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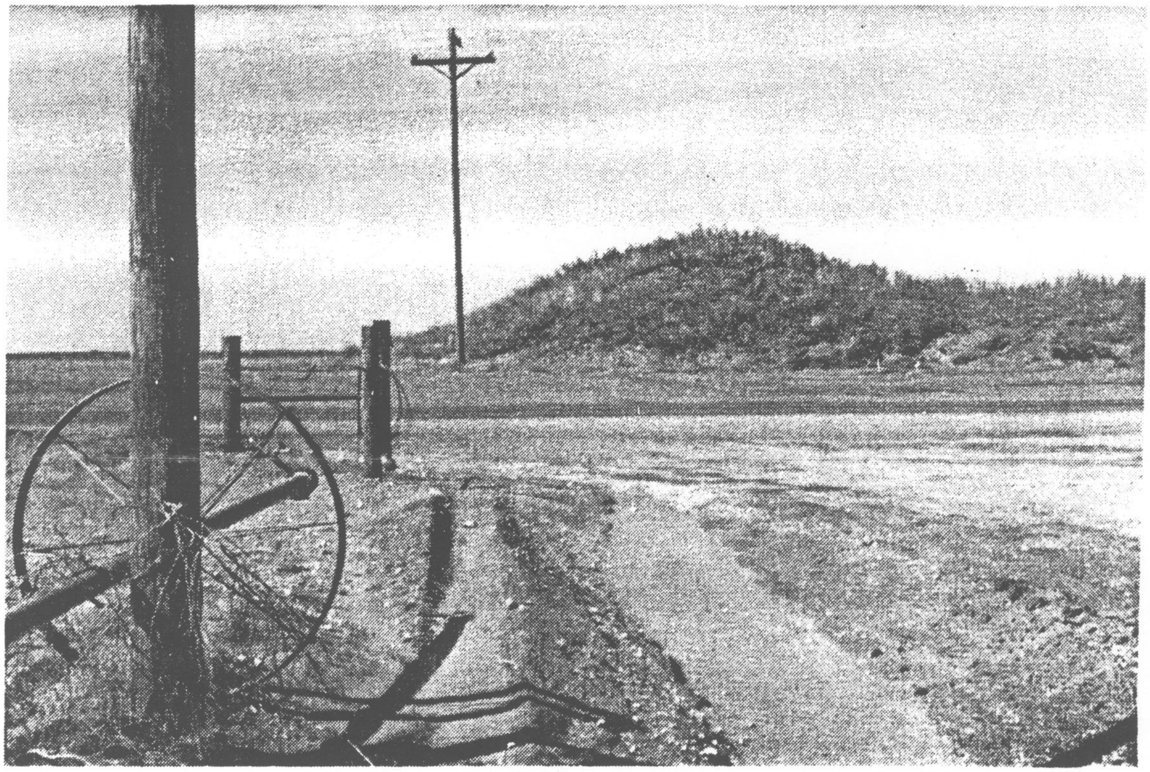

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SOIL MEASUREMENTS TO ESTIMATE ERODIBILITY BY WIND

by

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ABSTRACT

Dry soil-aggregate stability and aggregate-size distribution are primary factors affecting soil susceptibility to wind erosion. Dry, loose, finely divided materials are easily detached and transported by wind as shear friction velocity exceeds threshold friction velocity. Also, as aggregate resistance to abrasion from external physical forces increases, aggregate susceptibility to wind erosion decreases. Therefore, in wind erosion control and prediction modeling, it is important to know both dry-aggregate stability and aggregate-size distribution. This paper presents methods for measuring both of these soil properties. It was found that the logarithm of abrasive soil loss was linearly related to aggregate crushing energy, where crushing energy is the work needed to crush an aggregate to a specified end point, divided by the mass of the aggregate. For aggregates that are size-distributed log-normally, geometric mean diameter and geometric standard deviation can be calculated from two sieve cuts by use of the error function of the normal distribution. Distribution parameters also can be calculated from more complete sieving, as with nested rotary sieves. Once distribution parameters are known, the mass fraction of aggregates greater or less than any specified diameter can be calculated.

INTRODUCTION

Wind erosion research scientists have been charged to develop a physically based wind erosion model as a replacement for the wind erosion equation (Hagen, 1988). Improved wind erosion prediction technology requires that we improve our ability to measure and predict in time and space the susceptibility of soil to wind erosion.

The main properties of dry soil aggregates affecting their susceptibility to wind erosion are stability and size distribution. Aggregate density to a lesser extent affects soil erodibility but is much less variable than stability and size distribution. Soil-aggregate stability and size distribution vary widely in time and space.

Chepil (1950) determined from wind tunnel studies relative erodibility of soil as a function of proportions of dry soil aggregates in various sizes. Then from field studies (Chepil, 1960) converted relative erodibility to actual soil loss for specified conditions which was the basis for soil erodibility factor of the wind erosion equation (Woodruff and Siddoway, 1965). From their data, it is seen that nonaggregated sandy soils with only 1% of the sand having diameters greater than 0.84 mm are 10 and 100 times more erodible than aggregated soils with 53 and 77% of their aggregates greater than 0.84 mm, respectively (Woodruff and Siddoway, 1965). Similarly, dry aggregate stability may differ a hundredfold between soils.

DRY AGGREGATE STABILITY

Various methods based on different principles have been used to evaluate dry aggregate stability. Principles include relative aggregate size reduction from applied forces, rupture stress, and energy consumed in size reduction. In the relative size reduction technique, the aggregates were subjected to external forces in several ways: (1) placing in metal cylinders that were inverted end-over-end 20 times (Chepil, 1951); (2) repeated rotary sieving (Chepil, 1953); and (3) vigorous sieving with flat sieves (Toogood, 1978). For rupture stress measurement, aggregates were diametrically loaded between parallel plates (Rogowski et al., 1968; Rogowski and Kirkham, 1976; Skidmore and Powers, 1982).

Energy consumed in size reduction has been measured in a couple of different ways. Recognizing the desirability of knowing the work required to subdivide aggregates into smaller units, Marshall and Quirk (1950) used a drop-shatter method. Air-dried samples were shattered by dropping them onto a concrete floor from various heights. The kinetic energy was dissipated by impact with the hard surface. Others (Grossman et al., 1959; Farrell et al., 1967; Gill and McCreery, 1960) have used the drop-shatter technique to establish the relationship between the energy imparted to the soil and the degree of fragmentation.

Skidmore and Powers (1982) measured the energy consumed in crushing an aggregate by integrating the area under the force against a distance curve. Boyd et al. (1983) developed a soil-aggregate crushing-energy meter, SACEM, for measuring the energy consumed in crushing an aggregate.

Skidmore et al. (1988) evaluated four different measures of aggregate stability. The names and unit of measurement for each of these methods were: crushing-energy/surface-area (J/m^2), crushing energy (J/kg), rupture stress (kPa), and initial break force (N). Crushing-energy/surface-area was the work done in crushing an aggregate divided by the new surface area exposed, which gave energy per unit of surface area. The surface area was calculated by using the arithmetic mean of each of the sieve size fractions and assuming that the aggregates were spherical. The crushing energy was calculated by dividing the work done in crushing an aggregate by the mass of the aggregate being crushed. The rupture stress was calculated by dividing the initial break force by the cross sectional area of the aggregate. This required an independent measurement of aggregate density. The initial break force was simply the force on the aggregate at initial fracture.

Coefficient of variation for crushing energy (J/kg) < crushing-energy/surface area (J/m^2) < rupture stress (kPa) < initial break force (N). These four methods correlated reasonably well. When regressed on each other, the coefficients of determination ranged from 0.90 to 0.97. Sample numbers required to estimate the true mean within 25% of the mean at 0.05 level of significance were 10, 12, 20, and 22 for crushing energy, crushing-energy/surface area, rupture stress, and initial break force, respectively.

In general, the ranking of simplicity-of-measurement is in the same order as sample numbers required to estimate the mean value. The initial break force is easiest to measure but requires the greatest numbers of measurements. For the crushing-energy/surface-area method, work required to break aggregate bonds and the newly created external surface area are measured. This method also had the greatest range, more than two orders of magnitude, between the soft and hard soils. One of the drawbacks of this method is the tedium of measuring the new surface area exposed as a result of the crushing.

The energy consumed in size reduction of the crushing-energy method was also measured but instead of dividing by new surface exposed, the crushing energy was divided by the mass of the aggregate, thus making it more important to crush to the same end point each time. In spite of that, this method required the fewest aggregates for an estimate of the mean. The measurement is extremely simple but does require special equipment for measuring the energy (Boyd et al., 1983).

In a separate experiment, Skidmore et al. (1988) evaluated abrasive soil loss as influenced by aggregate stability. Soil loss correlated well with the aggregates' resistance to crushing. Log abrasive soil loss was linearly related to aggregate stability (crushing energy method), yielding a coefficient of determination of 0.99.

AGGREGATE SIZE DISTRIBUTION

Soil is sieved to determine the mass fraction of aggregates within various size classes. At least once each decade during the past half century, wind erosion researchers have contributed new information on rotary sieves and sieving for determining soil aggregate size distribution and stability. These papers include: Chepil and Bisal (1943) a rotary sieve method; Chepil (1952) an improved rotary sieve; Chepil (1962) a compact rotary sieve; Lyles et al. (1970) a modified rotary sieve; and Fryrear (1985) a rapid rotary sieve.

Chepil and Bisal (1943) proposed the rotary sieve over hand sieving mainly because of the wide variance in results obtained among different operators. They attributed this to differences in personal judgment as to the amount of shaking required. Variance between two operators was reduced by using the mechanically operated rotary sieve.

Results obtained by the various models of rotary sieves did not agree well. Lyles et al. (1970) tested the original, improved, compact, and modified rotary sieves for sieving accuracy with a nonabrasive stone, sand, and gravel mixture and found average errors of 9.4, 32.7, 13.0, and 2.3 percent, respectively. The improved accuracy of the modified rotary sieve was achieved by giving major consideration to mesh length, the primary factor controlling the time sieve material remains on the mesh area.

Even with stable material, size separation by sieving is inherently inaccurate, because of the difficulty of defining unambiguously the point at which to stop the sieving. Part of the difficulty arises because the "near-mesh" particles require many encounters with the sieve surface in order to pass through (Gupta et al., 1975). With material like soil aggregates, which become abraded or attrited during sieving, not only is defining the end point more difficult but fragile aggregates as from sandy soils may disappear during sieving.

Hagen et al. (1987) showed that for aggregates that are size distributed log-normally, the mass fraction of aggregates whose diameters are greater or less than some diameter may be represented by use of the error function of the normal distribution curve. This technique requires only two sieve cuts, from which the geometric mean diameter and geometric standard deviation are calculated. Since these two parameters describe the size distribution of log-normally distributed aggregates, the mass fraction of aggregates greater than some user-selected diameter can be calculated easily.

REFERENCES

Boyd, D. W., E. L. Skidmore, and J. G. Thompson. 1983. A soil-aggregate crushing-energy meter. Soil Sci. Soc. Am. J. 47:313-316.

Chepil, W. S. 1950. Properties of soil which influence wind erosion: II. Dry aggregate structure as an index of erodibility. Soil Sci. 69:403-414.

Chepil, W. S. 1951. Properties of soil which influence wind erosion: V. Mechanical stability of structure. Soil Sci. 72:465-478.

Chepil, W. S. 1952. Improved rotary sieve for measuring state and stability of dry soil structure. Soil Sci. Soc. Am. Proc. 16:113-117.

Chepil, W. S. 1953. Field structure of cultivated soils with special reference to erodibility by wind. Soil Sci. Soc. Am. Proc. 17:185-190.

Chepil, W. S. 1960. Conversion of relative field erodibility to annual soil loss by wind. Soil Sci. Soc. Am. Proc. 24:143-145.

Chepil, W. S. 1962. A compact rotary sieve and the importance of dry sieving in physical soil analysis. Soil Sci. Soc. Am. Proc. 26:4-6.

Chepil, W. S. and F. Bisal. 1943. A rotary sieve method for determining the size distribution of soil clods. Soil Sci. 56:95-100.

Farrell, D. A., E. L. Greacen, and W. E. Larson. 1967. The effect of water content on axial strain in a loam soil under tension and compression. Soil Sci. Soc. Am. Proc. 31:445-450.

Fryrear, D. W. 1985. Determining soil aggregate stability with a rapid rotary sieve. J. Soil and Water Conserv. 40:231-233.

Gill, W. R. and W. F. McCreery. 1960. Relation of size of cut to tillage tool efficiency. Agric. Eng. 41:372-374, 381.

Grossman, R. B., J. B. Fehrenbacker, and A. H. Beavers. 1959. Fragipan soils of Illinois: I. General characterization and field relationships of Hosmer silt loam. Soil Sci. Soc. Am. Proc. 23:65-70.

Gupta, V. S., D. W. Fuerstenau, and T. S. Mika. 1975. An investigation of sieving in the presence of attrition. Powder Technol. 11:257-271.

Hagen, L. J. 1988. New wind erosion model developments in the USDA. Proceedings of the Wind Erosion Conference, Texas Tech University, Lubbock, Texas.

Hagen, L. J., E. L. Skidmore, D. W. Fryrear. 1987. Using two sieves to characterize dry soil aggregate size distribution. Transactions of the ASAE 30:162-165.

Lyles, L., J. D. Dickerson, and L. A. Disrud. 1970. Modified rotary sieve for improved accuracy. Soil Science 109:207-210.

Marshall, T. J. and J. P. Quirk. 1950. Stability of structural aggregates of dry soil. Aust. J. Agric. Res. 1:266-275.

Rogowski, A. S. and D. Kirkham. 1976. Strength of soil aggregates: influence of size, density, and clay and organic matter content. Med. Fac. Landbouww. Rijksuniv. Gent 41:85-100.

Rogowski, A. S., W. C. Moldenhauer, and D. Kirkham. 1968. Rupture parameters of soil aggregates. Soil Sci. Soc. Am. Proc. 32:720-724.

Skidmore, E. L., J. B. Layton, and L. J. Hagen. 1988. Dry soil-aggregate stability: measuring and relating to wind erosion. In preparation.

Skidmore, E. L. and D. H. Powers. 1982. Dry soil-aggregate stability: energy-based index. Soil Sci. Soc. Am. J. 46:1274-1279.

Toogood, J. A. 1978. Relation of aggregate stability to property of Alberta soils. pp. 211-215. In W. W. Emerson, R. D. Bond, and A. R. Dexter (eds.) Modification of Soil Structure. John Wiley and Sons, New York.

Woodruff, N. P. and F. H. Siddoway. 1965. A wind erosion equation. Soil Sci. Soc. Am. Proc. 29:602-608.