In : Lee, Jeffrey A. and Zobeck, Ted M., 2002, Proceedings of ICAR5/GCTE-SEN Joint Conference, International Center for Arid and Semiarid Lands Studies, Texas Tech University, Lubbock, Texas, USA Publication 02-2 p. 317

How Wind Erosion Processes Affect Selection and Performance of Erosion Control Systems

L. J. Hagen, USDA, ARS, Wind Erosion Research Unit, Kansas State Univ., Manhattan, Kansas (E-mail: hagen@weru.ksu.edu)

Introduction

During the past decade, the physical processes governing erosion of soil by wind have been investigated by a number of researchers (Anderson et al., 1991; Armbrust and Bilbro, 1997; Gillette et al., 1997; Hagen et al.; 1992; Hagen et al.; 1999; Marticorena et al., 1997; and Mirzamostafa et al., 1998). The results of these investigations have improved our understanding of several wind erosion phenomenon. Among these are estimates of erosion threshold wind speeds, entrainment rates of loose soil, abrasion rates of crust/clods, breakage rates of saltation/creep, interception efficiencies of plants, and trapping rates of eroding soil. But to fully utilize our improved understanding of these processes, wind erosion models must incorporate them.

However, even models that incorporate most of these processes still rely upon the model user to optimize the design of individual wind erosion control systems. Generally, the goal of optimization is to achieve acceptable erosion control at minimum cost for a given land management system. While implementing erosion controls may or may not provide short term positive economic returns for the land manager, failure to control erosion often generates large offsite costs (Huszar and Piper, 1986).

Effectively mitigating offsite impacts may include the need to consider other factors in addition to total soil loss. For example, emissions of PM-10 (i.e., particulate matter less than 10 microns in diameter) from farmlands and other disturbed areas near the rural-urban interface may prevent urban areas from meeting air quality standards. Other critical offsite impacts are caused both nutrient and sediment transport to water bodies, pesticide movement to non-target areas, and decreased visibilities that hinder transportation. For all these cases, erosion control specialists need to understand the influence of various processes on their design parameters. They also may need to use specialized designs that vary depending on the location of critical offsite targets.

The objectives of this report are twofold. First, to present a brief overview of several of the wind erosion processes, and second, to suggest how these processes might influence selection and design of wind erosion controls.

Erosion Processes and Design of Controls

Soil Roughness

Currently, millions of hectares are protected from erosive winds by the combined use of soil roughness and immobile soil aggregates. It is a fragile control system and subject to failure when the soil aggregation decreases during prolonged droughts. The macro roughness of bare soil, as measured by conventional pin meters, controls the aerodynamic roughness of the surface. But the macro roughness is not highly correlated to the surface aggregate size distribution (Wagner and Hagen, 1992). Hence, these should be treated as separate parameters in design of erosion control systems.

Oriented soil roughness such as tillage ridges control erosion primarily by trapping and sheltering mobile particles between the ridges. However, their level of efficacy is variable depending on the wind regime speed and directional variability as well as surface conditions. They are most effective when the tops of the ridged surface are armored with immobile aggregates or residues. This raises the threshold wind speed at which erosion begins and sharply reduces the transport rate of mobile particles. Experiments show that as the clod cover on ridges is increased and mobile soil decreased, saltating particles no longer impact loose soil so the threshold velocity increases from dynamic to the static threshold (Hagen and Armbrust, 1992).

When ridges are not fully armored with immobile material and considerable soil movement is anticipated, the designer should specify creation of large ridges in order to maintain sufficient storage capacity in their sheltered region for the mobile soil particles. When erosive winds parallel to ridges are expected, random roughness and perhaps furrow dikes are useful to further enhance erosion control. Ridges are generally constructed parallel to crop strips. However, in some wind regimes, an enhancement of erosion control can be gained by separately optimizing both the angle of the crop strips and the tillage ridges.

The shearing stress on ridge tops and the turbulent diffusion above ridges is enhanced compared to a smooth surface. Thus, if tillage ridges are composed of mostly suspension-size soil aggregates, the ridges may increase rather than control erosion for this field condition.

Downwind Field Length to Nonerodible Boundaries

Reducing field length limits the opportunity for saltating particles to abrade and breakdown the immobile soil aggregates and crust cover over long downwind distances. Computer simulations of wind erosion on long fields with initially uniform surfaces, revealed that for some surface conditions there were intermediate field lengths that produced a significant maximum of soil loss per unit area. Many fields that are relatively stable often include small areas that may begin to erode and thereby destabilize the downwind area. In such cases, limiting field length can prevent large downwind areas from becoming unstable and eroding. Typically, strip cropping is used to limit field length, but any control device that traps the saltation may be used. The trapping capacity of downwind traps also should be evaluated in the design process.

Standing and Flat Vegetation

Standing vegetation controls erosion primarily by reducing wind shearing stress on the surface and, secondarily by intercepting particles of moving soil (Hagen, 1996). Obviously, the efficacy of the shear reduction on erosion is not a constant but depends on the particular wind regime. Nevertheless, residue stalks are generally 5 to 10 times more effective standing than flat. Hence, design of land management practices that reduce the flattening of standing vegetation are warranted in erosion prone areas.

Flat vegetation controls erosion mainly by sheltering the surface from impacting particles and, secondarily by reducing shear stress on the surface. At a fixed wind speed, one can readily estimate the reduction in emission rate of loose sand by estimating the shelter area provided by flat residue of a given diameter and assuming an average particle impact angles of 12 degrees above horizontal. Flat residue often tends to blow away, so management practices to keep it in place are useful.

Flat residue is more effective than standing in controlling water erosion. Thus, where both are significant, the designer must aim for an optimum combination of standing and flat residues to attain target values of erosion control.

Wind Barriers

Wind barriers may be composed of natural or manufactured materials. Their main function is to reduce wind speeds near the surface both slightly upwind and as well as downwind from the barrier. In general, barriers are useful for controlling wind erosion, but there are a number of challenges in designing optimum barrier systems. Barriers are most effective when combined with other erosion controls, because their zone of erosion control expands with increases in threshold velocity of the soil surface. Generally, it is critical to obtain barrier porosities less 70 percent and orient the barrier normal to the erosive winds during periods when the soil is erodible. Meeting these criteria can often require natural barriers to be composed of at least two rows.

Tall barriers on the downwind side of wide fields may trap much of the saltation/creep component of the eroding soil on the field, so models reporting only net field loss may suggest there was acceptable erosion control. Hence, when downwind trapping occurs, one challenge is to present sufficient information to those designing controls to show that there may be both a loss and deposition problem occurring on the same field.

A typical design with barriers and strip crops is to place the barriers on the strip borders. But barriers typically trap soil moving near the surface, and thus, serve as a non-erodible field boundary. Hence, in some design situations placing the barrier in the center of each strip can serve to reduce field lengths and thus, improve the level of erosion control.

Finally, one case where barriers may not be useful occurs when barriers are widely spaced on a surface composed mainly of saltation-size particles such as a coarse sand (Schwartz et al., 1997). In this case, the wind entrains sand until it reaches transport capacity and transports the load of sand to the nearest barrier. This process is then repeated across the field. Without barriers, the net removal from the field surface is equal to that with barriers, but rearrangement of surface sand on the field surface may be increased by the barriers.

Conclusions

In general, abatement of wind erosion must be achieved by combining a number of control mechanisms in a single control system. Significant progress toward optimizing wind erosion control systems can be achieved by considering how wind erosion processes affect the erodible surface conditions in particular wind regimes.

In : Lee, Jeffrey A. and Zobeck, Ted M., 2002, Proceedings of ICAR5/GCTE-SEN Joint Conference, International Center for Arid and Semiarid Lands Studies, Texas Tech University, Lubbock, Texas, USA Publication 02-2 p. 320

References

Anderson, R.S., M. Sorenson,, and B.B. Willets. 1991. A review of recent progress in our understanding of aeolian sediment transport. Acta Mechanica (Supplement) 1:1-19.

Armbrust, D.V. and J.D. Bilbro. 1997. Relating plant canopy characteristics to soil transport capacity by wind. Agron. J. 89(2):157-162.

Gillette, D.A., D.W. Fryrear, J.B. Xiao, P. Stockton, D.Ono, P.J. Helm, T.E. Gill, and T. Ley. 1997. Large-scale variability of wind erosion mass flux rates at Owens Lake. 1. Vertical profiles of horizontal mass fluxes of wind-eroded particles with diameter greater than 50 μm. J. of Geophys. Res. 102(D22):25,977-25,987.

Hagen, L.J. 1996. Crop residue effects on aerodynamic processes and wind erosion. Theoretical and Applied Climatology 54:39-46.

Hagen, L.J. and D.V. Armbrust. 1992. Aerodynamic roughness and saltation trapping efficiency of tillage ridges. Transactions of the ASAE 35(5):1179-1184.

Hagen, L.J., E.L. Skidmore, and A. Saleh. 1992. Wind erosion: prediction of aggregate abrasion coefficients. Transactions of the ASAE 35(6):1847-1850.

Hagen, L.J., L.E.Wagner, and E.L. Skidmore. 1999. Analytical solutions and sensitivity analyses for sediment transport in WEPS. Transactions of the ASAE 42(6):1715-1721.

Huszar, P.C. and S.L. Piper. 1986. Re-examination of the off-site costs from wind erosion in New Mexico. J. Soil and Water Cons. 44:334-338.

Marticorena, B., G. Bergametti, D.A. Gillette, and J. Belnap. 1997. Factors controlling threshold friction velocity in semiarid and arid areas of the United States. J. of Geophys. Res. 1 102 (D19): 23,277-23,287.

Mirzamostafa, N., L.J. Hagen, L.R. Stone, and E.L. Skidmore. 1998. Soil and aggregate texture effects on suspension components from wind erosion. Soil Sci. Soc. Amer. J. 62:1351-1361.

Schwartz, R.C., D.W. Fryrear, and A.S.R. Juo. 1997. Simulation of wind forces and erosion in a field with windbreaks. Soil Sci. 162(5):372-381.

Wagner, L.E. and L.J. Hagen. 1992. Relationship between shelter angle and surface roughness and cumulative sheltered storage depth. In: J. Karacsony and G. Szalai (eds.) Proceedings of the International Wind Erosion Workshop of CIGR; September 10-12.