Annual Crops As Wind Barriers

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MANY crops are susceptible to wind damage, and portions of the Central Plains of the United States have been changed from fertile productive land into sand dunes by severe wind erosion. Research to determine factors that influence susceptibility of a soil surface to wind erosion has led to a better understanding of this problem.

The erodibility of a field can be reduced by various methods. Two common methods are (a) to reduce the surface wind velocity and (b) to roughen the soil surface. The use of annual barriers to reduce the surface wind velocity is not new. Rows of corn, sunflowers, mogar, proso, sudangrass, and sorghum have been used as annual barriers in the USSR to prevent wind erosion and to trap drifting snow (4, 8)*. The additional snow depth protects crops from winter kill, decreases depth of freezing, and increases soil permeability; therefore, there is less surface runoff and more moisture is available for plant growth. Russian scientists (9) report that sunflower barriers spaced 50 to 75 ft apart tripled the amount of water stored in the soil from winter snows. In Taiwan (6), handwoven artificial barriers are being used extensively along the coast to prevent wind erosion during the winter windy season. Perennial grass barriers on rice paddy dikes increase rice production 30 to 40 percent along the Taiwan coastal areas and 10 to 20 percent inland.

Farmers in the United States have planted narrow crop strips for many years, but exiguous research has been conducted on the influence of annual crop barriers on the erodibility of a field. In central Texas, 2 and 4-row barriers of grain sorghum and sudangrass spaced 15 to 20 ft apart protect the sandy soil on which peanuts are grown. Annual barriers are also grown in the lower Rio Grande Valley to protect young vegetable crops†, in the Northern Plains (5) to shelter new tree plantings, and in the Central Plains (10) to trap drifting snow. Benefits are derived from the barriers because of the resulting change in air-flow patterns on the adjacent soil surface.

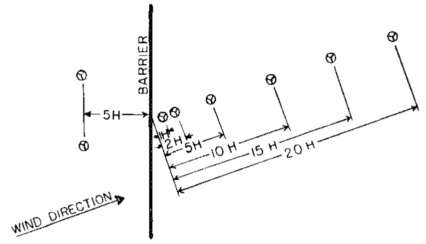

FIG. 1 Spacing and method of placing anemometers for horizontal wind-velocity measurements.

This research was conducted to measure the effect of annual crop barriers on the air-flow patterns over the adjacent soil surface and to develop techniques and methods to evaluate barrier influences.

Equipment and Procedure

In 1961, annual crops were planted as barriers at Manhattan, Kans., on July 25 and at Akron, Colo., on June 6 and August 7 (Table 1). The crops were selected on their past use by other researchers or on their possibilities as wind erosion barriers. Crops were planted in double-row (14 in. between rows) and single-row barriers 25 ft long with a plant spacing of 3 in.; however, their ultimate plant population was controlled by natural thinning and tillering. June 1 is the normal planting date for both Manhattan and Akron, but land and moisture were not available at Manhattan until July 25. The August 7 planting date was included at Akron to determine if crops could mature sufficiently to make a barrier with a 50-day growing season and if the late planting would resist lodging and weathering more than normal planting.

Wind velocity reduction profile measurements were made from December 2, 1961, to April 8, 1962, using modified, contacting-type, conical cup anemometers (2.5 in. in diameter) located 1 ft above the soil surface on all the barriers. Fig. 1 shows the spacing and method used in placing anemometers in the field. Horizontal profile anemometers were set 1 ft above the ground because the "threshold velocity" (velocity at which soil movement is initiated) of soils is generally reported at that height. The anemometers were spaced to the leeward side of the barrier according to the height of the barrier. The percent reduction in the open (windward) wind velocity at various distances to the leeward side of the barrier was computed with the formula $100(1 - V_l/V_o)$ in which V_l is the leeward velocity at the various locations and V_o is the open-wind velocity.

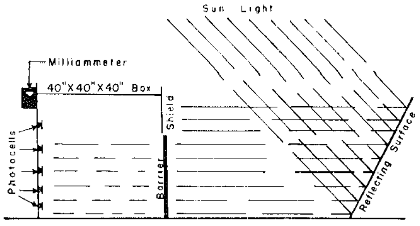

FIG. 2 Schematic diagram of density meter used in determining relative density of barriers.

To evaluate barrier influence, a barrier effectiveness index – hereafter denoted BI – was developed. The BI compares the wind velocity reduction of the barriers at 1 ft above the soil surface. The BI does not take into account changes in barrier density other than as these changes affect the barrier influence. The BI for each barrier was computed from the formula $BI = (1 - V_{l1}/V_o)1 + (1 - V_{l2}/V_o)2 + (1 - V_{l5}/V_o)5 + (1 - V_{l10}/V_o)10 + (1 - V_{l15}/V_o)15 + (1 - V_{l20}/V_o)20$ where V_{l1}, V_{l2}, V_{l5}, V_{l10}, V_{l15}, and V_{l20} are the leeward wind velocities at 1, 2, 5, 10, 15, and 20 *H* (*H* being the leeward distance equal to one barrier height and V_o the open wind velocity). Multiplying the above formula by $\frac{V_s}{V_o}$ (V_s is a standard reference velocity of 10 mph), the formula may be written as $BI_s = \frac{V_s}{V_o} BI$ and may be simplified to $\frac{V_s}{V_o^2}[(V_o - V_{l1})1 + V_o - V_{l2})2 + (V_o - V_{l5}) \ldots\ldots + V_o - V_{l20})]$ or $\frac{V_s}{V_o} \sum_{i = 1 \ldots 20} (V_o - V_{li})i$ The standard reference BI_s should aid future investigations based on the BI_s concept of evaluating barrier effectiveness. As indicated in the *BI* formula, velocity reduction was weighted according to its leeward distance from the barrier; e.g., a 10 percent reduction at 20 *H* had the same value as a 40 percent reduction at 5 *H*. The barrier that offered the most protection over the greatest distance had the largest *BI* and would be most effective in lowering wind velocity at 1 ft above the soil sur-

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Presented as Paper No. 62-214 at the Annual Meeting of the American Society of Agricultural Engineers at Washington, D.C., June 1962, on a program arranged by the Soil and Water Division. Approved as a contribution from the Soil and Water Conservation Research Division (ARS) USDA, in cooperation with the agricultural engineering department, Kansas Agricultural Experiment Station, as part of a thesis submitted in partial requirement for an M.S. degree in agricultural engineering at Kansas State University.

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[*] Numbers in parentheses refer to the appended references.

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This article is reprinted from the Transactions of the ASAE (vol. 6, no. 4, pp. 340, 341, 342 and 352, 1963), the Transactions of the American Society of Agricultural Engineers, Saint Joseph, Michigan

TABLE 1. EVALUATION OF ANNUAL CROP BARRIERS GROWN AT MANHATTAN, KANS., AND AKRON, COLO., 1961

Crop and variety	Manhattan, Kans.			Akron, Colo.			
	July 25 planting			June 6 planting			August 7 planting
	Height* in.	Stand	WA†	Height* in.	Stand	WA†	Height* in.
Grain sorghum (RS-610)	36	Excellent	Good	36	Excellent	Poor	1
Sudangrass (Greenleaf)	48	Excellent	Fair	60	Excellent	Good	1
Forage sorghum (Atlas)	60	Excellent	Fair	60	Excellent	Poor	1
Broomcorn (Black Spanish)	84	Excellent	Good	84	Excellent	Fair	1
Kochia scoparia		None		48	Fair	Good	None
Crotalaria juncea	48	Good			None		
Crotalaria muncronata	12	Fair			None		
Crotalaria incana	12	Poor			None		
Sunflowers (Native)		None			None		
Castorbeans (Pacific Hybrid 6)	48	Fair			Fair		1
Dalea alopecuriodes	12	Excellent			Good		1

* After killing frost.
† Weathering ability.

face. The *BI* also permits a statistical comparison of the protection derived from the various barriers.

The wind velocity was not constant for all the *BI* measurements; therefore, it was adjusted to the average wind velocity of all the measurements before analogies of barrier effectiveness were made. Assuming a linear relationship and a constant coefficient of variation between *BI* and wind velocity, the main *BI* values for the various treatments were adjusted (7, p. 138) to the average wind velocity of 9 mph. Adjusting the *BI* to the average wind velocity removes variation in *BI* due to wind velocity at the level measured.

Relative barrier density was measured with a density meter (Fig. 2) constructed on the principle that the amount of light transmitted through a barrier is related directly to the amount of air movement through a barrier. The ratio of the amount of light transmitted to the amount of light available indicates relative density of the barrier. The density meter was calibrated by covering the light intake opening with ½ and 1-in. cardboard strips. Densities ranging from 20 to 90 percent were obtained by removing alternate strips.

The leeward distance protected from wind erosion was computed using the curves in Fig. 3. The curves were drawn by assuming (a) a threshold velocity of 14 mph at 1 ft above the ground (2, 3), and (b) a surface roughness coefficient of 0.005 ft (1), which resulted in an exponential wind velocity-height relationship. The actual threshold velocity of soils varies from 13 to an indefinite limit, depending on previous history of the soil surface, but a bare, previously eroded soil surface usually starts eroding when the wind reaches 13 to 15 mph at the 1-ft height (2, 3).

The heads were clipped from sudangrass, forage sorghum, grain sorghum, and broomcorn to reduce lodging. The effective height of the barriers was determined by visually integrating barrier height and taking mean height as the effective height. The effective height was determined whenever wind velocity measurements were made and was used to locate leeward distances from the barrier for the anemometer locations.

RESULTS

Crop Stands and Weathering Ability

The height of crops at frost and stands obtained at Manhattan, Kans., and Akron, Colo., are presented in Table 1. August plantings at Akron grew very little and produced a leaf-stage plant, which wilted to the ground after frost. None of the crops listed below broomcorn in Table 1 constituted a barrier sufficient to control wind erosion. *Dalea alopecuriodes* had an excellent stand, but it was only 1-ft high and porous. *Crotalaria juncea* had a good stand, but the plants had only one main stem ¼ in. in diameter, which was not dense enough for an acceptable barrier.

TABLE 2. ANALYSIS OF BARRIER EFFECTIVENESS INDEX (BI) DATA USING FACTORIAL ARRANGEMENT OF THE TREATMENT

Source	df	SS	F	Percent of variation
Treatments	15	391.926		
Crops (C)	3	292.641	25.52*	55.0
Rows (R)	1	4.947	1.09	0.2
Locations (L)	1	1.397	4.01	1.2
CXR	3	11.470	1.28	1.3
CXL	3	61.202	4.17	18.3
RXL	1	5.596	1.14	0.4
CXRXL	3	14.672	1.52	6.0
Error	32	237.601		17.6

* Significant at 5 percent level.

Kochia scoparia weathered better than the other cultivated crops when grown in a fence row; however, these plants dislodged and blew away unless they were well anchored. Sudangrass weathered fairly well, but average height diminished as the season progressed. The sudangrass barriers were best for snow trapping; other barriers allowed the snow to blow through and spread on the leeward side (Fig. 4). Grain sorghum and forage sorghum are well adapted to the Central Great Plains, but both crops lodged severely at Akron, Colo. The broomcorn broke over to a height of 4 ft before the heads were clipped, but the remainder of the stalks weathered very well.

Horizontal Wind Reduction Profiles

Analysis of variance procedures utilizing a 2 × 2 × 4 factorial arrangement of the treatments was used to evaluate the *BI* data for crop, number of rows, and location effects. The main effects, as well as the interactions among main effects, were tested for significance by adjusting the *BI* values and by analysis of variance. The curves in Fig. 5 show a linear relationship and a definite need to adjust the *BI* values to the average wind velocity before making comparisons between barriers.

A summary of the analyses of the *BI* data is presented in Table 2. The amount of reduction by the various crops was significantly different, but neither the number of rows nor the location made any significant difference in the *BI*. By using a factorial arrangement of the treatments, 82.4 percent of the variation in *BI* was explained with the treatments and their interactions.

Table 3 shows adjusted mean *BI* values and the upper and lower values of the 95-percent confidence interval. If the mean *BI* value of one observation is not included in the confidence interval of the other observation, the two observations are said to be significantly different at the 5 percent level. For example, the mean *BI* for Akron 1-row grain sorghum was 8.26, which lies between the upper and lower values of the confidence interval of the Akron 2-row grain sorghum. Therefore, the two treatments were not significantly different. The mean *BI* value

TABLE 3. UPPER AND LOWER LIMITS OF THE 95 PERCENT CONFIDENCE INTERVALS OF THE ADJUSTED BI AND THE ADJUSTED MEAN BI (ADJUSTED TO 9.0 MPH WIND VELOCITY)

Crop	Barrier Effectiveness Index					
	1-row			2-row		
	Lower	Mean	Upper	Lower	Mean	Upper
Akron, Colo.						
Sudangrass	3.80	6.72	9.64	8.94	10.84	12.74
Grain sorghum	5.50	8.26	11.02	7.36	10.87	14.38
Forage sorghum	6.24	8.74	11.24	8.94	11.06	13.18
Broomcorn	−.04*	2.36	4.76	3.04	5.16	7.28
Kochia	....	....	....	15.99	18.09	20.19
Manhattan, Kans.						
Sudangrass	10.70	12.58	14.46	9.39	11.11	12.83
Grain sorghum	3.26	5.64	8.02	6.77	8.12	9.47
Forage sorghum	−.25*	3.96	8.17	3.25	7.04	10.83
Broomcorn	3.54	5.25	6.96	5.17	6.25	7.39

* Negative sign indicates that the barrier increased erodibility of the soil.

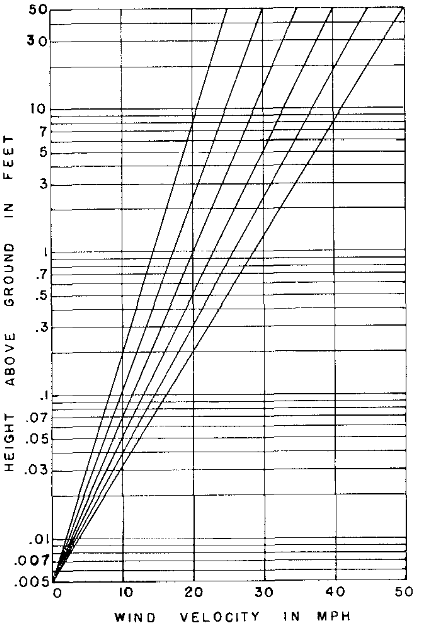

FIG. 3 Theoretical logarithmic height-wind velocity relationships over a bare, smooth, fallow soil surface for various wind velocities.

for Akron 1-row grain sorghum was not included between the upper and lower confidence interval values for Akron 2-row sudangrass; therefore, the two crops were significantly different at the 5 percent level.

Crop Density Data

Data obtained with the density meter were analyzed with a factorial arrangement of the treatments. Data in Table 4 indicate that crop densities were not significantly different, and the location or number of rows had no significant effect on the density of the barrier. The second order interactions were all significant, which indicates that the interaction of two of the main effects (crop, row, or location) resulted in enough difference in density to be significant. Main effects and their interaction accounted for 93.3 percent of the variation in density, and that crop densities were not different could be questioned because the crop effect was significant at the 0.06 level. The relative density of the various barriers are listed in Table 5.

TABLE 4. ANALYSIS OF DENSITY DATA USING FACTORIAL ARRANGEMENT OF THE TREATMENTS

Source	df	SS	F	Percent of variation
Treatments	15	0.8636		
Crops (C)	3	0.3767	2.73	19.2
Rows (R)	1	0.0391	2.12	5.3
Locations (L)	1	0.1376	3.62	12.0
CXR	3	0.1380	50.69*	21.7
CXL	3	0.1315	48.30*	20.7
RXL	1	0.0380	41.83*	8.9
CXRXL	3	0.0027	7.66	5.8
Error	32	0.2224		

* Significant at 1 percent level.

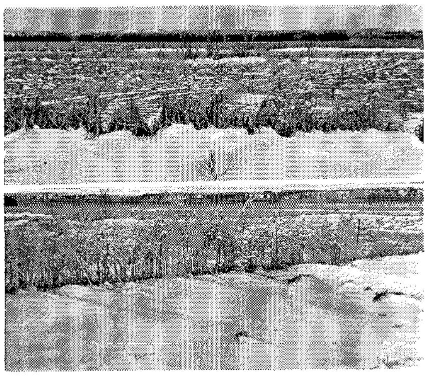

FIG. 4 (Top) Snow trapped by a 2-row sudangrass barrier with a relative density of 63 percent. (Bottom) Snow spread by a 1-row broomcorn barrier with a relative density of 40 percent.

Wind Erosion Protection

Protected distances to the leeward side of various crop barriers are presented in Table 5. The data indicate that the higher the wind velocity, the shorter the protected zone. Kochia had the greatest length of protection, followed by sudangrass and grain sorghum. Broomcorn at Akron, Colo., offered very little protection. The relationship between BI_s and D may be expressed with the formula $BI_s = 2.26 + 0.1519\ D\ (D \rightarrow 100)$ with a correlation coefficient of 0.70.

Discussion

Planting date affects both the height and weathering ability of annual crop barriers. For the crops tested at Akron, August was too late to plant because the crops did not mature sufficiently to form a barrier. Crops planted at normal planting time matured sufficiently to make barriers.

The *BI* was very useful when evaluating the horizontal velocity-reduction profile results. By expressing the relative protection derived from a barrier with one number, the most effective barrier could be selected, and the main effects (crop, row, or location) and their interactions could be tested for significance.

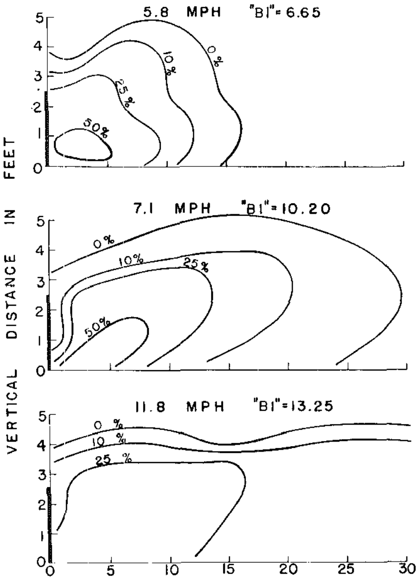

FIG. 5 Wind velocity reduction patterns obtained from vertical profile data on 2-row grain sorghum barrier for open-wind velocities of 5.8, 7.1, and 11.8 mph at the 1-ft elevation.

The density meter indicated relative density of a barrier. Checking the density-meter calibration with commercial snow fence readings indicated the procedure to be reliable.

The Kochia barrier was denser than any of the cultivated crops tested. This high density probably caused the plants

TABLE 5. AVERAGE STANDARD REFERENCE BI (BI_s), RELATIVE BARRIER DENSITY (D), AND PROTECTED DISTANCE TO LEEWARD SIDE OF VARIOUS CROP BARRIERS ASSUMING A THRESHOLD VELOCITY OF 14 MPH AT 1-FT HEIGHT

Barrier	H	BI_s	D	Leeward protected distance in barrier heights for a wind velocity at 50 ft of				
				30 mph (18)†	35 mph (29)†	40 mph* (38)†	45 mph (45)†	50 mph (50)†
	Feet		%	H‡	H‡	H‡	H‡	H‡
AKRON, COLO.								
Sudangrass								
1 row	3	9.9	43	12.5	9.5	7.5	6.0	5.0
2 rows	3	12.4	70	14.0	10.0	7.5	6.0	4.5
Grain sorghum								
1 row	2	12.9	37	14.0	7.5	2.0	1.0	0
2 rows	2	9.1	37	12.0	9.0	6.0	2.0	1.0
Forage sorghum								
1 row	1.5	11.8	38	12.0	7.0	5.0	4.0	3.0
2 rows	1.5	9.3	40	11.0	6.5	4.0	0	0
Broomcorn								
1 row	4	5.3	23	0	0	0	0	0
2 rows	4	8.5	45	8.0	1.0	1.0	1.0	1.0
Kochia	3.5	16.9	83	18.0	16.0	12.0	9.5	8.5
MANHATTAN, KANS.								
Sudangrass								
1 row	2	11.5	59	12.0	9.0	7.0	6.0	5.0
2 rows	2	11.2	63	13.5	10.0	8.0	6.5	5.5
Grain sorghum								
1 row	2.5	6.1	44	11.5	8.0	5.0	2.0	1.5
2 rows	2.5	9.4	53	9.0	5.0	4.0	3.5	2.5
Forage sorghum								
1 row	1.5	4.8	45	8.5	0	0	0	0
2 rows	1.5	8.0	44	9.0	6.5	4.5	3.5	2.0
Broomcorn								
1 row	3	6.6	40	10.5	4.5	2.0	0	0
2 rows	3	6.5	37	12.5	7.0	0	0	0

* Design wind velocity used in this research.
† Number in brackets is the percent reduction at 1-ft height needed to prevent wind erosion.
‡ H is leeward distance in barrier heights (If H = 3 ft, protected distance 12.5 or 37.5 ft).

to dislodge and blow away. However, the high density and superior height were undoubtedly responsible for the high *BI* derived from the Kochia barrier. All barriers showed effects of weathering; i.e., they had fewer leaves, some of the stalks were broken in half, and some lodged completely.

Broomcorn and forage sorghum barriers offer the most protection for vegetable crops because they are tall and dense while green. Their spacing depends on the height of the crop being protected and the design wind velocity. To protect young trees and to control wind erosion, sudangrass or grain sorghum should be used as they offer some protection at the 1-ft height during the wind erosion season. Considering the data from Akron, 2-row sudangrass or grain sorghum barriers should be 22 and 12 ft apart, respectively, to control wind erosion during a wind velocity of 40 mph at 50 ft above the soil surface. One-row barriers of sudangrass could be spaced the same as the 2-row barriers, but 1-row barriers are susceptible to lodging and would not be satisfactory under most conditions. If the Kochia plants could be held in place with some other crop, this combination might protect 42 ft to the leeward side of the barrier, which is nearly double the distance protected by sudangrass.

CONCLUSIONS

This research has shown that annual crop barriers can reduce surface wind velocity and thereby protect the soil surface from wind erosion. Although dense barriers are susceptible to damage from drifting snow deposited within the barriers, they offer more protection than porous barriers. Sudangrass and grain sorghum proved to be the best barriers. However, future research may show taller crops such as kenaf or hybrid broomcorn to be more resistant to weathering and more effective in controlling wind erosion.

The barrier effectiveness index method of evaluating barrier influence — developed in connection with this research — was very satisfactory in making statistical comparisons of barrier influence as measured 1 ft above the soil surface. The index should be useful in evaluating other barrier, shelterbelt, and windbreak influences.

The density meter, also developed in connection with this research, worked very well for determining relative barrier density. The principle involved in its design may be adapted to future barrier, shelterbelt, and windbreak research.

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