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RELATIONSHIP BETWEEN SHELTER ANGLE SURFACE ROUGHNESS AND CUMULATIVE SHELTERED STORAGE DEPTH[1]

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ABSTRACT: A team of U.S. Department of Agriculture scientists is developing a computer-based Wind Erosion Prediction System (WEPS) (HAGEN, 1991). WEPS is a continuous, process-based, wind erosion model that requires accurate descriptions of soil surface variables. Among the variables used to define a soil's susceptibility to wind erosion are surface roughness and surface storage. In this report, three aspects of surface roughness are discussed. First, roughness measurement techniques are briefly reviewed, and a new method to digitize profile meter photos using image analysis is reported. Second, results from a study on the relationship between surface soil roughness and cumulative sheltered storage depth are reported. Third, expected uses for the new shelter angle distribution roughness index and the cumulative sheltered storage depth within WEPS are discussed.

INTRODUCTION: The effects of soil surface roughness on wind erosion processes are well documented (CHEPIL and MILNE, 1941; WOODRUFF and SIDDOWAY, 1965; FRYREAR, 1984). Management practices such as tillage are often used to create ridges and soil aggregates that produce rough surfaces to help control wind erosion, especially in areas where maintaining adequate surface residue is difficult (FRYREAR and SKIDMORE, 1985).

RÖMKENS and WANG (1986) described soil roughness as consisting of four classes or forms: 1) roughness due to individual particles or aggregates of 0-2 mm in magnitude; 2) surface variations, often referred to as random roughness, due to cloddiness on the order of 100 mm in magnitude; 3) systematic or oriented roughness due to tillage implements, 100-300 mm in magnitude; and 4) higher order roughness due to field topography. The second and third types of roughness are of the most interest in wind erosion studies, because they are the ones that change most rapidly due to weathering and tillage and are subject to management.

Point soil surface elevation data can be obtained through a variety of methods using image analysis (RICE et al., 1988), microprocessors (RADKE et al., 1981 and VAN OUWERKERK et al., 1982), laser systems (RÖMKENS et al., 1988 and HUANG and BRADFORD, 1990), or photogrammatic techniques (WELCH et al., 1984). One of the simplest devices to measure soil surface profile elevation data is a pin meter, which consists of a row of equally spaced pins that are lowered onto the surface until contacts are made. The relative pin elevations are then recorded either manually, electronically, or photographically.

Manual recording of pin elevation data is time consuming and can be prone to human errors. Electronic recording of field elevation data is usually faster than manual techniques and less likely to contain human errors and produces data sets readily accessible by a computer for further analysis. However, automated electronic measurement requires that a data acquisition system, sensors, and power source be available at

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the measurement site. The costs of potential specialized training, maintenance, and repair must be considered along with the initial cost of the system, especially when multiple field instruments are required. Photographic techniques produce a record of pin positions at low cost and require a minimum of skill. Despite its simplicity in field operation, the photographs still need to be analyzed to obtain surface elevation data. The required digitization process can be performed manually or by some automated or semi-automated process.

Because a myriad of measurement devices are available that can obtain point soil surface elevation data in a wide range of resolutions and scales, roughness data used in this form are not convenient from both a research and a modeling perspective. Thus, the need exists for a roughness index to describe soil surface roughness. POTTER et al. (1990), mention that soil surface roughness was first described as the standard deviation of surface elevations measured at selected intervals by KUIPERS (1957) and refined by ALLMARAS et al. (1966) into an index known as random roughness (RR). This index has been widely used to describe surface roughness for a range of soils and tillage implements. The RR index is determined by surface cloddiness with the effects of oriented and systematic roughness removed. POTTER also cites other proposed roughness indexes (LINDEN and VAN DOREN, 1986 and RÖMKENS and WANG, 1986) and explains that none of these indices individually appears to contain all the information perceived necessary for evaluating surface roughness effects on wind erosion. This was the reason for development of a new surface roughness index as described by POTTER et al. (1990).

This new index, based on a shelter angle concept, is sensitive to management factors such as tillage and weathering influences such as rainfall and also to be responsive to directional and oriented roughness as well as random roughness. A shelter angle is defined for each surface point, obtained from standard surface elevation data, as the largest angle above horizontal formed by a line tangent from the point to any upwind point within the radius of influence on the surface (approx. 0.3 m). The cumulative frequency distribution of those shelter angles is then used as the roughness index, which can be described conveniently by a two-parameter Weibull function.

$$F_{(SA)} = 1 - e^{[-(SA/C)^k]} \qquad (1)$$

Where:
F = Cumulative Frequency
SA = Shelter Angle (degrees)
C = scale factor
k = shape factor

The shelter angle distribution is expected to benefit wind erosion modeling efforts in three primary areas: 1) allowing computation of the fraction of saltating particles impacting clods, crust, or other surface cover; 2) providing a relationship between surface roughness and threshold friction velocities; and 3) being related to storage capacity, which, in turn, indicates the amount of surface area available for deposition and shelter from abrading saltating material during a wind erosion event.

In this report, three aspects of surface roughness are considered. First, a new method of digitizing transect surface profile meter photos using image analysis techniques is presented. Second, results from a study on the relationship between the shelter angle distribution roughness index parameters and cumulative sheltered storage depths are reported. Finally, use of the new shelter angle roughness index and cumulative sheltered storage depth in WEPS is discussed.

PROFILE METER PROGRAM (PMP): The USDA-ARS Wind Erosion Research Unit previously digitized transect, surface profile, field, pin meter photos manually using a standard digitizing tablet. The method was slow and susceptible to errors such as digitizing the same pin more than once, skipping pins, or inaccurately positioning the digitizing pen/cursor on the pin tips. Operator fatigue and variations in individual operator attentiveness to detail also affected data quality. Because, the photo-encoding, transect, surface profile, pin meter was a low-cost and effective means of obtaining point surface elevation data in the field, a method was pursued to semi-automate the photo digitization process. The result was the Profile Meter Program (PMP) (WAGNER and YU, 1991).

The PMP automates acquisition of transect, soil surface, elevation data from pin meter photographs. The program uses simple image analysis techniques to process the scanned image of a photograph and determine pin tip locations. The PMP simplifies digitization, reduces by up to one-fourth the time required to obtain elevation data from a pin meter photo, and eliminates many operator-induced errors prevalent in hand digitizing techniques. The PMP incorporates the following additional features: 1) a user-friendly interface with on-line context-sensitive help; 2) the ability to handle a range of transect, surface profile, pin meter designs; 3) support for manipulating data files; 4) storage for information about individual photographs and data files; 5) graphical display of the digitized pin meter photographs on screen; 6) a graphical screen editor, controlled by a pointing device such as a mouse, for manual selection and editing of pin tip locations, reference marks, and area of interest regions; and 7) output flexibility by providing a selection of output options and formats.

The minimum set of computer hardware and peripherals for PMP include seven elements: 1) An IBM[2] microcomputer or compatible with 640 kilobytes of RAM memory with an Intel 80286 or faster processor recommended to process a photograph in a reasonable time (less than 1 min). 2) MS-DOS or PC-DOS version 2.1 or higher. 3) Additional computer memory supporting the Lotus/Intel/Microsoft (LIM 4.0) Expanded Memory Standard (EMS) is needed. EMS memory required depends upon the size of the image and the scanner digitizing resolution used. Approximately 1.5 megabytes of EMS memory is necessary for a 7.6 cm by 12.7 cm (3x5 in) photo digitized at 118 dots/cm (300dpi). 4) A 16-color 640x350 pixel (EGA) or 640x480 pixel (VGA) graphics adapter with corresponding color monitor is required. 5) In addition, a Microsoft compatible mouse; 6) a digitizing scanner with software that is capable of producing single-plane (black and white) digitized images that can be stored in the PC Paintbrush (PCX) graphics file format (a relatively inexpensive hand digitizing scanner has provided satisfactory results); and 7) a hard disk for storing the digitized images and resulting data files are necessary.

The image processing program operation consists of the following steps: 1) The pin meter photo is first scanned by a digitizing scanner at the desired resolution. This operation produces a rectangular single-plane (black and white) bitmap image of the photo stored in the PCX graphics format. 2) The digitized image is loaded into memory by the PMP and displayed on the screen. Using the mouse, the operator marks the location of the pin meter reference points (used to determine the scale factor between the digitized image pixel units and the desired output elevation units) and specifies the area of interest (AOI) within which the PMP will search for and locate pin tips. 3) The pin tip detection process is then initiated to record the location of each pin tip. If any pin tips were missed or located incorrectly, the operator can manually mark their locations with the mouse on the display. 4) Finally, the elevation data can be reported in the desired format. These elevation data then can be processed to determine the shelter angle distribution index parameters and/or the cumulative sheltered storage depth parameters.[3]

CUMULATIVE SHELTERED STORAGE DEPTH: As mentioned previously, in wind erosion

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[2]The use of trade names in this publication does not imply endorsement of the products named.

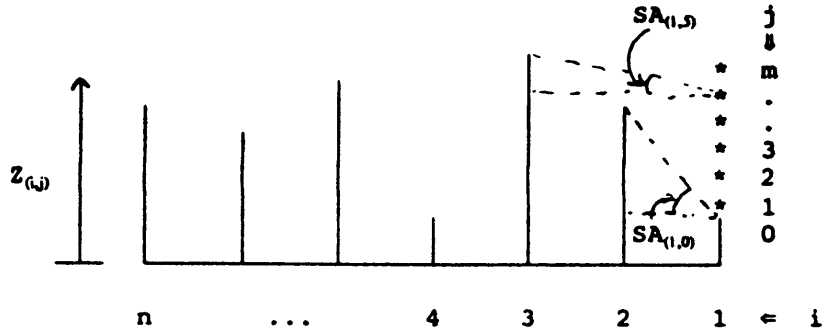
[3]A copy of the PMP program and user's manual can be obtained by mailing a formatted disk(s) capable of storing a total of 720k to the first author.

modeling, it is necessary to estimate not only the fraction of sheltered surface area but also the amount of storage capacity in the sheltered areas on the surface. For this reason, a cumulative sheltered storage depth was developed and a preliminary relationship was obtained between the shelter angle distribution roughness parameters and the cumulative sheltered storage depth parameters.

The cumulative sheltered storage depth is the cumulative depth of storage sheltered by angles greater than any specified shelter angle in units of length (typically in mm). A typical cumulative storage depth curve is shown in Figure 1 along with the shelter angle distribution for the same data. It can be computed in the following manner:

1. Consider a random rough surface:

Pin Meter Pins: Schematic View



Where:
- i = pin no.
- n = maximum no. of pins
- j = increment height no.
- m = maximum no. of height increments
- h = increment height value (mm)
- $Z_{(i,j)} = Z_{(i,0)} + (h*j)$ = height of pin i at increment height j (mm)
- $SA_{(i,j)}$ = shelter angle of pin i at incremental height j (degrees)

2. Calculate the shelter angles at each pin for ($1 \le l \le$ radius of influence / d) in the following manner:

$$SA_{(i,j)}\Big|_{j=0}^{m} = \tan^{-1}\left[\frac{(Z_{(i+l,0)}-Z_{(i,j)})}{l \times d}\right]_{max\ SA} \qquad (2)$$

Where:
- d = distance between adjacent pins (mm)
- l = no. of pins to lookahead: (l x d) $\le$ radius of influence

3. After performing the calculations for the series of shelter angles for each pin, $SA_{(i,j)}$, by adding h increments to each pin height until the computed shelter angle is less than or equal to zero, they can be presented in a tabular format (artificial data used for illustrative purposes only):

Pin No.	No. of incremental heights (j) 0	1	2	3	4	5	6 ... m
1	40	30	20	10	5	2	0
2	15	10	5	2	0		
3	10	5	3	0			
.							
.							
.							
n							

Note: The second column (j = 0) consists of the actual shelter angles used to obtain the shelter angle distribution of the surface elevation data, $SA_{(i,0)}$, per the definition of a shelter angle distribution.

4. Now compute the individual sheltered storage depths in the following manner:

$$CSSD_{(k)}\Big|_{0^\circ}^{90^\circ} = \frac{\left[\sum_{i=1}^{n}\sum_{j=1}^{m}\left(if\ (SA_{(i,j-1)} \geq k > SA_{(i,j)})\ \begin{matrix} then\ j \\ else\ 0 \end{matrix}\right)\right] \times h}{n} \tag{3}$$

Where: k = unit shelter angles: 0, 1, 2, ... 90 (degrees)
$CSSD_{(k)}$ = cumulative shelter storage depth at shelter angle k (mm)

5. Finally, graphing the results produces a curve similar to that in Figure 1. Note that maximum storage occurs at a shelter angle of 0° and that any point on the curve represents the cumulative sheltered storage depth for all shelter angles greater than the specified shelter angle. This curve illustrates how a soil surface's trapping potential changes with deposition.

6. A three-parameter exponential function has been used to describe the cumulative sheltered storage depth and takes the form:

$$CSSD_{(SA)}\Big|_{0^\circ}^{90^\circ} = C_1 \times \exp[-(SA^b)] + C_2 \tag{4}$$

where: $CSSD_{(SA)}$ = Cumulative Sheltered Storage Depth (mm)
SA = Shelter Angle (deg)
C_1 = scale parameter
b = shape parameter
C_2 = vertical displacement parameter

Because it is desirable, from a modeling standpoint, to predict the cumulative sheltered storage depth from the shelter angle distribution, the three parameters were assumed to be functions of the shelter angle distribution Weibull shape (k) and (C) scale coefficients. 384 individual pre- and post-tillage data sets obtained from three different soil types were used to develop the relationships between the CSSD and SA Weibull coefficients shown in Figures 2 and 3. Post-tillage data sets were obtained after tillage operations conducted with a point chisel, sweep chisel, offset disk, tandem disk, moldboard plow, and rotary tiller. Data sets included transect, point soil surface elevation data, both perpendicular and parallel to tillage direction. The shelter angle Weibull shape parameter (k) did not show a particularly strong relationship to any of the CSSD parameters, as shown in Figure 2. Therefore, oly Weibull C values were included in the subsequent preliminary regression analysis.

$$C1_{(CSSD)} = 0.302200 * C_{(SA)} * C_{(SA)} - 3.959 * C_{(SA)} + 32.8 \quad (R^2 = 0.792)$$
$$C2_{(CSSD)} = -0.060100 * C_{(SA)} * C_{(SA)} + 1.629 * C_{(SA)} - 10.45 \quad (R^2 = 0.493)$$
$$b_{(CSSD)} = -0.009496 * C_{(SA)} + 0.5217 \quad (R^2 = 0.679)$$

SA AND CSSD USE IN WEPS:

The shelter angle and the cumulative sheltered storage depth distributions are expected to be useful in wind erosion modeling efforts in the following ways: 1) By knowing the shelter angle distribution, the fraction of saltating particles impacting unsheltered surface areas can be estimated. If the percent of aggregates exposed at the surface and fraction of intervening crusted or loose soil areas are known, the fraction of saltating particles impacting clods, crust, and loose material can be computed assuming positions for clods, crust, and loose material; 2) The shelter angle distribution should provide a relationship between surface roughness and threshold surface friction velocities; and 3) the cumulative sheltered storage depth distribution along with surface aggregate size distribution, should indicate the changes in the amount of surface area and volume available for deposition and shelter from abrading saltating material during a wind erosion event.

CONCLUSION:

The PC-based PMP was successful in automating the acquisition of transect, surface elevation data from pin meter photographs. The shelter angle frequency distribution and cumulative sheltered storage depth appear to provide relevant information for WEPS with respect to estimating the fraction of sheltered surface area and the storage capacity in the sheltered areas on the surface. The cumulative sheltered storage depth distribution should provide an estimate of how a soil surface's trapping potential changes with deposition during a wind erosion event. The three parameters (C_1, b, C_2) of the exponential function used to describe the cumulative sheltered storage depth are reasonably related to the shelter angle Weibull distribution scale (C) parameter but appear to be relatively independent of the shape (k) parameter.

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