55	0.60	1.93	8.0	0.0	0.41	0.33
4-23-89	0.00	0.55	0.60	1.93	7.0	0.0	0.51	0.31
1-22-90	0.04	0.65	0.50	1.93	1.7	20.0	0.09	0.04
1-24-90	0.04	0.64	0.50	1.93	1.7	20.0	1.77	1.85
1-26-90	0.04	0.65	0.50	1.93	1.7	0.0	0.61	1.17
1-29-90	0.04	0.64	0.50	1.93	1.7	20.0	0.78	1.03
2-12-90	0.04	0.65	0.50	1.93	1.7	20.0	0.40	1.28
3-12-90	0.04	0.65	0.85	1.93	1.7	20.0	0.08	0.47
3-14-90	0.04	0.65	0.85	1.93	1.7	20.0	4.57	3.91
4-02-93	0.01	0.74	0.05	1.93	4.5	0.0	3.47	1.62
3-17-94	0.03	0.60	0.40	1.93	2.0	0.0	0.14	0.20
3-18-94	0.03	0.60	0.40	1.93	2.0	0.0	0.14	0.04
3-22-94	0.03	0.60	0.40	1.93	2.0	0.0	0.38	0.11
3-24-94	0.03	0.60	0.40	1.93	2.0	0.0	0.18	0.30
4-07-94	0.03	0.60	0.40	1.93	2.0	0.0	0.52	0.89
4-15-94	0.03	0.60	0.40	1.93	2.0	0.0	2.02	1.52
4-25-94	0.03	0.60	0.40	1.93	2.0	0.0	4.85	2.27
2-10-95	0.05	0.72	0.40	1.93	2.0	0.0	1.08	1.51
3-22-95	0.03	0.72	0.57	1.93	1.7	0.0	0.20	0.36
1-23-96	0.02	0.60	1.00	1.93	5.1	0.0	0.01	0.00
2-14-96	0.03	0.58	1.00	1.93	5.0	0.0	0.01	0.00
3-05-96	0.03	0.57	1.00	1.93	5.0	0.0	0.00	0.00
4-29-97	0.06	0.50	1.00	1.93	1.8	0.0	0.80	0.77
5-02-97	0.06	0.50	1.00	1.93	1.8	0.0	1.24	2.30

However, the intercept for a linear regression line was greater than zero, and the slope was less than one (P = 0.05), suggesting that the model overestimated soil loss for the small storms but underestimated for the largest storms. The predicted soil losses likely can be improved by preparing input files of daily weather and then using other submodels in WEPS to estimate the variations in aggregate/crust stabilities and surface wetness, which were assumed as constants in this analysis. For example, the model's overprediction of erosion on 3-12-90 likely was caused by surface wetness from rainfall on the two preceding days. The model underprediction on 4-02-93 likely was caused by low values for the reported wind speed data used as inputs. Thus, additional quality control checks on the input data may be necessary. Further examination of additional measured erosion data also may lead to some modifications in the current erosion submodel.

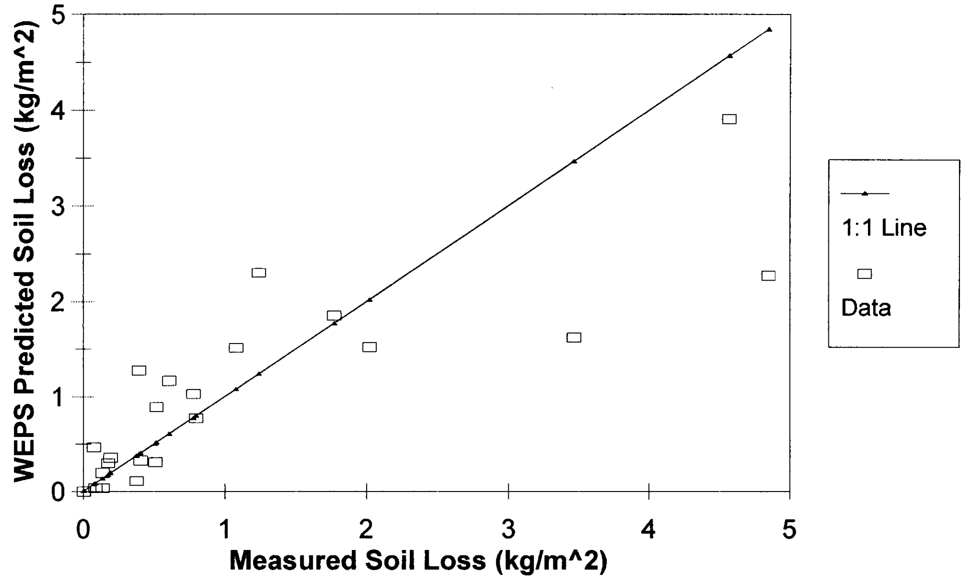

Figure 1. Measured versus predicted soil loss for a series of daily wind erosion events at Big Spring, TX from 1989 to 1997.

Summary

For each storm, total, horizontal soil discharge at a distance of 180 m downwind was estimated from the upwind horizontal soil flux collected in sediment samplers for a selected series of 24 storms that occurred at Big Spring, TX from 1989 to 1997. The downwind soil discharge was divided by field length to estimate average soil loss each storm for a field 180 m in length. Measured wind speed data and both estimated and measured surface conditions were used as inputs to the Wind Erosion Prediction System (WEPS) erosion submodel to simulate the erosion events. Reasonable agreement ($R^2 = 0.65$) was obtained between the estimated and simulated erosion values. Further improvements in agreement can likely be achieved by simulating both surface wetness and aggregate/crust stability as variable inputs to the erosion submodel using other WEPS submodels. Additional quality assurance checks also need to be conducted on some of the measured input data proposed for use in the validation exercise for wind erosion models.

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