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Wind Erodibility of Knolly Terrain

The wind erosion equation for determining the conditions of soil cloddiness, soil surface roughness, vegetative cover, and width of field needed to reduce potential soil loss to a tolerable amount has been applicable so far only to a level terrain. In this article the authors present an analysis of research data from which they derive suggested guidelines for estimating the conditions required to reduce potential soil loss from other than level terrain.

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THE amount of soil lost from both level and knolly terrains due to the erosive action of wind has not been measured directly because of the difficulties involved in finding comparable sites where accurate measurements could be made. It is easier, than attempting to find comparable fields and measuring soil loss on them, to determine the wind drag on knolls, then to determine the influence of the drag on soil loss in a wind tunnel calibrated against soil loss for a standard width of flat field, and then to compute soil loss resulting from the wind drag on the different knolls in the field. This approach has been used to determine the relative erodibility of knolly and level terrains.

In one of the earliest studies of the effect of knolls on wind velocity and surface drag, Doughty and staff (*6*) found that over knolls with slopes up to about 1.5 percent, the lines of equal wind velocity (figure 1) are virtually parallel and generally conform with a pattern that exists over level ground. But over knolls with slopes greater than 1.5 percent, the lines representing equal velocity are compressed, indicating that a steeper velocity gradient occurs there.

The greater the slope, the steeper is the wind velocity gradient and the greater is the wind drag, provided the length of slope does not exceed a certain limit. The limit for a 3 percent slope is about 300 feet; for a 10 percent slope it is about 800 feet. Beyond those limits the lines of equal wind velocity tend to follow the contour of the land. Thus, for practical purposes, topographic protrusions whose slopes exceed 1.5 percent and whose slope lengths are within the limits mentioned are called knolls.

The wind velocity gradient over knolls, as expressed by the rate of increase of velocity with $\log_{10}$ of height, is called the drag velocity, shown by symbol $V*$, and the surface drag, τ, is equal to $\rho V*^2$, with ρ the density of the air (*1*). Soil loss was found to vary as $\tau^{2.5}$ (*7*). When V_* is expressed in cm per sec and ρ in g per cm^3, τ is in dynes per cm^2.

To compute the relative soil loss from knolls with different slopes, the (a), (b), and (c) portions of figure 1, increased in scale, were employed. Assuming that the uppermost velocity line at the top of a knoll with 1.5 percent slope is at a height of 1 foot, then the uppermost line at the top of a knoll with a 3 percent slope is at 0.6 foot, while over a knoll with a 6 percent slope it is at 0.32 foot and over a knoll with a 10 percent slope it is at 0.18 foot.

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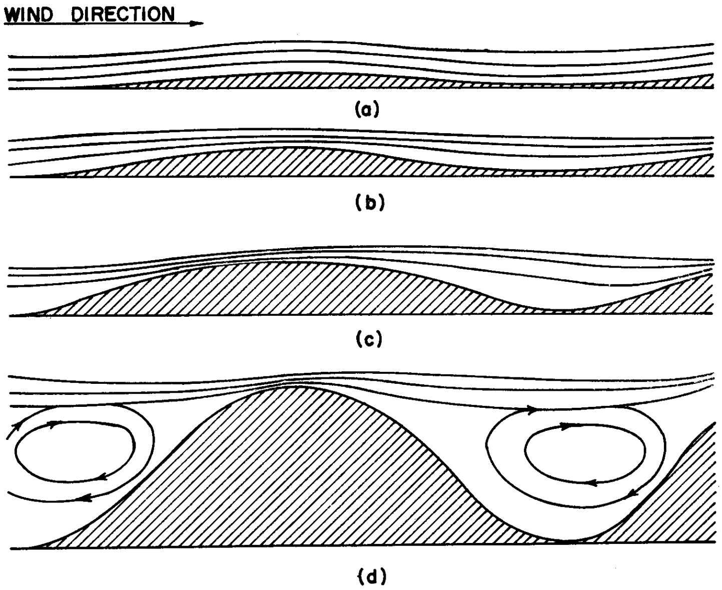
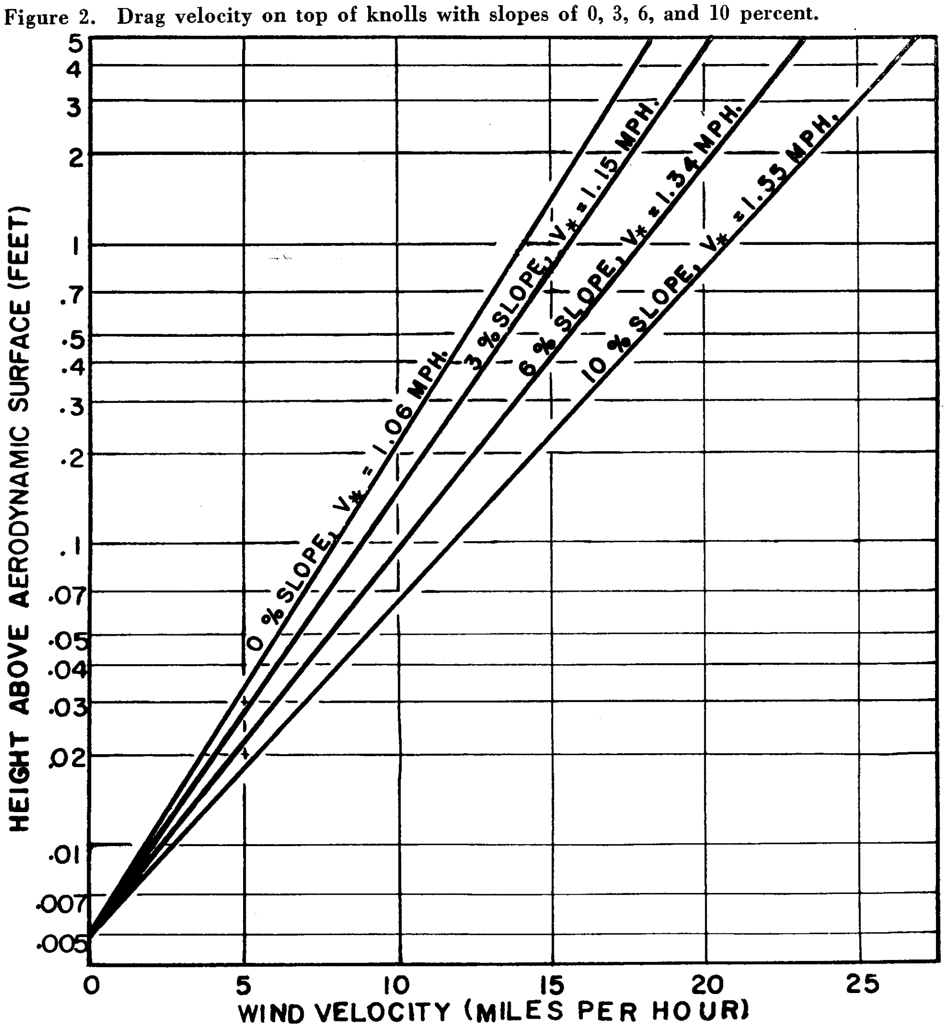


Figure 1. Lines of equal wind velocity over (a) a change of elevation of 1.5 feet in 100 feet, (b) a knoll not exceeding 400 feet in diameter with 3 percent slopes, (c) a knoll not exceeding 400 feet in diameter with 6 percent slopes, and (d) ridges with slopes greater than 25 percent. All diagrams are not to scale. (After Doughty and staff, 1943 (*6*); and data secured in 1962.)

Now, assume that the point of zero velocity, *k*, for an erodible soil surface is at the 0.005-foot height, as it would be on a smooth, bare fallow surface, and that wind velocity at the 1-foot height over a level surface is 14 miles per hour (any velocity could be assumed). The velocity distributions over knolls with different slopes can then be shown graphically on a semilog scale by drawing straight lines joining *k* with a 14-mile-per-hour wind velocity at heights of 1, 0.6, 0.32, and 0.18 foot. This procedure was used in constructing figure 2.

Figure 2. Drag velocity on top of knolls with slopes of 0, 3, 6, and 10 percent.



Since drag velocity, V_*, equals velocity at 30 *k* divided by 8.5, then V_* equals 1.06, 1.15, 1.34, and 1.55 miles per hour, while τ equals 2.7, 3.2, 4.3, and 5.7 dynes per cm^2, respectively (*1*). Therefore, the relative soil loss ($\tau^{2.5}$ for any surface divided by $\tau^{2.5}$ for a level surface) is equal to 100, 150, 320, and 660 percent at the top of knolls with 0, 3, 6, and 10 percent slopes, respectively. The relative soil loss so determined is expressed by curve (a) in figure 3.

The relative soil loss from the windward slopes of knolls is less than that from the tops of knolls because the angle of repose of the topsoil grains is greater on the windward slopes than on level ground. The wind drag required to move the grains varies proportionately with the tangent of the angle of repose, Φ (expressed in degrees), of the top grains with respect to the mean drag level of the wind (*2*). Since Φ equals 24, 25.6, 27.5, and 29.75 degrees for 0, 3, 6, and 10 percent slopes, the relative soil loss expressed as $\left(\frac{\tau}{\tan\,\Phi}\right)^{2.5}$ for any windward slope divided by $\left(\frac{\tau}{\tan\,\Phi}\right)^{2.5}$ for a level surface equals 100, 130, 230, and 370 percent, respectively. The relative soil loss, I_s, so determined, is expressed by curve (b) in figure 3. Curve (b) represents the relative soil loss from windward slopes where the average wind drag is about the same as at the tops of knolls. Virtually the same intensity of wind drag that occurs at the tops of knolls occurs throughout the upper one-third of windward slopes.

Both curves (a) and (b) in figure 3 conform with the equation $I_s = as^b + (cd^s)^{-1}$, where s is percentage knoll slope and a, b, c, and d are constants.

Estimating Potential Soil Loss

To estimate the potential soil loss from the top of a knoll, it is necessary to multiply the potential soil loss, *I*, for a level surface by the relative soil loss, I_s, shown by curve (a) in figure 3 for a particular average knoll slope. To estimate the potential soil loss from the windward slope where the wind drag is about the same as on top of the knoll, it is necessary to multiply *I* for a level surface by I_s shown by curve (b) in figure 3 for a particular average knoll slope. The wind erosion equation (*5*) can then be used to determine the intensity of practices needed to reduce to any level the potential soil loss at the

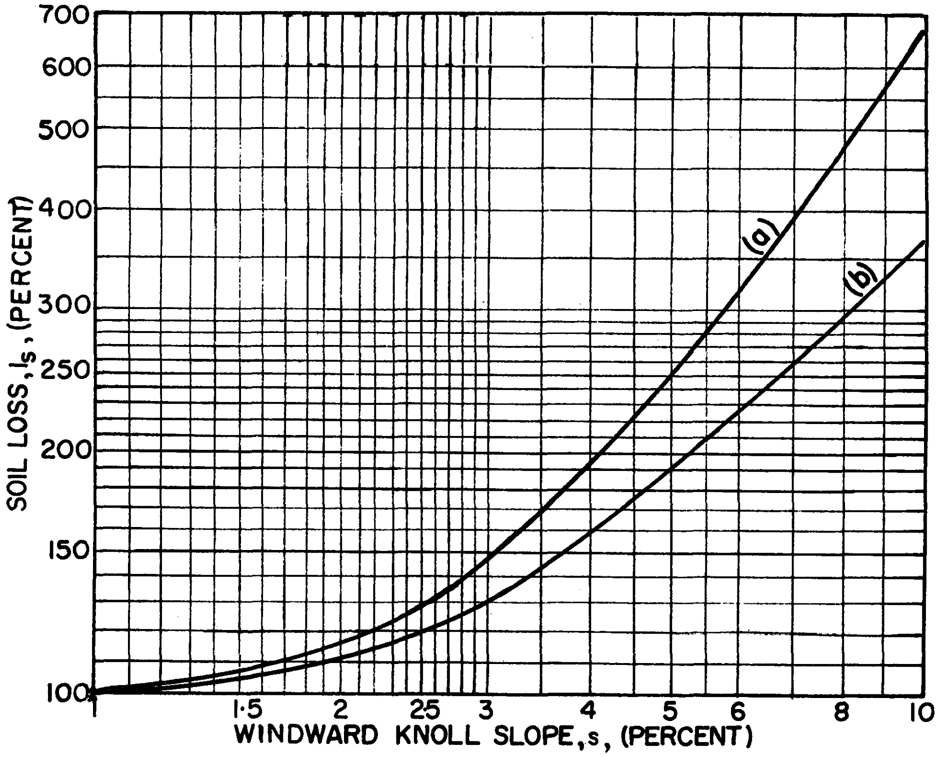


Figure 3. Potential soil loss expressed as percentage of that on level ground: (a) from top of knoll, and (b) from windward slope where the wind drag is about the same as on top of knoll.

top and for some distance down the windward slope of the knoll. I_s always equals or is greater than 100 percent; this indicates that more intensive practices are needed to control wind erosion on knolls than on level ground unless all or nearly all of the knoll slope faces away from the significantly prevailing wind erosion direction (*4*).

The drag velocity and the surface drag on the leeward and the lower portions of the knoll slopes are generally lower than on level or nearly level ground because the knolls shelter the adjacent ground. However, sheltering is not uniform and varies with wind direction. Furthermore, sheltering on the leeward slopes is of little consequence because the impacts of jumping grains of soil material dislodged from tops of knolls cause soil removal from sheltered areas that otherwise would remain stable. Movement down the leeward slopes also is facilitated to some degree because the angle of repose of the grains there is smaller than on windward slopes. For these reasons, the windward and the leeward slopes, if they are no greater than 10 percent, do not differ greatly in susceptibility to wind erosion.

The foregoing analysis has revealed that knolly land generally is more erodible than level land. On the other hand, a surface with microroughness elements, such as cultivator furrows and ridges, is less erodible than a smooth one (*3*). Therefore, a surface with a scale of roughness somewhere between knolly and microrough must be as erodible as a level surface. That scale of roughness is not known at the present time.

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