1260

Designing narrow strip barrier systems to control wind erosion

L. J. HAGEN, E. L. SKIDMORE, and J. D. DICKERSON

ABSTRACT—Compared to conventional barriers, additional factors to consider in designing narrow strip barrier systems for wind erosion control include barrier capacity and trapping efficiency (TE), i.e., the percentage of soil entering a barrier strip that is retained. A prediction equation for TE, developed from wind tunnel tests, shows TE depends on barrier height, width, and windspeed. Two-row barriers provided the best combination of consistent performance and high TE per row. The wind erosion equation can be used to obtain an initial spacing for barriers with 100 percent TE, but the initial spacing must be reduced in proportion to TE to avoid excessive soil movement. If barrier capacity is low enough so the trapped soil also reduces barrier TE, the spacing needs to be further reduced or the barrier size must be increased.

BARRIER strips of small grains or grasses planted various distances apart are often used to control wind erosion (*1*, *4*, *5*). The strips may range in width from 10 feet to single rows and are planted in spring or fall.

Barrier strips may also be used to trap snow or shelter young plants from the wind. Used thusly, they are more effective than traditional tree windbreaks in providing uniform snow distribution and protection from wind when wind direction is not perpendicular to the barrier (*1*, *5*).

To control wind erosion a barrier system must reduce soil movement to a tolerable level, adequately hold the soil it traps, and permit optimum use of a field for crops. Past research (*2*, *3*) determined the spacing needed for alternate crop-fallow strips to control wind erosion. Those spacings were incorporated into a wind erosion equation (*6*, *7*). Consequently, the wind erosion equation can be used to design barrier-strip systems when the barriers have adequate capacity and 100 percent trapping efficiency (TE), i.e., trap 100 percent of the soil entering the barrier strip.

Narrow crop-barrier strips often have a TE less than 100 percent, however; and large differences in rate of soil movement can occur with equally spaced barriers, depending on their TE. In this study we evaluated TE of narrow crop-barrier strips and determined design procedures for barrier-strip systems when using barriers with less than 100 percent TE.

Barrier Trapping Efficiency

Procedure

Barrier TE was investigated experimentally using windspeed, barrier height, and barrier width as variables.

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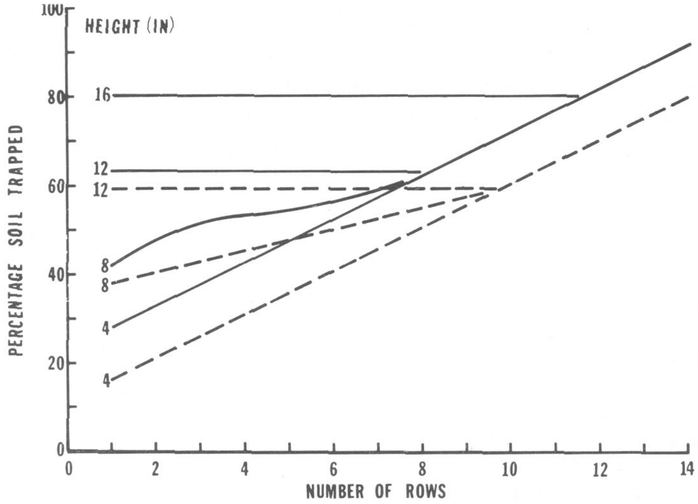


Figure 1. Trapping efficiencies (TE) for free-stream windspeeds of 25 mph (solid lines) and 30 mph (dashed lines) calculated from regression equation.

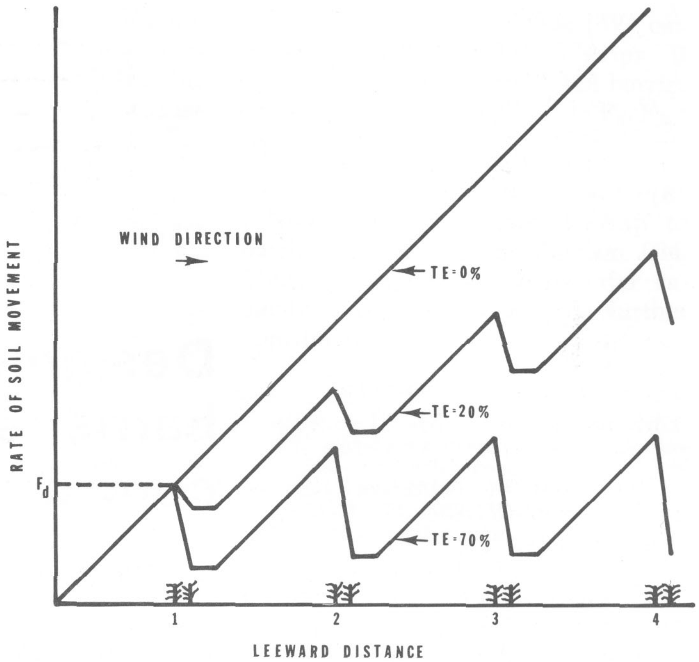


Figure 2. Effect of barrier trapping efficiency (TE) on rate of soil movement leeward from edge of *eroding field*.

A 30-foot, portable wind tunnel was positioned normal to barrier strip rows with each strip near the downstream end of the tunnel. Soil samplers [Bagnold type (2)] were placed both windward and leeward of the barrier strip in the tunnel. TE was determined by the difference in windward and leeward weight of the samples of eroding soil caught.

TE tests were conducted on winter wheat barriers 4, 6, and 9 inches tall and on sudangrass barriers 8 and 14 inches tall. The barriers were 1, 2, 4, 8, and 12 rows wide with 8-inch row spacings. Free-stream wind tunnel windspeed was used as a reference, and tests were made at four windspeeds from 22 to 38 miles per hour.

Results

Data from the winter wheat and sudangrass barriers were combined to form 109 TE observations. Stepwise, multiple regression was applied to the data, and a TE prediction equation with a coefficient of determiation (r^2) of .75 was computed as

$$\begin{aligned} TE = {} & 83.8 + 7.54(N) - 3.24(V) \\ & + .206(H)(V) \\ & - .653(H)(N) \qquad (1) \end{aligned}$$

where N is number of rows, H is barrier height in inches, and V is windspeed in miles per hour. As shown by a plot of the prediction equation (Figure 1), various combinations of barrier height and width can be used to achieve a given TE. Note also that small increases in barrier height or width do not always increase TE.

TE was inversely related to windspeed, because average height of soil flow increased and effective plant height decreased as windspeed increased. The data were mostly for standing plants, but single-row barriers occasionally were broken-over by windspeeds exceeding 30 miles per hour. Then their TE's were less than 10 percent. When tunnel windspeed decreased much below 22 miles per hour, TE for all barriers rose sharply because any obstruction trapped soil particles just starting to move.

If wind erosion control is the only goal, high TE per row of barrier minimizes the use of land for barriers. This can be accomplished by increasing the height of low barriers and using barrier widths with high TE per row. On a per row basis, TE was highest for single-row barriers and decreased as row numbers increased. Single-row barriers did not perform consistently, however, and tended to break-over at high windspeeds. Thus, a two-row barrier appears to be the most efficient use of land over a wide range of conditions. Factors such as high windspeed, low barrier height, or significant amounts of soil to trap could dictate use of barriers wider than two rows, however.

Barrier Strip Systems

Effect of Barrier TE on Spacing

Once barrier TE is known, proper barrier spacing can be calculated. Rate of soil movement across an unprotected, eroding field increases linearly, as shown by the sloping line in figure 2 (2). The linear increase continues until the carrying capacity of the wind is approached far downwind. Properly spacing wide crop barriers with high TE on an eroding field permits the soil-flow rate only to reach some design flow (F_d). In contrast, the effect of narrow barriers that trap only a percentage of the moving soil is illustrated by the stepped lines in figure 2. With narrow barriers, the soil-flow rate increases downwind until the constant percentage reduction in soil flow by the barrier equals the increase in soil flow between barriers.

From figure 2 we see that the maximum rate of soil movement between any two barriers (F_{jk}) depends on barrier TE and leeward distance. The subscripts (j and k) refer to the barriers that bound the leeward position of F_d and powers of TE. For example, from figure 2:

$$F_{12} = F_d\,(2 - TE)$$

and

$$F_{23} = F_d\,[3 - 3TE + (TE^2)]$$

Consequently, the ratio (F_d/F_{jk}) is a function of TE alone. Values of (F_d/F_{jk}) were calculated for TE's from 10 to 90 percent, in increments of 10, for up to 20 barriers in series (Figure 3). F_{jk} increases to maximum asymptotically. For barriers with TE greater than 60 percent, the maximum flow is reached after crossing 5 or fewer barriers.

So as not to exceed F_d, the distance between barriers with TE's less than 100 percent must be less than the distance between barriers with 100 percent TE's. Using the wind erosion equation (7), the barrier-strip spacing (W) for barriers with 100 percent TE and insignificant height can be determined. Then the spacing (W_n) of barrier strips with TE's less than 100 percent is

$$W_n = W(F_d/F_{jk}) + 10(H_b) \quad (2)$$

where H_b is the barrier height and its addition accounts for leeward area sheltered by the barrier. If the field is long enough so maximum soil flow is developed (Figure 3), then equation 2 reduces to

$$W_n = W(TE/100) + 10(H_b) \quad (3)$$

If other considerations dictate what W_n must be, W_n and an estimate of H_b can be used to compute TE necessary for wind erosion control, and then figure 1 can be used to determine the necessary barrier dimensions.

Effect of Barrier Capacity on Spacing

In designing a barrier system, barrier dimensions must be checked for capacity to hold the soil to be trapped. Field observations of filled barriers suggest models of filled barrier strips as shown in figure 4. In general, the momentum of saltating grains carry them past the first row of the barrier. The windward edge of the trapped sand should correspond roughly to the angle or repose for sand, 24 degrees; and the leeward edge must be a 12-degree or greater angle for the streamlines to detach from the surface. Finally, most barriers will fill only to about 2 inches from the top.

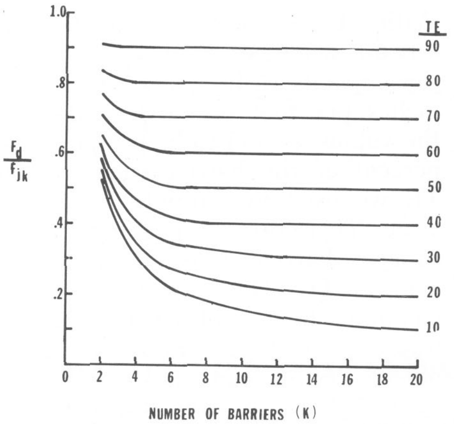


Figure 3. Ratio of design flow to actual maximum flow at various leeward positions for barriers of various trapping efficiencies.

From the geometry of the models, we computed barrier capacity per foot of barrier as shown by the dashed lines in figure 5.

The amount of soil to be trapped by a barrier can also be checked with the aid of figure 5 by using the design erodibility (tons per acre per year) from the wind erosion equation (7) and W_n to determine the soil volume to be trapped. If soil to be trapped exceeds 10 percent of the barrier capacity, the trapped soil will begin to reduce barrier TE. Hence, barrier height should be reduced by the height of the soil (H_m) in the barrier and the reduced barrier height in figure 1 should be used to obtain a new TE. Finally, W_n can be recomputed.

This procedure conservatively estimates W_n, because the barrier fills with less soil when W_n is decreased and TE will not decrease to the value used in the computation. Hence, if the soil to be trapped approaches 40 to 60 percent of the barrier volume, a couple of iterations of the procedure may be necessary to obtain accurate answers. If soil to be trapped exceeds 60 percent of the barrier capacity, abrasion of the barrier and increasing height of trapped soil in the airstream will sharply lower barrier TE. Then closer barrier spacing or larger barriers should be tried.

H_m can be estimated by assuming the soil is distributed in a partly filled barrier as it would be in a low barrier that is filled by the volume of soil to be trapped (Figure 4). The number of rows and volume of soil to be trapped in figure 5 can be used to get the height of the low, filled barrier. Then 2 inches must be subtracted to obtain H_m.

Application

Design Steps

First, use the wind erosion equation (6) and local experience to identify a field width and soil erodibility that will give adequate protection from wind erosion. The wind erosion equation assumes barriers have 100 percent TE and adequate capacity. Next, explore the kinds of narrow barrier strips that can be conveniently established, and note their characteristics during the wind erosion period. Consider things that will optimize the use of land for barriers, and compute TE for the chosen barrier type. Use barrier TE to calculate a new barrier spacing, and check to be sure the barrier has adequate capacity so barrier TE will not be affected by the amount of soil trapped. If soil to be trapped exceeds 10 percent of barrier

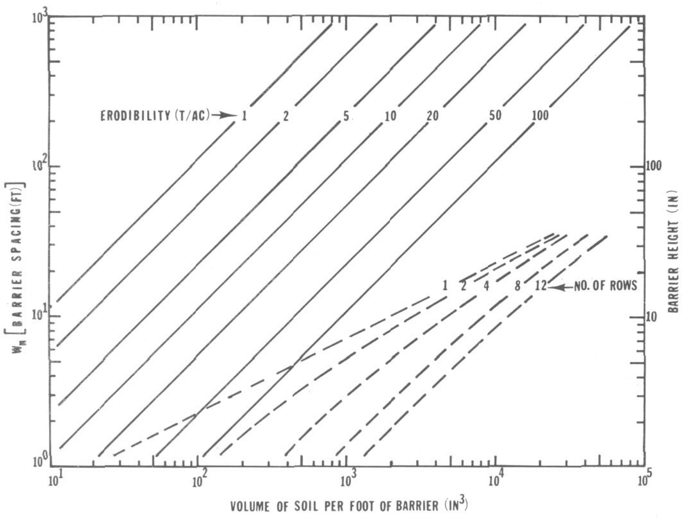
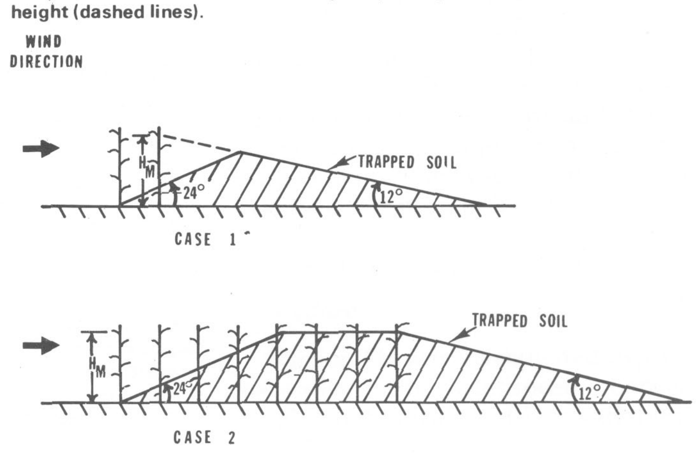


Figure 4. Models for computing barrier capacity.

Figure 5. Volume of soil to trap for given barrier spacing and soil erodibility (solid lines) and barrier capacity for given number of rows and height (dashed lines).



capacity, reduce barrier TE and recompute the field barrier spacing or increase barrier size. These general design steps should be applicable to a wide range of barrier types with TE's less than 100 percent. However, information is needed on TE of more kinds of narrow barriers.

Examples

Consider an example of a large field on which we will allow erosion of 5 tons per acre per year. Further, assume we find, by using the wind erosion equation (*6*), that wide barrier strips with a spacing (W) of 320 feet are needed. We decide, however, to use two-row rye barriers 8 inches tall to control wind erosion on the field. From figure 1 we find a TE of 40 percent for the rye barriers at a windspeed of 30 miles per hour. Because it is a large field, we will need many barriers (maximum soil-flow rate will be reached). From figure 3, we find (F_d/F_{jk}) is 0.4. The barrier spacing then is

$$W_n = 320(.4) + 10(.67) = 134.7 \text{ feet} \quad (4)$$

Using W_n of 135 feet and an erodibility of 5 tons per acre per year, figure 5 shows that about 630 cubic inches of soil per lineal foot of barrier will need to be trapped by the barrier. With a barrier height of 8 inches and a two-row barrier, figure 5 shows barrier capacity to be about 2,000 cubic inches per foot of barrier. Because the volume of soil to be trapped is 32 percent of the barrier capacity, the TE we used to compute W_n is too large. Therefore, we must use a larger capacity barrier or recompute W_n for a lower TE. Here we choose to recompute. First, subtract the height of trapped soil (H_m) from the barrier height. To estimate H_m, we find in figure 5 that a two-row, 4-inch barrier will hold 630 cubic inches of soil per foot. Because a barrier usually fills within about 2 inches of the top, H_m is 4 minus 2, or 2 inches. Now, from figure 1, we find a TE of 31 percent for the original barrier when reduced in height by H_m. Finally, the revised barrier spacing is

$$W_n = 320(.31) + 10(.67) = 105.9 \text{ feet} \quad (5)$$

Now design flow (F_d) will not be exceeded because barrier spacing has been reduced to account for lowered TE as the barrier fills.

The preceding example illustrates a case where TE was reduced as the barrier filled. For a more typical case, consider a wide vegetable field where erodibility must be held to 1 ton per acre per year. Assume the wind erosion equation shows spacing (W) can be 160 feet between barrier strips. If we again choose an 8-inch-tall barrier of rye, two-rows wide, we get (F_d/F_{jk}) equals .4 and

$$W_n = 160(.4) + 10(.67) = 70.7 \text{ feet} \quad (6)$$

Now the ratio of soil to trap to barrier capacity is 68/2000 or .034. Thus, 3.4 percent of the barrier capacity will be filled, and no further adjustment of W_n is necessary.

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