FIELD MEASUREMENT OF WIND EROSION IN SOUTHERN ALBERTA: PRELIMINARY RESULTS

W.M. WHITE, A.G. LIMBIRD and S.C. JOSEFOWICH
DEPARTMENT OF GEOGRAPHY, UNIVERSITY OF CALGARY

ABSTRACT

During the 1980's, the impact of frequent droughts and consequent erosion of topsoil by the wind have become of increasing concern to the agricultural community of southern Alberta. This paper outlines the design and implementation of a methodology aimed at producing a reasonably accurate assessment of soil loss along with observations on, and preliminary results of, the initial field season.

INTRODUCTION

The classic works of Bagnold (1941) and Chepil (1945,1946) relied on wind tunnel work backed up by extensive field investigations to establish the principles upon which most subsequent wind erosion research has had its basis. Since their pioneering efforts, however, the general trend has been to focus on statistical theory and wind tunnel simulations with comparatively little field verification of the results. In lieu of the latter it has become common practice to compare simulation results with those generated via existing, generally accepted models such as the equations of Bagnold (1941) and Chepil (1945,1946), the Wind Erosion Equation (Woodruff and Siddoway 1965) or more recent proposals by Gillette (1986) or Fryberger (in Kalma et al, 1988).

It is this frequent failure to back up theoretical assessments with practical field or ground truthing that causes debate as to the utility or validity of such models. Expense, constraints of time, inconvenience or the inability to control and separate the effects of the various factors involved in the erosion process are all reasons for failing to conduct field trials. These are all valid concerns but do not preclude the necessity for attempting field evaluations in order to see how well the simulations correspond with results gathered under actual field-test conditions.

BACKGROUND

Extensive review of the literature and consultation with established researchers in the field of wind erosion reveals two salient facts. First, there is no standard device available for sampling wind blown sediments. Second, there is no standard technique for estimating soil losses due to erosive wind action. The approach taken by many researchers studying wind erosion seems to depend mainly on their technical and academic background, previous experiences or research objectives (Bagnold 1941, Bocharov 1984, Chepil and Woodruff 1957, DePloey 1980, Gillette and Goodwin 1974, Hilliard and Rostad 1987, Marston 1986, Nickling 1975, SENSIT 1987, Svasek and Terwindt 1974).

The approach taken for this study was to delineate certain criteria and choose the sampler design or designs which best fit these categories, bearing in mind the cautions sounded by Jones and Willetts (1979) that any sediment trapping device will have inherent drawbacks of some kind and that of Nickling (1987) that there is no single best design.

The selection criteria for the collection devices included simplicity yet durability of construction, ease of operation and maintenance in the field, ability to function reliably while operating unattended for varying periods of time in extreme weather conditions, and relatively low construction cost. As anticipated, none of the available devices were ideal. However, two units were more suitable than the others so both models were used in the sediment sampling network.

An array of Big Springs #8 aeolian dust samplers (BSNE) developed specifically for this type of work at the USDA-ARS Wind Erosion Research Center in Texas (Fryrear 1986) trapped low level saltating and suspended soil particles in the region from 0.15 meters to 2.00 meters above the erosive surface. Leatherman aeolian sand traps, designed for dune migration studies (Leatherman 1978, Marston 1986, Rosen 1978) but with extensive modification, were adapted to collect material moving via creep and saltation from the surface up to 0.06 meters. A second set of the latter was constructed to sample from the surface up to 0.15 meters.

It is of interest that the BSNE design has a stated sample collection and retention efficiency of 80 to 90% whereas the Leatherman unit collects 70 to 75% of windblown dust. These values are directly dependent on particle size and wind velocity.

FIELD AREA: LOCATION, SOILS and CLIMATE

With the assistance of the agricultural fieldman for the County of Vulcan, two cooperative farmers were found in the vicinity of Champion, northwest of Lethbridge in southeastern Alberta, an area where typical dryland grain farming practices dominate. Soils of this region are predominantly orthic and eluviated dark brown chernozems with textures varying from loam to loamy sand in the southern most parts of the district (Wyatt et al 1925, Clayton et al 1977)

The field area was located in the Chinook belt and therefore was subject to frequent intervals of warm, high velocity winds. This type of climatic activity may reduce or eliminate snow cover thereby exposing the soil surface (Grace and Hobbs 1986). During the 1987-1988 field season temperatures ranged from +27.8 to -30.2 degrees Celsius and a maximum wind velocity in excess of 135 kmph. at 10.0 meters was recorded in late March 1988. Numerous freeze-thaw events associated with Chinook activity worked effectively to alter both aggregate and soil crust strength.

DATA COLLECTION

Two discrete classes of information were collected at the field sites. On a weekly basis, bulk soil samples were carefully scraped from the upper 1.0 to 1.5 cm. of the Ap horizon for determination of percent moisture, percent organic matter, water-soluble salt content and texture (percent sand, silt and clay). Anemometers located at 1.0, 2.0 and 10.0 meters above the surface described hourly windspeed and direction regimes. Temperature, relative humidity and precipitation amounts were also recorded. A CR21 datalogging computer was used to compile and store all meteorological input.

Sediment samplers were inspected on a weekly basis, cleaned and when measurable amounts of eroded material had been trapped, these were retained in separate containers for transportation back to the laboratory.

By January 1988 suitable techniques were devised to allow measurements of surface organic residue cover and sampling of relatively undisturbed soil for dry aggregate distribution and stability analyses.

FIELD SAMPLING NETWORK

The fields used in this research were located 3.2 kilometers (2.0 miles) apart, aligned east-west and since there were no fencelines, trees or brush, windflow was essentially unobstructed. Each site was a summerfallowed strip in a quarter section field. Fetch across each was 805 meters (0.5 miles) at the trailing or lee edge. The samplers were installed in a line oriented north-south along the downwind boundary of the sites. It was reasoned that any materials trapped at this location would be similar in composition and volume to that which would be transported off the fields during an erosive event.

Due to previous and present cultivation practices, one of the sites did not experience measurable erosion. Therefore, the data from the first year of the project came from only one field location. This site experienced 19 separate erosive events during the 1987-88 field season; 8 between October and the end of January and 11 during the period including February, March and the first week of April (Fig. #1). An erosive event was defined as a period during which the mean 1.0 meter wind velocity exceeded the threshold value of 4.5 m sec^{-1} (Chepil 1945, Grace and Hobbs 1986, Lancaster 1988).

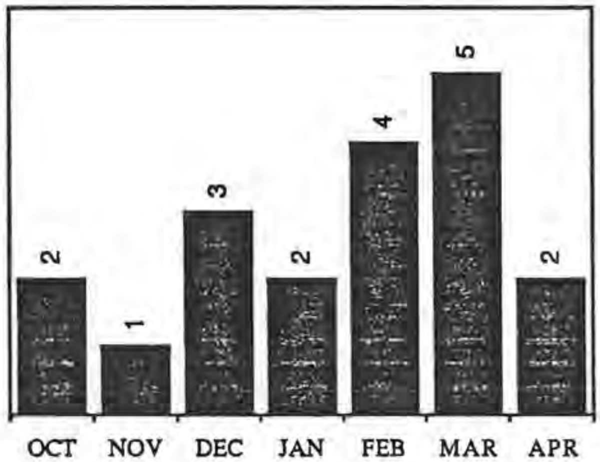

Figure #1: *Total Number of Erosive Events*
October 1987 - April 1988

At each of five sampling points located at regular intervals across the width of the field an array of BSNE samplers was installed after the pattern employed by Zobeck and Fryrear (1986). An array included four units mounted on a common pole at heights of 0.15, 0.50, 1.00 and 2.00 meters above the surface. Bagnold (1941) and most other investigators indicated that on the order of 85% of blown sediment moves within 1.0 meter of the surface and the greater part of that mass within 0.50 meters of the surface. Since this suggests that the BSNE array would not sample adequately in this zone, modified Leatherman units were installed at each of 4 sampling points in close proximity to the BSNE arrays to provide a fifth data point nearer to the surface.

DATA ANALYSES

In keeping with the stated objective of simplicity, initial data analyses attempted to describe sediment flow using a minimum number of variables. The first analysis followed that of Zobeck and Fryrear (1986) where each of the 19 events was treated as a separate occurrence to derive an event specific model of the process. Sample mass and height data, dependent and independent variables respectively, were fitted into a simple power equation. Since the statistical analyses for all 19 events were consistent, the 50 hour interval between February 20-22, 1988 was used as a representative case. Table #1 lists the height and weight data for this period.

Table #1: *Linear/Log_{10} Data Conversion*
February 20-22 Erosive Event

Linear		Log_{10}	
Height (m)	Weight (gm cm^{-2})	Height (m)	Weight (gm cm^{-2})
0.010	114.815	-2.000	2.060
0.150	35.481	-0.824	1.550
0.500	6.290	-0.301	0.798
1.000	2.208	0.004	0.344
2.000	0.839	0.301	-0.076

The first run using the raw date produced an r^2 value of 0.439 indicating the expected reduction of mass flow with height but not an accurate description of that flow (Fig. #2a). A $\log_{10}$ transformation was performed on the data resulting in an r^2 value of 0.920 (Fig. #2b). The decreasing mass with height relationship was being described more accurately with a dramatic improvement in the description of the flow being observed. The latter was not unexpected given the logarithmic characteristics of the wind profile (Deacon 1948, Scott and Carter 1986) and the assumed impact of wind velocity on erosive transport near the surface.

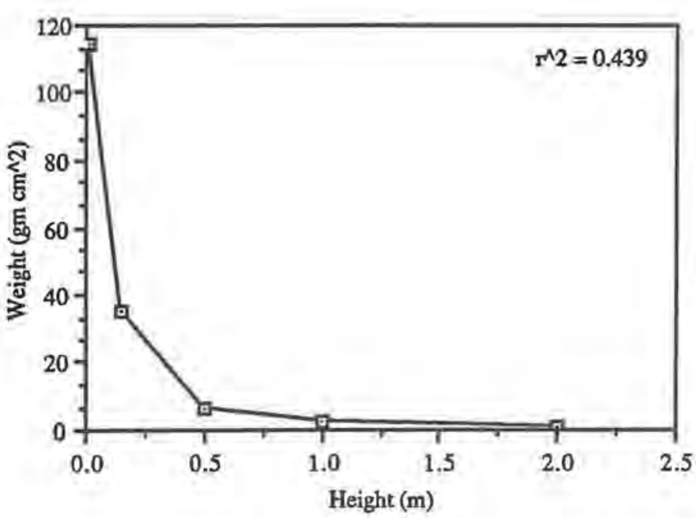

Figure #2a: *Simple Power Equation: $y = ax^b$*

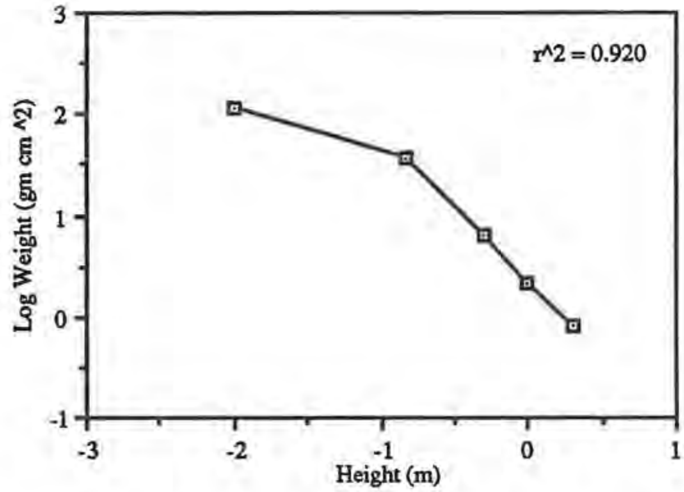

Figure #2b: *Simple Power Equation:* $y = ax^b$
Log_{10} *Transformation of the x,y Variables*

Substitution of the coefficients a = 0.466 and b = -0.884 back into the power equation provided an opportunity to compare the estimating capabilities of the simple model with the measured values from the sediment samplers (Tab. #2). The resulting error factors ranged from -55.86% to +49.59 % of the measured values indicating that this model was far from adequate leaving the door open for further investigation.

Table #2: *Error Factors of the Measured Values*

Height (m)	y measured ($gm\ cm^{-2}$)	y estimated ($gm\ cm^{-2}$)	difference ($gm\ cm^{-2}$)	as % of y estimated
0.010	114.815	171.751	56.936	+49.59
0.150	35.481	15.660	19.821	-55.86
0.500	6.290	5.347	0.844	-14.07
1.000	2.208	2.899	0.691	+31.30
2.000	0.839	1.585	0.394	+33.08

A second attempt replaced the power equation with a simple exponential equation of the form $y = ae^{bx}$. Although the variables remained as previously noted, the r^2 value dropped to 0.425 which was less acceptable than the power relationship.

Since these relatively simple analyses did not yield acceptable results on a single event basis, the data for all 19 erosive events were combined and regression equations were developed for both the power and exponential forms. Both models produced r^2 values less than 0.30.

It was apparent at this point that to improve the accuracy it would be necessary to sacrifice simplicity to some degree therefore a number of additional independent variables were incorporated in the analyses. These included percent soil moisture and organic matter, water-soluble salt content, texture (percent sand, silt and clay), duration of the individual events (number of hours the 1.0 meter anemometer recorded wind speeds in excess of the threshold velocity 4.5 m sec^{-1}) and mean 1.0 meter wind speed and direction for each event. The augmented data set was analyzed on a complete verses single event basis.

Polynomial regression gave an inadequate r^2 value of 0.529. The final approach was to perform multiple regression analyses with a $\log_{10}$ transformation of all variables which substantially improved the r^2 to 0.702. Analysis was halted at this stage to allow further examination and reconsideration of what had transpired before proceeding further.

CONCLUSIONS AND FURTHER DIRECTIONS

Sediment transport by wind cannot confidently be described by the simple 2-variable relationship as proposed by Zobeck and Fryrear (1986). Various manipulations of the available data were tried but none proved adequate for the stated objectives of this research.

The basis for estimating soil loss is the integration of an equation to determine the total mass of sediment moving between any two points on the curve so described which is then extended to the total eroding surface. Since the starting point requires the best possible description of that curve, any less accurate equation would introduce an error factor which would be magnified as the procedure was carried further. From these analyses the greatest potential still appears to lay in treating each erosive event individually but by first using a general model and step-wise deletion to produce the best description with the least number of independent variables.

Another alternative, which would compliment the latter, is a re-examination of how the independent variables were treated. For example, Marston (1986) found a better relationship between $(V\text{-}Vt)^3$, where V = mean velocity and V_t = threshold velocity, and mass flow than between average velocity at a given height and mass flow. Information on percent surface organic residue cover and dry aggregate composition of the surface soils is now available for the last 11 events and will be used in any future analyses. For the second field season data will be collected on surface roughness characteristics and soil crust strength, both of which will be added to the list of independent variables. More importantly, the addition of sampling points in the 0.06 to 0.15 meter interval range should improve the accuracy of the regression equation.

ACKNOWLEDGMENTS

We would like to thank the financial assistance provided by the Alberta Environmental Research Trust, Agriculture Canada and the Department of Geography, University of Calgary. We also gratefully acknowledge Dr. Wayne Lindwall for his critical comments and helpful suggestions, Ted Rhodes for the loan of meteorological instrumentation, Don Clopton for field selection and both Harvey Fath and the Little Bow Hutterite Colony for allowing us the use of their land.

REFERENCES

Bagnold, R.A. (1941). The Physics of Blown Sand and Desert Dunes. Chapman and Hall, London, 265 pp.

Bocharov, R.A. (1984). A description of Devices Used in the Study of Wind Erosion of Soils. Russian Trans. Ser. 14. A.A. Balkema, Rotterdam, 90 pp.

Chepil, W.S. (1945,1946). The Dynamics of Wind Erosion. Pts. 1-6. Soil Sc. Vols. 60 and 61.

Chepil, W.S. and Woodruff, N.P. (1963). The Physics of Wind Erosion and Its Control. Advances in Agronomy 15. Academic Press, New York. pp 211-302.

Clayton, J.S., Ehrlich, W.A., Cann, D.B.C., Day, J.A. and Marshall, I.B. (1977). The Soils of Canada. Res. Br. - Can. Dept. of Agri., Ottawa. 2 Vols. and 2 Maps.

Deacon, E.L. (1949). Vertical Diffusion in the Lowest Layers of the Atmosphere. Royal Met. Soc. Quarterly. Jour. 75. pp 89-103.

DePloey, J. (1980). Some Field Measurements and Experimental Data on Wind Blown Sands. Assessment of Erosion. M. DeBoodt and D. Gabriels (Eds.). Wiley and Sons, New York. pp 541-544.

Fryrear, D.W. (1986). A Field Dust Sampler. Jour. of Soil and Water Cons. Vol. 41 (2). pp 117-120.

Gillette, D.A. (1986). Wind Erosion. Soil Conservation: Assessing the National Resources Inventory. Vol. 1. Nat. Acad. Press, Washington D.C. pp 129-162.

Gillette, D.A. and Goodwin, P.A. (1974). Microscale Transport of Sand-Sized Soil Aggregates by Wind. Jour. of Geophysical. Res. 79 (27). pp 4080-4084.

Grace, B and Hobbs, E.H. (1986). The Climate of the Lethbridge Agricultural Area, 1902 to 1985. LRS Mimeo. Rpt.#3 (rev.). Agric. Can. Res. Stn, Lethbridge Alberta. 39 pp.

Hilliard, C.R. and Rostad, R.P.W. (1987). Preliminary Report on the Erodibility of Saskatchewan Soils. Publ. M81-1987. Sask. Inst. of Pedology. 10 pp.

Jones J.R and Willetts, B.B. (1979). Errors in Measuring Uniform Aeolian Sand Flow by Means of an Adjustable Trap. Sedimentology 35. pp 463-468.

Kalma, J.D., Speight, J.G. and Wasson, R.J. (1988). Potential Wind Erosion in Australia: A Continental Perspective. Jour. of Clim. 8 (4). pp 411-428.

Lancaster, N. (1988). On Desert Sand Seas. Episodes. Int. Geo. Newsmag. Vol. 11, No. 1 pp 12-17.

Leatherman, S.P. (1978). A New Aeolian Sand Trap Design. Sedimentology 25. pp 303-306.

Marston, R.A. (1986). Manoeuvre-Caused Wind Erosion Impacts: South Central New Mexico. Aeolian Geomorphology. W.G. Nickling (Ed.). Allen and Unwin, Boston. pp 274-290.

Nickling, W.G. (1975). Eolian Sediment Transport: Simms River Valley, Yukon Territory. Unpubl. PhD. Thesis. Univ. of Ottawa 1976, 246 pp.

Nickling, W.G. (1987). Modification to the Gillette Sampler. Pers. Comm., June 3, 1988.

Rosen, P.S. (1978). An Efficient, Low-Cost Aeolian Sampling System. Geol. Surv. of Can. Paper 78-1A. Curr. Res., Part A. pp 531-532.

Scott, W.D. and Carter, D.J. (1986). The Logarithmic Wind Profile in Wind Erosion: An Algebraic Solution. Boundary Layer Met. 34. pp 303-310.

SENSIT (1987). Eroding Mass Monitor. SENSIT Co. Longmont, Colorado. 3 pp pamph.

Svasek, J.N. and Terwindt, J.H.J. (1974). Measurement of Sand Transport by Wind in a Natural Beach. Sedimentology 21. pp 311-322.

Wyatt, F.A., Newton, J.D. and Allen, J.A. (1925). Soil Survey of the Macleod Sheet. Bulletin #11. Coll. of Agric., Univ. of Alta. 81 pp and maps.

Woodruff, N.P and Siddoway, F.H. (1965). A Wind Erosion Equation. Soil Sc. Soc. of Amer. Proc. 29 (5). pp 602-608.

Zobeck, T.M. and Fryrear, D.W. (1986). Chemical and Physical Characteristics of Windblown Sediment 1: Quantities and Physical Characteristics. Trans. Amer. Soc. of Agric. Engg. 29 (4). pp 1032-1036.

Alberta Conservation & Reclamation Conference '88

Proceedings of a Conference jointly sponsored by

the Alberta Chapters of the

Canadian Land Reclamation Association and the Soil and Water Conservation Society

held September 22-23, 1988
Kananaskis Village, Alberta

ALBERTA CONSERVATION AND RECLAMATION CONFERENCE '88

Proceedings of a Conference

Jointly Sponsored by the Alberta Chapters of the

Canadian Land Reclamation Association

and

Soil and Water Conservation Society

Held September 22 and 23, 1988

at the Lodge at Kananaskis, Alberta

C.B. Powter, compiler

1989

TABLE OF CONTENTS

All papers are presented here as submitted by the authors; the material has not been edited.

This report may be cited as:

Powter, C.B. (compiler), 1989. Alberta Conservation and Reclamation Conference '88. Proceedings of a Symposium sponsored by the Alberta Chapters of the Canadian Land Reclamation Association and the Soil and Water Conservation Society. 183 pp.

ACKNOWLEDGEMENTS

The two sponsoring groups wish to acknowledge the efforts and support of the following individuals and organizations, without whom the conference would not have been a success:

Alberta Environment, Land Reclamation Division - Mailing

David Walker (Walker and Associates) - Registration and Graphics for the Proceedings Cover

Betty Meier (Alberta Environment, Land Reclamation Division) - Registration

Chris Powter (Alberta Environment, Land Reclamation Division) - Session Chairman

Larry Brocke (Alberta Environment, Land Reclamation Division) - Session Chairman

John Toogood - Session Chairman

Al Watson (Alberta Environment, Land Reclamation Division) - Audio visual

Grace LeBel (Kananaskis Centre for Environmental Research) - Conference facilities and accomodations

Dr. Dennis Parkinson (Kananaskis Centre for Environmental Research) - Opening remarks

Dr. James McMahon (Utah State University) - Luncheon address

Andy Russell - Banquet address