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WIND EROSION IN SEMIARID LANDSCAPES: PREDICTIVE MODELS AND REMOTE SENSING METHODS FOR THE INFLUENCE OF VEGETATION

Semiannual Status Report

for January 1, 1992 to June 30, 1993

Principal Investigator: H. Brad Musick
Biology Department
University of New Mexico
Albuquerque, NM 87131

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H. Brad Musick
C. Randall Truman
Steven M. Trujillo

University of New Mexico
Albuquerque, NM 87131

OBJECTIVES

The objectives of this research are: (1) to develop and test predictive relations for the quantitative influence of vegetation canopy structure on wind erosion of semiarid rangeland soils, and (2) to develop remote sensing methods for measuring the canopy structural parameters that determine sheltering against wind erosion. The influence of canopy structure on wind erosion will be investigated by means of wind-tunnel and field experiments using model roughness elements to simulate plant canopies. The canopy structural variables identified by the wind-tunnel and field experiments as important in determining vegetative sheltering against wind erosion will then be measured at a number of naturally vegetated field sites and compared with estimates of these variables derived from analysis of remotely sensed data.

STATUS

I. Wind-tunnel Experiments

The final wind-tunnel experiments were completed during spring of 1993. The experiments were conducted at the USDA Wind Erosion Laboratory at Big Spring, Texas, with the collaboration and generous assistance of USDA scientist Dr. W. D. Fryrear. Tentative conclusions have been drawn from a preliminary analysis of the results. Additional analyses now underway include estimation of error and uncertainty and use of more sophisticated techniques for derivation of friction velocity values from the windspeed profile measurements.

A. Phase 1: Canopies Modeled as Solid Roughness Elements

These experiments were designed to determine the influence on threshold friction velocity of three structural variables applicable to arrays of solid cylindrical roughness elements:

1) Lateral cover (or Frontal Area Index): the product of height, diameter, and number per unit ground area of roughness elements,

2) Element aspect ratio: the ratio of element height to element diameter,

3) Array scale factor: ratio of absolute dimensions for arrays identical in structural relationships but differing in absolute size.

We tested 27 combinations of these 3 structural variables, with 5 replicate determinations of threshold friction velocity for each combination.

As reported earlier, preliminary analysis confirms the findings of previous studies showing that lateral cover strongly determines protection against wind erosion. After error and uncertainty analysis, our results will be quantitatively compared with those of other investigators in an attempt to resolve the quantitative disparities among the results of previous studies. Preliminary analysis also indicates that the influence of element aspect ratio is less than expected and may perhaps be insignificant for all but some extreme cases.

Results obtained using small-scale physical models must be insensitive to scale if they are to be applicable to the larger-scale natural structures they are intended to simulate. We included an examination of scale-factor effects in our experimentation because some previous experiments similar to ours had given indications of possible scale-factor effects, which would tend to invalidate extrapolation of results to the field scale. In our first series of experiments we found only one case of possible scale-factor effects. This case was retested in Spring 1993, and the new results indicated that scale-factor effects were small and probably insignificant. Pending additional analysis of the data, we tentatively conclude that we were unable to detect any scale-dependence in our results; this finding supports the validity of applying our wind-tunnel results to the field.

B. Phase 2: Canopies Modeled as Porous Roughness Elements

In our Phase 1 experiments we followed the approach of previous studies in using solid objects as models of individual plant bodies. In Phase 2, we used porous objects as more realistic models of plant bodies in order to determine the influence of canopy porosity on protection against wind erosion. Our experimental investigations of canopy porosity effects, completed in Spring 1993, are a major advance beyond previous studies of this type.

Porous elements were constructed by mounting a varying number of narrow cylinders vertically in a cluster, thus forming a porous roughness element cylindrical in overall shape. To isolate the effect of porosity, we made the overall dimensions and aspect ratios of the porous elements and the lateral cover of the porous-element array identical to those of solid cylinders used in our Phase 1 experiments. Arrays consisting of large numbers of these porous elements were placed on the floor of the wind tunnel, which was covered with erodible sand, and threshold friction velocity was determined using the same procedures as in our experiments with solid elements.

The labor required for assembly of porous elements limited the number of tests that could be performed within the scope of this study. We have tested five different array configurations carefully selected to provide information on several key questions.

Preliminary results indicate that:

1) The protection provided by arrays of porous model canopies depends on two variables, the porosity of the canopies and the lateral cover of the array, as calculated using overall dimensions of the canopies. Characterizing these arrays solely by the total frontal area of stems is inadequate to account for their effects; two porous-element arrays having the same stem lateral cover, but differing in porosity and in canopy lateral cover, were found to give different degrees of protection. This finding supports our approach in modeling semiarid vegetation as an array of discrete porous plant bodies rather than as an array of stems and leaves without regard to their aggregation into discrete plant bodies.

2) Relative to solid elements, slightly porous elements provide greater protection against wind erosion, while highly porous elements provide equal or lesser protection. This finding that protection is maximal at some intermediate level of porosity (i.e., between solid and highly porous) is in agreement with results previously obtained for two-dimensional wind barriers such as snow fences and windbreaks.

3) The effect of porosity is quantitatively important in some cases; slightly porous elements raised threshold friction velocities above bare-soil values more than 1½ times as much as solid or highly porous elements. This finding indicates the need for further experimentation to more fully characterize the quantitative effect of canopy porosity on wind erosion.

4) The protection provided by porous roughness elements having the "cylindrical cluster of cylinders" structure we used appears to be related to the ratio of total frontal area of "stems" to frontal area of the overall canopy; two arrays with identical values of this ratio, but with five-fold and compensating differences in number of stems per cluster and stem diameter, were found to have almost identical threshold friction velocities. This finding provides a useful starting point for further work to determine the most appropriate structural measure of canopy porosity for protection against wind erosion by arrays of discrete, three-dimensional, porous canopies.

II. Field Experiments

A. Effect of Solid Roughness Element Array on Saltation Threshold

In Spring 1993, we conducted a full-scale field test of the relationships derived from our Phase 1 wind-tunnel experiments, which used solid roughness elements. An array of solid cylindrical objects of approximately the same size as natural plant bodies was placed on a large cleared field, and the threshold friction velocity was determined by simultaneous monitoring of the wind profile and sand flux (Stockton and Gillette, 1990; Musick and Gillette, 1990) during several episodes of blowing sand. The roughness element array was then removed from the field and the threshold friction velocity of the bare soil was similarly determined in order to determine the Critical Friction Velocity Ratio (threshold friction velocity with roughness/threshold without roughness) for comparison with the wind-tunnel results.

The experiment was conducted at the USDA/ARS Jornada Experimental Range near Las Cruces, New Mexico, with the cooperation of USDA scientists. Five-gallon plastic pails partially filled with soil for anchorage and sealed with lids were used as roughness elements. Fifteen hundred pails were arrayed with 3 m center-to-center spacing on a cleared semicircular field 95 m in radius.

Instrumentation and data recording equipment were provided on loan by the USGS Desert Winds Project (PI Carol Breed, Flagstaff). Instruments for measurement of wind direction, the vertical profile of windspeed, and airborne particle movement were located at the focus of the semicircle so that the maximum fetch of 95 m would apply to a 180° range of wind directions. Data were collected continuously, with an averaging or summation period of one minute, for approximately three months; pails were arrayed on the field for the first half of this period and removed for the second half. Mass flux of airborne sediment was also measured using three stacks of three each Big Spring Number Eight sand catchers; sediment was collected from these weekly for mass and particle size measurements to be made by D. W. Fryrear (USDA Big Spring). Catcher mass data and a cursory examination of the recorded data indicate that there were at least six (and probably more) episodes of substantial sand movement lasting an hour or more from the usable range of wind directions during both the "with-roughness" and "without-roughness" conditions.

Analysis of the data is currently in progress. It was observed at the end of the experiment that the performance of the two lowest anemometers had deteriorated considerably through exposure to blowing sand and dust. Wind-tunnel facilities at the UNM Fluid Dynamics Laboratory are being used to determine post-exposure calibration constants for the anemometers for comparison with pre-exposure calibration data to ascertain the degree of deterioration. One of the first steps in field data analysis will be to screen the data from the latter part of the experiment and remove data showing evidence of inaccurate anemometer readings. Also, sampling periods with wind direction outside the usable range will be identified and omitted from further analysis.

To develop methods for determination of threshold friction velocity from the wind and sand flux data obtained in this experiment, we undertook (in collaboration with P. Helm, USGS Flagstaff) a detailed examination of similar data from two other field sites: a vegetated site near Yuma, monitored by the USGS Desert Winds Project, and a bare field previously monitored by D. W. Fryrear and P. H. Stockton as a validation site for the Sensit sand flux detection instrument. We found that the relation of sand flux occurrence to friction velocity is not a simple step function, and this finding was confirmed by preliminary analyses of the data obtained by this project from the Jornada field.

The finding that saltation threshold response in the field is not a simple step function requires that we develop new analysis methods for deriving a useful measure of threshold friction velocity. To ensure that the measure of threshold friction velocity thus derived is comparable to values measured under controlled laboratory conditions, we will try to identify the interactions between physical phenomena and measurement limitations that give rise to the deviations from ideal step-function response. Methods thus derived will then be used to determine threshold friction velocities for the "with-roughness" and "without-roughness" field conditions, and the ratio of these values will be compared with our Phase 1 (solid elements) wind-tunnel results to check the validity of extrapolation to full-scale field conditions.

B. Effect of Model Porous Canopy Structure on Local Patterns of Wind-borne Sediment Deposition and Deflation

Airborne transport of sediment in partially vegetated arid rangelands often results in localized patterns of deposition and deflation in the vicinity of individual plant bodies. Schlesinger et al. (1990) suggest that the redistribution of soil from open areas between canopies to dunes underneath canopies is a key process in a feedback cycle leading to increased desertification of semiarid lands; increased spatial heterogeneity of soil resources promotes further invasion of grasslands by desert shrubs and contributes to significant changes in ecosystem function, including emission of greenhouse gases.

Previous observations, mostly anecdotal with the exception of Hesp (1981), indicate that the localized patterns of blowing sand accumulation and deflation in the proximity of plant canopies are largely determined by the structural properties of the individual plant bodies through their influence on airflow patterns. We also observed in our wind-tunnel experiments that patterns of deposition and deflation around our model plant canopies varied with canopy structure. In view of the recently suggested importance of localized sediment redistribution (Schlesinger et al., 1990) and the scarcity of quantitative and experimental data, we undertook a pilot field study of the effect of model porous-canopy structure on patterns of windblown sand deposition and deflation.

The experiment was performed on a small portion of the same cleared field used for the other experimental work, in order to benefit from the measurements of wind and sand flux already being made. The study is a collaborative effort with Dr. T. M. Zobeck (USDA/ARS, Lubbock TX), who provided laser profiler measurements of soil microtopography. The model canopies were designed, similarly to those used in our Phase 2 wind-tunnel experiments, as cylindrical arrays of narrow, vertically-oriented cylinders (model "stems") of uniform height. Six model canopies were constructed by cementing 0.25 in diameter dowels into a pegboard base, which was buried 2 in deep upon installation in the field. Canopy structure was varied to give two levels each of three structural variables: 1) porosity, 2) aspect ratio (height/diameter ratio), and 3) absolute size (i.e., overall dimensions varying by a scale factor). Canopy diameters were 30 cm and 60 cm, and canopy height varied from 7.5 cm to 57 cm.

Laser profiler measurements of a 1 m by 1 m area around the model canopies were made immediately after the canopies were embedded in the soil and the surface was smoothed, and again after 7 weeks exposure, during which time substantial sand movement was recorded by the BSNE catchers and other instruments. Quantitative analysis of these data is now in progress. In addition to previously used methods of analysis using statistical software, we are exploring the application of image processing and topographic modeling software to these data as means of enhancing visual representation and analysis capabilities.

III. Remote Sensing

We have obtained two near-coincident SPOT scenes of the Jornada Experimental Range. From this combination of nadir-view and off-nadir-view scenes we had planned to calculate an estimate of vegetation lateral cover for comparison with estimates derived from ground sampling of a number of sites.

We have purchased part of the hardware required for processing of this satellite imagery, but acquisition of the remaining hardware by our collaborators in this effort (Sevilleta LTER) has been considerably delayed. It now appears unlikely that analysis of the SPOT imagery can be undertaken within the scope of this grant.

PUBLICATIONS AND PRESENTATIONS

A. Completed or submitted

1. Musick, H. B. 1992. Effect of vegetation on surface stability. Presented at USGS Global Change/Arid Lands Processes Workshop, Flagstaff, Arizona, August 18-20, 1992.

2. Trujillo, S. M., C. R. Truman, and H. B. Musick. 1992. The effects of roughness element geometry on saltation threshold in a turbulent boundary layer (Abstract). Bulletin of the American Physical Society, Program of the 1992 Annual Meeting of the Division of Fluid Mechanics 37:1784. (Abstract transmitted with previous status report)

3. Musick, H. B., S. M. Trujillo, and C. R. Truman. 1993. Influence of vegetation structure on susceptibility to wind erosion (Abstract). Bulletin of the Ecological Society of America 74(2) Suppl.:370. (Poster to be presented at Ecological Society of America Annual Meeting, August 1993)(Abstract enclosed)

3. Musick, H. B. 1993 (submitted). Monitoring vegetation and its role in surface changes. In Monitoring Land-Surface Processes and Synoptic Climatology at Desert Sites in Arizona and New Mexico, C. S. Breed (ed.). U. S. Geological Survey Bulletin ###.

B. Planned

1. Trujillo, S. M. 1993. Predictive modeling of the influence of vegetation on wind erosion in semiarid rangelands for remote sensing applications. M.S. Thesis. (completion anticipated October 1993)

2. Musick, H. B., and C. R. Truman. 1993. Saltation threshold response to wind at field sites. (to be submitted to Earth Surface Processes and Landforms)

3. Musick, H. B., C. R. Truman, and S. M. Trujillo. 1993. A field test of relations between lateral cover and wind erosion thresholds. (to be submitted as journal paper)

4. Truman, C. R., S. M. Trujillo, and H. B. Musick. 1993. Wind-tunnel modeling of the influence of vegetation structure on wind erosion thresholds:
I. Effects of lateral cover and element aspect ratio.
II. Effects of element porosity.
(to be submitted as journal papers)

5. Musick, H. B., T. M. Zobeck, and C. R. Truman. 1993. The influence of plant canopy structure on local accumulation and deflation of blowing sand: an experimental study using model porous canopies. (to be submitted as journal paper)

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ABSTRACT FORM

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Author to contact:	H. Brad Musick
Institution:	Biology Department, University of New Mexico
Address:	Albuquerque, NM 87108
Phone number:	(505) 265-9440

Who will present paper?	Musick	
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MUSICK, H. BRAD, STEVEN M. TRUJILLO, and C. RANDALL TRUMAN. University of New Mexico, Albuquerque, NM, 87108, USA.

Influence of vegetation structure on susceptibility of soil to wind erosion.

The change from physical stability of the soil surface to vigorous sediment transport by wind is a potentially important state transition for sparsely vegetated ecosystems on susceptible soils. Wind thresholds for eolian sediment transport are determined by soil properties and by the structure and amount of vegetation. We examined the influence of vegetation structure on wind thresholds in wind-tunnel and field experiments using model roughness elements to simulate plant canopies. For arrays of solid model canopies, wind thresholds were closely related to lateral cover, defined as the product of frontal silhouette area per canopy and number per unit ground area of canopies. Geometrical relationships between lateral cover and other structural variables lead to predictions of the influence of vertically-projected canopy cover, canopy height/diameter ratio, and canopy spacing on protection against wind erosion. Tests using three-dimensional porous objects as more realistic models of canopy structure indicated that wind thresholds were highest at intermediate levels of canopy porosity.