ANNUAL CROPS AS WIND BARRIERS

by

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TABLE OF CONTENTS

INTRODUCTION

In the dryland areas of the world, wind erosion can be a serious problem, particularly when the area is under cultivation. If the dryland farmer becomes careless and does not strive to protect his soil with good conservation practices, the fertile topsoil may be blown away and his land rendered useless. Man is not solely responsible for the wind erosion problem. Various types of wind deposits are evident throughout the world and some of these deposits are older than the civilization of the area. Drought at times has reduced or stopped the vegetative growth, thus increasing the land's susceptibility to wind erosion.

History of the Central Great Plains (Montana, North Dakota, South Dakota, Wyoming, Nebraska, Colorado, Kansas, Oklahoma, Texas, and New Mexico) shows that the period of most extensive and severe wind erosion occurred in the 1930's. At one time or another during this period the entire plains region was affected. Many fields lost as much as 12 inches of topsoil and some sandy land was converted to sand dunes (5, 27). Joel (13) in a survey of portions of the Southern Great Plains (Oklahoma, Texas, and New Mexico), found that in the 1930's cultivated and idle land suffered more than three times as much wind erosion as pasture land. This testifies that poor farming practices are a major hazard with respect to the wind erosion problem.

The recommended conservation practices for wind erosion control are 1) shelterbelts, 2) strip farming, 3) stubble mulch practices, and 4) deep plowing; however, even the best conservation practices cannot give enough protection to stop all wind erosion. But, if the conservation practices of creating a soil condition resistant to erosion, and sheltering the soil from wind are followed, the amount of erosion will be greatly decreased.

OBJECTIVE

The primary objective of this investigation was to determine if annual crop barriers can protect the soil surface from wind erosion.

Secondary objectives were 1) to develop methods of measuring barrier density, and 2) to develop methods of expressing the protection derived from a barrier.

STATEMENT OF PROBLEM

The application of annual crops for protection from wind erosion is relatively new to the Central Great Plains area. Some barriers have been grown on the St. Johns area of south central Kansas, but very little has been reported on these barriers. A few farmers in the Central Great Plains have planted two-row strips of sorghum, but no measurements as to their effectiveness were made. Experiments are going on at Akron, Colorado, to determine the snow spreading ability of sorghum barriers, but no wind velocity profiles are being taken. If annual crop barriers can effeciently reduce the wind's velocity they may help in preventing wind erosion.

Tree shelterbelts reduce the wind's velocity, but trees are hard to get established in the dry land areas of the Central Great

Plains. It takes 10-15 years before the trees are large enough to offer much protection, and by then they may not be needed. Annual barriers can be spaced to give the protection needed when it is needed. If a farmer sees that he will have enough available soil moisture to raise his crops he may not want to put in annual barriers. But, if it is dry his crops may need protection from blowing soil, and annual barriers give some protection.

REVIEW OF LITERATURE

Most of the research conducted on annual barriers has been on the snow spreading abilities of annual crop barriers. Sobolev (22) reports that barriers have been used to 1) protect soil from wind erosion, 2) protect crops from winter kill, 3) decrease depth of freezing, 4) raise the permeability of the soil, 5) decrease surface runoff, and 6) increase soil moisture. On the new lands in Kazakhstan, Russian scientists found that when snow ridging (ridges constructed by windrowing snow) was used nearly twice as much water was added to the soil as compared to where snow ridging was not used. When sunflower strips were grown (14), nearly three times as much water was stored in the soil during the winter months.

According to Denisov (9), the collective farm Sibirgak in the Steppe had the following wheat yields:

Year	With borders	Without borders
Wet years 1954	33.8 bu./ac.	25.2 bu./ac.
1956	37.9 bu./ac.	26.6 bu./ac.
Dry years 1951-53, 1955 1957, 1959	15.6 bu./ac.	4.6 bu./ac.

At Sibniskhoz in 1956, spring wheat with corn borders had yields of 40 bu./ac. with borders and 30 bu./ac. without borders. The cost of raising grain on fields with borders was one-half the cost of raising grain on fields without borders, because nearly twice as much grain was harvested without any appreciable increase in cost of tillage.

The Russian scientist (9) must be convinced of the usefulness of borders, because in 1956, 1,235,000 acres of fall-plowed land was bordered in Altai province. The borders were strips left from the previous fall harvest of corn, sunflower, mogar, pros, sudan or sorghum. The intervening area was fall-plowed and planted to wheat the next spring. Borders have been used on vegetable and melon plantings, potatoes, on fields of sown grass, and on new shelterbelts and orchards.

The people in South Africa (19) have used barriers consisting of Karroo bushes, vygies, thorntrees, and agaves (American aloe). Also, on bare, wind eroded spots they have placed dead branches along contour banks so that seeds carried along by the winds could find protection in these covered banks. In New South Wales (8) to control wind erosion trouble spots they cross-plowed with single furrows about 10 feet apart each way. The areas slowly revegetate, but only in the plowed furrows. Their best method was to completely plow trouble areas and sow them to oats. Volunteer oats was allowed to grow and it made a good knee-high self-grown cover crop. In the Walpeup District of Victoria (21) rye was found to be the best crop for wind erosion trouble spots.

In the sandy lands of China, single rows of willow belts averaging 12 feet in height are planted every 50-60 feet. Where an intensive type of agriculture is practiced this close spacing is necessary and economical (25).

Woodruff (26) found that complete protection from wind erosion of dune sand occurs within a net distance of 9 barrier heights from a single row belt for a wind velocity of 40 miles per hour (mph) measured at a 50-foot height. Studies have also shown that the extent of the sheltered area depends chiefly upon the total average height and the density or penetrability of the barrier. Robins (18) noted that the fully protected zone of any barrier was reduced as the wind velocity increases, even though the percent reduction of the open wind remains constant. Caborn (4) concluded that a shelterbelt which allows wind to penetrate through it at a reduced velocity causes a lower degree of shelter on the leeward side of the belt, but the sheltered zone extends over a considerably greater distance. Therefore, a barrier of moderate penetrability to the wind provides the most effective shelter. Nøkkentved (17) and Blenk (3) found that on the basis of wind tunnel results the optimum density was 52 percent, i.e., 52 percent of the area was composed of barrier surface. Jensen (12) showed that independent of the turbulence of the free wind, the optimum density was 60 to 65 percent. Konstantinov (15) found an optimum density of 70 percent in the case of natural shelterbelts. Gorshenin (11) considered that the protective efficiency immediately to the leeward side of a barrier increases in direct proportion to increasing open-wind velocity, but at distances greater than 10 H (H is barrier height) this relationship reversed, i.e., the protection increases with an increase in open wind velocity.

Complete protection from wind erosion must be based on a reduction of wind velocity to a value not exceeding the minimum velocity, known as the threshold velocity, required to cause movement of a given soil. The threshold velocity v_o, for a smooth, bare soil surface after erosion has been initiated and before wetting and subsequent surface crusting by rain, is about 14.3 mph at one foot above a bare, smooth and level terrain (6). Using a power law zero plane method for determining the protection offered by snow fencing spaced 70 feet apart, Schultz (20) concluded that snow fence improved the erosion condition slightly by raising the zero plane. But even a modest lifting could mean a substantial reduction on the amount of erosion.

From his wind tunnel studies Woodruff (24) noted that barriers divert the air current upward and cause a drag on the wind at approximately the same height as the barrier. This reduces the drag on the original ground surface, lowers the prevailing surface velocity, and creates a pool of relatively calm air within the zone influenced by the barrier. The rate of soil movement varies as the cube of the wind velocity; therefore, if a barrier can reduce a 20 mph wind to 15 mpn, i.e., a $100(1-15/20)=25$ percent reduction, the rate of soil movement will be reduced $100(1-15^3/20^3)= 52$ percent.

While using sawdust to simulate snow in wind tunnel studies, Woodruff (24) noted that four snow fences spaced 12 H apart caught four times as much snow as a solid wall, 1.2 to 1.8 times as much as two snow fences with similar spacing, and approximately 2.5 times as much as a single fence. The significance of barrier density on the velocity reduction can be noted by comparing the amount of sawdust caught by a snow fence with the amount caught by a solid wall. These studies indicate the importance of correct spacing of annual barriers, because the full efficiency of the fence was not utilized with a single barrier.

EQUIPMENT AND PROCEDURE

Annual barriers can be used in the dryland portions of the Central Great Plains to protect the soil from wind erosion and to trap drifting snow; therefore, one set of barriers was planted at the USDA, Central Great Plains Field Station At Akron, Colorado. Another set of barriers was planted at the Kansas State University, Ashland Bottoms Agronomy Farm located south of Manhattan, Kansas.

Crops used in this investigation have been used by other researchers (9, 22) or were recommended by Kansas State Extension Agronomist (23), Soil Conservation Service plant materials technician (16), or Donovan from Rhodesia (10). The following crops were used: 1) sunflowers, 2) Kochia, 3) broomcorn, 4) grain sorghum, 5) forage sorghum, 6) sudangrass, 7) castor beans, and 8) Crotalaria. Everyone agreed that the best crop, from the standpoint of size and weathering ability, would be hemp. Due to the narcotic drug obtainable from this crop, it was not used.

The experiment was replicated twice and the plots were completely randomized. The barriers were planted with a Columbia plot drill shown in Plate 1. The two-row barriers were spaced 14 inches apart. This narrow spacing reduced the amount of land used and allowed adjacent rows to support each other. All crops were planted with the seeds spaced approximately 3 inches apart in the row. The final stand was determined by the plant's natural thinning, and tillering. For example, the Kochia could not possibly grow with a spacing as close as sudangrass.

The crops were planted in late spring to mid-summer and grew naturally until killed by frost. The first of June is the normal planting date at both Akron and Manhattan, but land and moisture were not available at Manhattan until July 25. The August planting date was included at Akron to determine if the crops could mature sufficiently to make a barrier without forming a head, and to determine if late plantings would be more or less resistant to lodging and weathering than the normal plantings. After frost the heads and tops of the tall crops were hand clipped to reduce the amount of lodging. Lath was set up on the exposed ends of the barriers to keep the wind from destroying the edges of the plots. Portable snowfence barriers 3 feet high were placed on the ends of the plots where there was no crop adjacent to the barrier being measured. These portable barriers were used to keep the wind from blowing around the end of the barrier, and were removed when velocity measurements were completed.

Horizontal and vertical wind velocity measurements were made during the period of December 2 to April 8. Modified, contacting type, conical cup anemometers, as shown in Plate 2, were used to make horizontal wind velocity measurements on the barriers.

EXPLANATION OF PLATE I

Small plot drill used to plant barriers.

PLATE I

EXPLANATION OF PLATE II

Horizontal profile anemometer dismantled to show how the anemometer was modified. Small copper wire (A) is connected to the insulated terminal and makes one contact with a short 6/32 inch bolt (B) for each revolution of the anemometer cups. A central source of power is connected at (C) and the number of revolutions are recorded by the electrical counter (D).

PLATE II

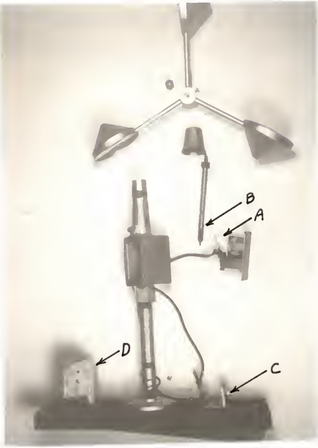

Figure 1 shows the spacing and method used in placing the anemometers. All horizontal wind velocity anemometers were set one foot above the ground because the "threshold velocity" (velocity at which soil movement is initiated) of soils is reported at this height (6). Three 10-minute tests were made on each barrier. The percent reduction in the open (windward) wind velocity at the various distances to the leeward side of the barrier was computed with the formula $100 - 100 (V_{\ell}/V_{o})$ in which V_{ℓ} is the leeward wind velocity at the various distances and V_{o} is the open wind velocity.

The percent reduction required to prevent wind erosion was determined by utilizing a height-velocity relationship as shown in Fig. 2. The relationship assumes 1) a threshold velocity of 14.3 mph at the one foot height (6), 2) a roughness coefficient of 0.005 foot (2), and 3) a design velocity of 23 mph at one foot above the ground (29).

It is difficult to analyze the horizontal wind velocity reduction profiles and determine which crops are significantly different. Therefore, an effectiveness index (EI) was computed for each crop with the following formula $EI = (1 - V_{\ell 1}/V_{o})1 + (1 - V_{\ell 2}/V_{o})2 + (1 - V_{\ell 5}/V_{o})5 + (1 - V_{\ell 10}/V_{o})10 + (1 - V_{\ell 15}/V_{o})15 + (1 - V_{\ell 20}/V_{o})20$, where $V_{\ell 1}$, $V_{\ell 2}$, $V_{\ell 5}$, $V_{\ell 10}$, $V_{\ell 15}$, and $V_{\ell 20}$ are the leeward velocities at 1, 2, 5, 10, 15, and 20 H. The effectiveness index as such expresses the relative degree of protection derived from the barrier. The velocity reduction is weighted according to its leeward distance from the barrier; for example, a 10 percent reduction at 20 H has the same value as a 40 percent reduction at 5 H.

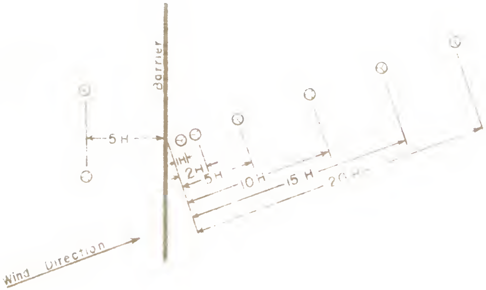

Fig. 1. Location and placement of horizontal wind velocity anemometers as viewed from above.

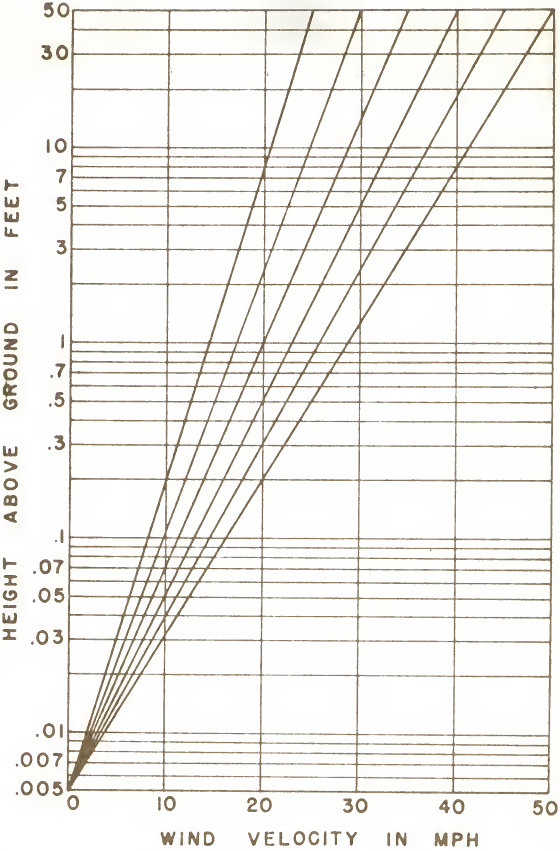

Fig. 2. Height-wind velocity relationships over a bare, smooth, fallow soil surface for various wind velocities based on experiments conducted by Bagnold (2), Chepil (6), and Zingg (29).

The barrier that offers the most protection over the greatest distance has the largest effectiveness index and would be the most effective barrier for wind erosion control.

The vertical wind velocity anemometers were light-weight, plastic cup anemometers, as shown in Plate III, with a low start and stop velocity, and a rapid response to changes in wind velocity. The leeward staff of anemometers was portable, so 3-minute wind velocity measurements could be made at the leeward location indicated. Figure 3 shows the procedure used in placing the vertical wind velocity anemometers in the field. The percent reduction was computed as before, and by connecting points of equal reduction the air-flow pattern to the leeward side of the barrier was determined.

Barrier density was measured with the equipment shown in Plate IV. The density meter was designed and built to study the variations in density within a barrier, and the density-effectiveness index relationship of the barriers.

The reflecting surface was located 4 to 6 feet in front of the box depending on the length of shadow cast by the barrier. The intensity of the reflected light was measured with photocells, and a ratio of intensity with a barrier as compared to without a barrier was used to determine the relative density. The distance to the reflecting surface was not critical as long as it was kept constant for the standard measurement (no barrier) and while measuring the barrier. A standard measurement was made for each barrier. The reflecting surface was tilted such that the sun's rays were always directed into the box and were parallel with the soil surface.

EXPLANATION OF PLATE III

Fig. 1. Vertical profile anemometer dismantled to show plastic cup rotor (A), bearing assembly (B), small copper wire contacts (C), offset nail to make and break contacts (D), and housing (E).

Fig. 2. Vertical profile anemometer assembled to show plexiglass insulated contact (A), grounded contact (B), and condenser (C).

PLATE III

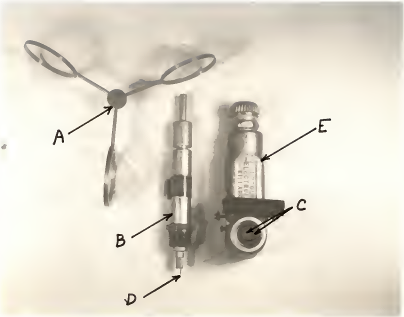

Fig. 1.

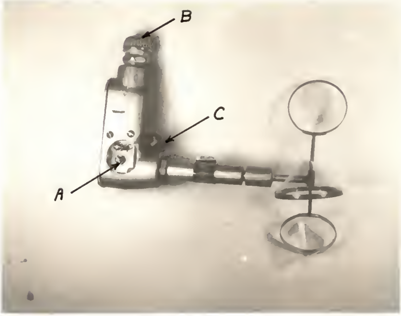

Fig. 2.

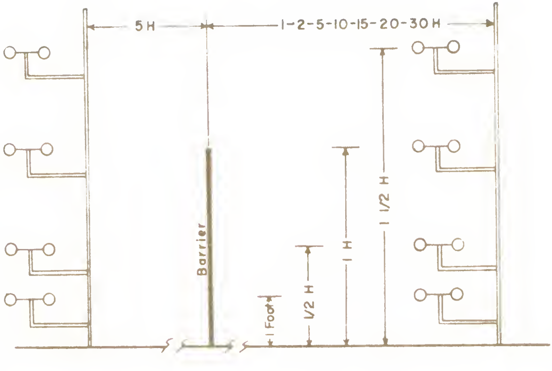

Fig. 3. Placement of vertical wind velocity anemometers as viewed from the side.

EXPLANATION OF PLATE IV

Fig. 1. Side view of density meter showing the 5 rows of photocells (6 per row), the adjustable shield, and the aluminum reflecting surface. The photocells are hooked in series, and the rows can be switched on individually or as a group.

Fig. 2. Density meter set up in the field showing the aluminum reflecting surface (A), the 40"X40"X40" cardboard box (B), and the milliammeter (C).

PLATE IV

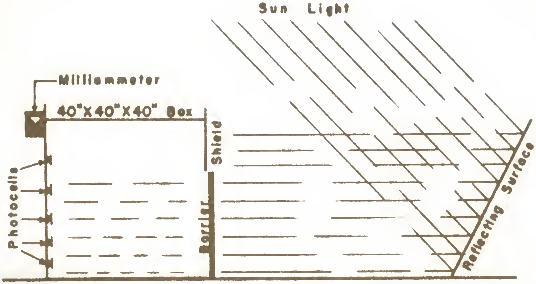

Fig. 1.

Fig. 2.

RESULTS

The late (August) planting at Akron did not produce enough growth and the crops wilted to the ground after frost. Some of the Manhattan crops were producing seed when frost killed them. The height of the crops at frost and the stands obtained from both locations are given in Table 1.

Several of the crops did not have enough of a stand to constitute a barrier. The Dalea alopecuriodes had an excellent stand, but it was only one foot high and porous. Crotalaria juncea had a good stand, but the plants had only one main stem 1/4 inch in diameter; therefore, it was not dense enough to make an acceptable barrier.

The crops that were tall enough and dense enough to make an acceptable barrier are listed in Table 2. The acceptable crops that did form a head were clipped to reduce lodging. Kochia was not clipped because it was not susceptable to lodging.

The average height was estimated by visually determining the "effective height" of the barrier. The "effective height" is the height of an equivalent barrier of uniform height, and it was used to lay out the leeward distances for the anemometer locations.

Horizontal Wind Velocity Profiles

The velocity of the natural wind does not remain constant for a very long period of time; therefore, it is impossible to measure all the crops at the same wind velocity. Variation in effectiveness index due to variation in wind velocity was removed with the analysis of covariance technique. This made it possible

Table 1. Crops grown, planting location, stand, and height after killing frost.

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

* Crop was not planted

Table 2. Clipped height, average height, and weathering ability of acceptable barriers as of April 8, 1962.

Crop	Clipped height feet	Average* height feet	Weathering ability
		Akron, Colorado	
Grain sorghum	2	1/2	Poor
Forage sorghum	3 1/2	1 1/2	Poor
Sudangrass	3	3	Good
Broomcorn	4	3	Fair
Kochia (fence row)	--	3 1/2	Good
		Manhattan, Kansas	
Grain sorghum	2 3/4	2 1/2	Good
Forage sorghum	3 1/2	1 1/2	Poor
Sudangrass	3	2	Fair
Broomcorn	3 3/4	3	Good

* May also be called "effective height".

to determine if location, number of rows, crops or observations were significantly different (observations are the replications of crops within a location). Table 3 shows the F-value when the effect of wind velocity was removed. The correlation coefficient squared, r^2, is the amount of variability explained. Variation in wind velocity explained 16.24 percent of the total variation in effectiveness index.

Removing the effect of wind velocity, location, crops, and observations have significant slopes and adjusted mean values. The number of rows does not affect the wind velocity-effectiveness index relationship, but the number of rows does change the mean value of the effectiveness index. More detailed analysis of the wind velocity-effectiveness index relationship is shown in Table 4.

The variation due to crops shows that the barriers at Akron were more uniform than those at Manhattan. This is substantiated by the variances of the different treatments, and by the fact that locations and crops were significantly different in Table 3.

The effectiveness indexes were adjusted to a wind velocity of 9.0 mph (9.0 mph was the average wind velocity of all the velocity measurements made) with the formula

$$\hat{y} = \bar{y}_i - b(\bar{x}_i - \bar{x}_G) \qquad (1)$$

Where:

$\hat{y}$ = adjusted mean
$\bar{y}_i$ = average effectiveness index per observation
b = slope of wind velocity-effectiveness index curve
$\bar{x}_i$ = average wind velocity per observation
$\bar{x}_G$ = average wind velocity for entire experiment

Table 3. Tabulation of F-values with level of significance when testing the slope of the wind velocity-effectiveness index curve b and when testing the adjusted mean values of effectiveness index.

Source	Removing wind velocity and testing	
	b-slope	Mean
Locations	13.30*	98.01*
Rows	2.10	23.42*
Crops	4.20*	29.26*
Observations	3.72*	10.97*

* Significant at 5 percent level.

Table 4. Analysis of covariance between wind velocity and effectiveness index where b denotes slope of line, F = test statistic used, σ^2 = variance (standard deviation squared), r^2 = percent variability explained by wind velocity (regression coefficient squared), and the percent of variability due to crops and error after the effect of the variation in wind velocity has been removed.

No. rows	b	F	σ^2	r^2	Remaining variation	
					Crops %	Error %
			Akron, Colorado			
1	0.152	5.32**	16.66	0.78	30	70
2	-.551*	14.28**	15.33	10.70	46	54
			Manhattan, Kansas			
1	-0.632*	5.81**	12.99	11.20	30	70
2	0.553	2.29	9.40	12.40	10	90

* Minus sign denotes a negative slope.
** Significant at 5 percent level.

After adjusting the effectiveness indexes to a common wind velocity the 95 percent confidence intervals were computed with the formula

$$\hat{y} \pm t_{.05}\sqrt{\frac{\text{within mean square}}{n_o}} \qquad (2)$$

Where:

$t_{.05}$ = t-value at 5 percent level with same degrees of freedom as within mean square

within mean square = within mean square value from analysis of covariance

n_o = corrected n since unequal observation size was used

The value of n_o is corrected with the formula

$$n_o = \frac{1}{a-1}\left[n_G - \left(\frac{n^2}{n_G}\right)\right] \qquad (3)$$

Where:

a = number of crops

n = number of observations per crop

n_G = grand total of number of observations

Table 5 shows the adjusted mean effectiveness indexes and the minimum and maximum effectiveness index values as determined with the 95 percent confidence interval.

If the mean effectiveness index 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 effectiveness index for Akron one-row grain sorghum was 8.26, and it lies between the minimum and maximum effectiveness index values (95 percent confidence interval) of the Akron two-row grain sorghum. Therefore, the two observations were not significantly different. The mean

Table 5. Minimum and maximum effectiveness index values as computed with the 95 percent confidence intervals, and the adjusted mean effectiveness indexes (adjusted to 9.0 mph wind velocity).

Crop	Effectiveness Index					
	1-row			2-row		
	Min.	Mean	Max.	Min.	Mean	Max.
	Akron, Colorado					
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, Kansas					
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	-0.25*	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 actually increased the erodibility of the soil.

effectiveness index value for Akron one-row grain sorghum was not included between the minimum and maximum effectiveness index values for Akron two-row sudangrass; therefore, the two crops were significantly different at the 5 percent level.

Table 6 shows that of the cultivated crops, sudangrass was the most effective even though it was relatively short. The Kochia plants at Akron dislodged and blew away even when planted in combination with broomcorn. Therefore, Kochia in a fence row was measured to determine the effectiveness index of the Kochia plants. Kochia offers the most protection for the greatest distance and it had the highest effectiveness index.

Density

Kochia as shown in Plate V made a very dense barrier in comparison to sudangrass, as shown in Plate VI, or broomcorn, as shown in Plate VII. In Table 7 the effect of density on effectiveness index was removed with analysis of covariance techniques. Variation in density explained 9.34 percent of the total variation in effectiveness index. Holding density constant the slope values in Table 7 were not significant, but the mean values of crops and observations were significant.

Vertical Wind Velocity Profiles

Vertical cross sectional views of the wind velocity reduction patterns to the leeward side of the barriers are shown in Fig. 4. The reduction patterns extend further to the leeward side of the barrier as the wind velocity increases. The velocity reduction

Table 6. Average percent reduction of the open wind velocity on the leeward side of the barrier for the two locations with accompanying effectiveness index (E.I.), average open wind velocity (V_o), and average relative density (R.D.).

		Percent reduction at leeward locations						E.I.	V_o	R.D.
	Height feet	1H %	2H %	5H %	10H %	15H %	20H %		mph	%
		Akron, Colorado								
Sudangrass										
1-row	3	76	65	51	27	10	3	9.31	7.7	43**
2-row	3	65	60	48	29	17	9	11.37	10.6	70
Grain sorghum										
1-row	0.5	48	38	34	24	17	10	9.90	11.4	37
2-row	0.5	62	44	40	26	10	10	10.69	14.9	37
Forage sorghum										
1-row	1.5	53	56	38	23	12	3	8.34	11.3	38
2-row	1.5	24	45	35	20	12	6	7.87	10.2	40
Broomcorn										
1-row	4	6	-38*	10	14	3	-4*	0.85	6.5	23
2-row	4	53	22	24	13	2	0	3.94	6.2	45
Kochia	3.5	65	78	76	43	31	11	16.99	12.3	83
		Manhattan, Kansas								
Sudangrass										
1-row	2	66	69	51	26	13	6	10.34	9.7	59
2-row	2	53	67	54	29	15	9	11.22	6.5	63
Grain sorghum										
1-row	2.5	62	45	38	22	12	3	8.02	9.2	44
2-row	2.5	53	52	28	15	6	4	6.17	8.2	53
Forage sorghum										
1-row	1.5	11	19	32	11	2	6	4.55	9.9	45
2-row	1.5	46	56	36	13	2	-2*	4.58	7.1	44
Broomcorn										
1-row	3	33	44	26	19	7	1	5.66	9.9	40
2-row	3	39	29	32	22	16	10	9.17	10.0	37

* Minus sign denotes increase in velocity.

** A density of 100 percent would be a solid wall.

EXPLANATION OF PLATE V

Kochia growing naturally in a fence row. Vertical profile measurements are being taken with the windward staff of anemometers (A) and the leeward staff of anemometers (B). Also shown are the leeward horizontal profile anemometers at 1H (C) and at 2H (D).

PLATE V

EXPLANATION OF PLATE VI

One-row sudangrass barrier at Akron, Colorado, February, 1962.

PLATE VI

EXPLANATION OF PLATE VII

One-row broomcorn barrier at Akron, Colorado, February, 1962.

PLATE VII

Table 7. Tabulation of F-values with level of significance when testing the slope of the density-effectiveness index curve b and when testing the adjusted mean values of effectiveness index.

Source	Removing density and testing:	
	b-slope	Mean
Location	79.49	2.43
Rows	3.47	1.41
Crops	6.09	3.72*
Observations	1.18	2.65**

* Significant at 1 percent level.
** Significant at 5 percent level.

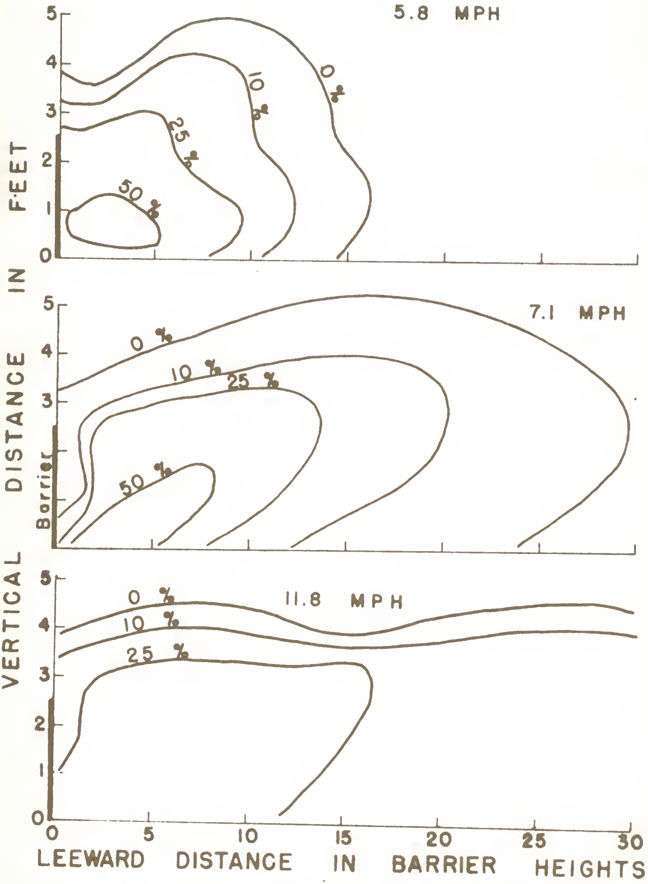

Fig. 4. Wind velocity reduction patterns obtained from vertical profile data on two-row grain sorghum barrier for open wind velocities of 5.8, 7.1, and 11.8 mph at the one foot elevation.

patterns bellowed out considerably for the 7.1 mph wind, but at 11.8 mph the reduction pattern flattened out. As the reduction pattern flattened out percent reduction above two feet increased.

Figure 5 shows the percent reduction patterns obtained for a nearly constant open wind velocity over widely different crops. Excessive reduction by the two-row grain sorghum decreased the total protection at the one foot height for this wind velocity. Reduction by one-row sudangrass was very good, but the one-row broomcorn did not reduce the wind velocity enough to provide protection at the one foot height. One-row broomcorn does give good protection near the ground surface, but some of this protection may have been due to the roughness of the soil surface; therefore, the barrier that offers the greatest protection at the one foot height is considered the most effective for wind erosion control.

Open wind velocity determines the amount of reduction needed for wind erosion control. For example, consider the design wind velocity of 23 mph at the one foot elevation. This wind must be reduced 38 percent $[(23 - 14.3)/23 = 0.38]$ at the one foot height to lower the wind velocity to a threshold velocity of 14.3 mph. Table 8 shows the percent reduction needed at the one foot height and the protected leeward distance of the barriers for various wind velocities.

Kochia had the greatest length of protection followed by sudangrass and grain sorghum. As the required amount of percent reduction increases the protected distance decreased rapidly. Some of the crops could not be used as barriers for the higher wind velocities because they offered very little protection.

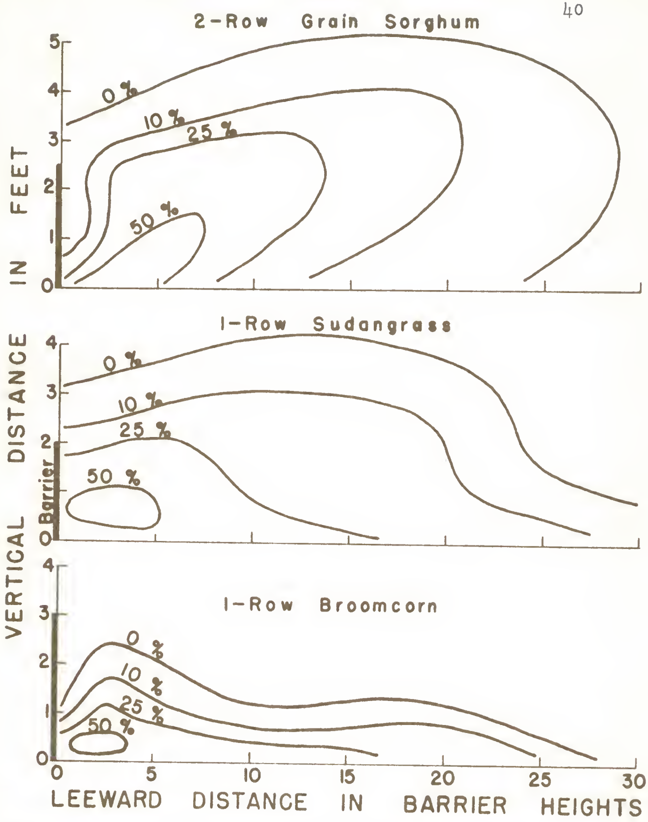

Fig. 5. Influence of crop on the shape of wind velocity reduction patterns to the lee of a barrier for a nearly constant (7.1 - 8.9 mph) wind velocity.

Table 8. Protected distance to the lee of various crop barriers for various wind velocities.

Crop	Height feet	Leeward protected distance for a wind velocity at 50 feet of:				
		30 mph (18)* H	35 mph (29)* H	40 mph (38)* H	45 mph (45)* H	50 mph (50)* H
Akron, Colorado						
Sudangrass						
1-row	3	12.5	9.5	7.5	6.0	5.0
2-row	3	14.0	10.0	7.5	6.0	4.5
Grain sorghum						
1-row	2	14.0	7.5	2.0	1.0	0
2-row	2	12.0	9.0	6.0	2.0	1.0
Forage sorghum						
1-row	1.5	12.0	7.0	5.0	4.0	3.0
2-row	1.5	11.0	6.5	4.0	0	0
Broomcorn						
1-row	4	0	0	0	0	0
2-row	4	8.0	1.0	1.0	1.0	1.0
Kochia	3.5	18.0	16.0	12.0	9.5	8.5
Manhattan, Kansas						
Sudangrass						
1-row	2	12.0	9.0	7.0	6.0	5.0
2-row	2	13.5	10.0	8.0	6.5	5.5
Grain sorghum						
1-row	2.5	11.5	8.0	5.0	2.0	1.5
2-row	2.5	9.0	5.0	4.0	3.5	2.5
Forage sorghum						
1-row	1.5	8.5	0	0	0	0
2-row	1.5	9.0	6.5	4.5	3.5	2.0
Broomcorn						
1-row	3	10.5	4.5	2.0	0	0
2-row	3	12.5	7.0	0	0	0

* Number in brackets is the percent reduction at one foot needed to prevent wind erosion.

DISCUSSION

Experimental Layout

Planting date determines the height and weathering ability of annual crop barriers. For the crops tested, the August planting date was too late because the crops did not mature sufficiently to form a barrier. When the crops were planted at their normal planting time they matured sufficiently by frost to make a barrier. A study of planting dates as released by experiment station agronomists would show how late the crops could be planted and still mature, but may not show the weathering ability in relation to planting date.

Kochia weathered better than any of the cultivated crops when grown in a fence row. The Kochia plants dislodge very easily and blow away unless well anchored. Sudangrass weathers fairly well, but there was a reduction in average height as the winter season progressed. This was very noticable at Manhattan, because of increased exposure to snow. Several snow storms deposited snow on the sudangrass barriers while the snow blew through the other barriers and was deposited on the leeward side as shown in Plate VIII. Grain sorghum and forage sorghum both lodged badly particularly at Akron, but no definite reason can be given. Both crops are well adapted to the Central Great Plains. The broomcorn broke over to a height of 4 feet before the heads were clipped, but the remainder of the stalks weathered very well.

EXPLANATION OF PLATE VIII

Fig. 1. Snow retained by one-row sudangrass barrier.

Fig. 2. Snow retained by one-row broomcorn barrier.

PLATE VIII

Fig. 1.

Fig. 2.

Horizontal Wind Velocity Profiles

The effectiveness index was very useful when evaluating the horizontal profile results. By expressing the protection derived from a barrier with one number the most effective barrier could be selected. Then by proper analysis techniques some of the variables were removed and some were tested for significance. Previously, horizontal wind velocity reduction profiles were shown and no significant statements could be made as to the relative effectiveness of the barriers. With the effectiveness index, barriers can be compared at any level of significance.

The number of leeward locations and the leeward extent of the horizontal profile influence the size of the effectiveness index. Therefore, wind velocities must be measured at the same number of locations and at the same leeward distances from the barriers.

Kochia was a more effective barrier than any of the other crops. Sudangrass made the most effective barrier of the cultivated crops followed by grain sorghum, forage sorghum, and broomcorn. The two-row barriers were slightly more effective than the one-row barriers.

Density

The density meter worked very well and seemed to give a good indication of the relative density of a barrier. The meter was calibrated with sheets of cardboard. One sheet was cut into 1/2 inch strips and another sheet into 1 inch strips. Then by removing alternate strips various densities could be obtained. The fact that the crop with the highest density was also the most effective would indicate that the density readings were reasonable. Since the variation in density within a barrier was fairly large a higher correlation would probably exist between the average density and the average effectiveness index than existed between all the samples.

The Kochia barrier was denser than any of the cultivated crops. The very high density was probably responsible for the plants dislodging and blowing away, but it was also responsible for the high effectiveness derived from the Kochia barrier. Two-row sudangrass was fairly dense, and its small stalks weathered better than the large stalks of grain sorghum or forage sorghum. Broomcorn weathered well and its density was slightly smaller than the density of grain sorghum. Broomcorn stalks are smaller than grain sorghum stalks and there are fewer leaves on the broomcorn; therefore, the density of broomcorn would be smaller than the density of grain sorghum even for the same plant population.

Vertical Wind Velocity Profiles

The shapes of the wind velocity reduction patterns to the leeward side of a barrier are influenced by wind velocity. The range of wind velocities was not great enough to make any definite statements about the relationship between the wind velocity and the reduction patterns. The reduction patterns appear to flatten out considerably for the higher wind velocities. There is a difference between the reduction patterns to the leeward side of different crops. The vertical extent of the velocity reduction is less for the more porous barriers than for the more dense barriers. The more dense barriers should be used for protecting growing vegetable crops, young trees, and for preventing wind erosion.

SUMMARY AND CONCLUSIONS

The main purpose of the barriers studied in this investigation was for wind erosion control, so the crops were planted as near their normal planting date as possible. The crops could be planted later than normal if the late planting doesn't increase lodging.

The effectiveness index method for evaluating horizontal wind velocity profile data works very well for determining the most effective barrier. This method may find application to future barrier evaluation studies where detailed wind velocity measurements are made.

The barrier density required to effectively stop wind erosion is at least 60 percent, and this compares favorably with the optimum densities given in previous research (17, 3, 12, 15). Since it is nearly impossible to grow a perfectly uniform barrier the 60 percent density should be considered as a minimum. This density will give protection in the vertical direction to a height equal to the height of the barrier for a leeward distance of about 10 H. The method of determining density with photocells may be modified to determine the density of shelterbelts. According to the results obtained in this investigation one-row barriers are nearly as effective as two-row barriers. The one-row barriers are more susceptible to lodging than the two-row barriers; therefore, two-row barriers would be more suitable for wind erosion control. Two-row sudangrass barriers spaced 8 H apart will protect the soil surface from the design wind velocity of 40 mph at 50 feet (23 mph at one foot) above the surface. Two-row grain sorghum barriers would have to be spaced 5 H apart to protect the soil surface.

Two-row broomcorn is not dense enough to protect the soil surface from wind erosion; therefore, if broomcorn barriers are used more than two rows should be planted. If forage sorghum barriers are used for wind erosion control extreme care should be excerised in selecting the variety that is most resistant to lodging.

SUGGESTIONS FOR FUTURE RESEARCH

Several new crops have been observed which may make better barriers than those tested. They include *Sorghum almum*, Kenaf (*Hibiscus cannabinus*), and new hybrid varieties of grain sorghum, forage sorghum, broomcorn, and *Crotalaria juncea*.

Detailed investigations of the relationships and interactions of wind velocity, density, and effectiveness index could answer some very prominent questions about the optimum density needed for wind erosion control.

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APPENDIX

Table 9. Tabulation of wind velocity (X_1) and effectiveness index (Y) sum of squares.

Crop	n	X_1^2	X_1	X_1Y	Y	Y^2
			Akron, Colorado			
Sudangrass						
1-row	8	320.17	49.3	335.523	50.36	393.5582
2-row	17	1598.45	157.1	1792.622	182.42	2146.1668
Grain sorghum						
1-row	9	734.30	73.0	651.781	76.09	690.7227
2-row	5	709.42	57.0	553.698	47.75	486.2723
Forage sorghum						
1-row	11	1154.94	110.6	864.433	94.27	1219.8581
2-row	12	1503.31	126.9	1149.584	122.02	1613.2480
Broomcorn						
1-row	12	801.85	97.1	260.533	29.99	123.4513
2-row	12	681.95	88.9	586.580	72.76	589.7608
Kochia	14	1717.30	150.6	2594.015	239.43	4201.2463
			Manhattan, Kansas			
Sudangrass						
1-row	15	1041.29	116.1	1311.754	176.46	2359.7172
2-row	11	841.90	93.4	998.517	119.60	1434.5706
Grain sorghum						
1-row	12	952.40	104.8	609.576	65.39	465.8825
2-row	14	967.88	114.8	898.939	107.49	924.8725
Forage sorghum						
1-row	3	297.28	29.6	130.668	13.60	64.1962
2-row	5	300.91	38.5	252.048	31.61	231.5391
Broomcorn						
1-row	18	1730.79	173.7	975.175	101.42	735.3830
2-row	17	1795.15	169.9	1152.858	116.04	921.7512

Table 10. Tabulation of density (X_2) and effectiveness index (Y) sum of squares.

Crop	n	X_2^2	X_2	X_2Y	Y	Y^2
Akron, Colorado						
Sudangrass						
1-row	5	1.0135	2.15	10.9246	22.46	129.5684
2-row	6	2.9526	4.20	40.0935	56.45	626.4927
Grain sorghum						
1-row	3	0.4161	1.11	8.7512	24.02	229.0482
2-row	-	--	--	--	--	--
Forage sorghum						
1-row	6	0.9644	2.26	18.5024	52.77	854.8249
2-row	6	1.0482	2.38	32.4402	74.68	1283.9134
Broomcorn						
1-row	9	0.7077	2.09	6.4370	27.38	106.4432
2-row	6	1.2139	2.67	22.2538	49.50	423.5652
Manhattan, Kansas						
Sudangrass						
1-row	6	2.1067	3.53	47.6327	83.78	1274.6256
2-row	5	2.1049	3.17	28.1826	45.06	498.2778
Grain sorghum						
1-row	6	1.1705	2.61	8.0157	18.65	58.9767
2-row	8	2.3743	4.27	30.5144	56.85	479.0149
Forage sorghum						
1-row	3	0.6226	1.36	6.2766	13.60	64.1962
2-row	2	0.3970	0.88	7.7967	17.61	155.2941
Broomcorn						
1-row	6	0.9678	2.38	12.9883	36.91	276.6539
2-row	9	1.2256	3.30	15.3188	42.50	216.3822

Table 11. Tabulation of vertical profile data.

Barrier, Height, and Average Wind Velocity	Vertical Distance above the Ground feet	Percent reduction at leeward distances of:						
		1H %	2H %	5H %	10H %	15H %	20H %	30H %
Sudangrass	1	62	56	30	38	26	17	8
1-row	1.5	15	23	9	26	21	12	12
1.5 feet	2.5	6	5	2	13	15	12	12
8.9 mph	4	12	8	-6	-1	0	8	13
Sudangrass	0.5	58	59	63	25	26	26	12
1-row	1	48	80	39	18	21	10	0
2 feet	2	17	22	37	14	14	11	11
7.8 mph	3	1	3	5	12	10	4	8
Sudangrass	0.5	10	56	33	20	-3	-14	5
1-row	1	25	36	30	17	-9	-9	-19
2 feet	2	17	10	4	8	0	-11	-11
3.1 mph	3	-5	6	12	2	18	2	0
Broomcorn	0.5	59	58	44	30	21	21	--
1-row	1	1	30	11	0	5	-14	--
3 feet	3	-22	-5	-11	-5	2	-22	--
8.7 mph	4	-15	4	5	17	21	16	--
Grain sorghum	1	28	36	34	31	23	17	16
2-row	1.5	21	25	25	10	24	18	16
3 feet	3	16	29	35	39	38	18	17
11.8 mph	4	0	1	1	6	-5	8	13
Grain sorghum	0.5	26	57	58	--	7	--	-4
2-row	1	7	44	51	--	14	--	-6
2.5 feet	1.5	6	27	27	--	11	--	0
7.1 mph	4	-10	-5	7	--	12	--	2
Grain sorghum	0.5	66	47	52	14	--	-14	-32
2-row	1	50	58	47	25	--	11	5
2.5 feet	2.5	26	28	26	10	--	8	22
5.8 mph	4	-3	10	17	8	--	0	23
Grain sorghum	0.5	34	72	40	37	20	19	4
2-row	1	71	56	23	22	18	8	-1
2.5 feet	2.5	16	33	19	21	-4	1	0
7.0 mph	4	13	2	6	7	-3	7	5
Kochia	1	42	75	74	40	28	16	-10
	2	56	59	67	36	27	18	16
3 feet	2.5	47	42	40	30	25	13	22
11.0 mph	5	32	3	9	16	18	2	25
Kochia	1	60	51	77	47	-1	-6	-12
	2	64	55	70	52	24	16	13
3 feet	2.5	48	45	72	32	18	8	13
7.9 mph	5	36	35	42	38	16	5	14

SAMPLE CALCULATIONS

Calculations based on the data from Table 9 and 10 use the following common terms.

X_{ijkl} = wind velocity (Table 9) or density (Table 10) for location l, crop k, row j, and sample i

Y_{ijkl} = effectiveness index for location l, crop k, row j, and sample i

n_{jkl} = number of samples per crop k, of row j, and of location l

a = number of crops

Σx^2 = corrected X sums of squares

Σy^2 = corrected Y sums of squares

Σxy = corrected XY sums of products

b = slope of the wind velocity (Table 9) or density (Table 10) effectiveness index curve, $\frac{\Sigma xy}{\Sigma x^2}$

$\Sigma d_{y.x}^2$ = summation of the deviations from regression,

$$\Sigma y^2 - \frac{(\Sigma xy)^2}{\Sigma x^2}$$

r^2 = proportion of variability in Y explained by X,

$$\frac{(\Sigma xy)^2}{\Sigma x^2 \Sigma y^2}$$

To determine if the single-row crops from Akron were significantly different the following calculations were used.

T' = total uncorrected sums of squares and products

$$\sum_{i}\sum_{k}(X_{ijkl}) \; ; \; \sum_{i}\sum_{k}(Y_{ijkl}) \; ; \; \sum_{i}\sum_{k}(X_{ijkl})(Y_{ijkl})$$

B' = crop uncorrected sums of squares and products

$$\sum_{k}\frac{(\sum_{i} X_{ijkl})^2}{n_{jkl}} \; ; \; \sum_{k}\frac{(\sum_{i} Y_{ijkl})^2}{n_{jkl}} \; ; \; \sum_{k}\frac{(\sum_{i} X_{ijkl})(\sum_{i} Y_{ijkl})}{n_{jkl}}$$

c = correction factors for sums of squares and products

$$\frac{(\sum_{ik}\sum X_{ijkl})}{\sum_k n_{jkl}} \;;\; \frac{(\sum_{ik}\sum Y_{ijkl})}{\sum_k n_{jkl}} \;;\; \frac{(\sum_{ik}\sum X_{ijkl})(\sum_{ik}\sum Y_{ijkl})}{\sum_k n_{jkl}}$$

T = total corrected sum of squares and products T'-C as shown below

	n	ΣX^2	ΣXY	ΣY^2
T'	40	3011.23	2112.270	2427.5903
C	1	2722.50	2068.358	1571.3876
T	39	288.73	43.912	856.2027
B'	4	2793.65	2118.026	1844.1588
C	1	2722.50	2068.358	1571.3876
B	3	71.15	49.668	272.7712

Then by substracting B from T the within terms are obtained.

	d.f.	Σx^2	Σxy	Σy^2
T	39	288.73	43.912	856.2027
B	3	71.15	49.668	272.7712
Within	36	217.58	-5.756	583.4315

The slope b, and the deviations from regression are then obtained and the crops are tested for significance.

	d.f.	$\Sigma d^2_{y.x}$	Mean Square	F
Total	38	849.5243		
Within	35	583.2792	16.665	
Adj. Crops	3	266.2451	88.748	5.325**

$$b = \frac{\Sigma xy}{\Sigma x^2} = 0.1521$$

$$r^2 = \frac{(43.912)^2}{(288.73)(856.2027)} = 0.0078$$

$$n_o = \frac{1}{a-1}\left[\sum_k n_{jkl} \quad \frac{\sum_k (n_{jkl})^2}{\sum_k n_{jkl}}\right] = \frac{1}{3}\left[40 - \frac{410}{40}\right] = 9.92$$

σ_c^2 = variance due to crops and it is estimated by

$$\frac{88.748 - 16.665}{9.92} = 7.266, \; \sigma^2 = 16.665$$

The percent variation due to crops was found by 100 $\left[\frac{\sigma_c^2}{\sigma^2 + \sigma_c^2}\right] = 30\%$

The percent variation due to error was found by 100 $\left[\frac{\sigma^2}{\sigma^2 + \sigma_c^2}\right] = 70\%$

To determine if locations were significantly different the following computations were used. Corrected sum of squares and products for locations were determine with,

$$\Sigma x^2 = \underset{ijk}{\Sigma\Sigma\Sigma}(X_{ijkl}^2) - \frac{(\underset{ijk}{\Sigma\Sigma\Sigma} X_{ijkl})^2}{\underset{jk}{\Sigma\Sigma} n_{jkl}}$$

$$\Sigma y^2 = \underset{ijk}{\Sigma\Sigma\Sigma}(Y_{ijkl}^2) - \frac{(\underset{ijk}{\Sigma\Sigma\Sigma} Y_{ijkl})^2}{\underset{jk}{\Sigma\Sigma} n_{jkl}}$$

$$\Sigma xy = \underset{ijk}{\Sigma\Sigma\Sigma}(X_{ijkl})(Y_{ijkl}) - \frac{(\underset{ijk}{\Sigma\Sigma\Sigma} X_{ijkl})(\underset{ijk}{\Sigma\Sigma\Sigma} Y_{ijkl})}{\underset{jk}{\Sigma\Sigma} n_{jkl}}$$

Total corrected sum of squares and products was determined by:

$$\Sigma x^2 = \underset{ijkl}{\Sigma\Sigma\Sigma\Sigma}(X_{ijkl}^2) - \frac{(\underset{ijkl}{\Sigma\Sigma\Sigma\Sigma} X_{ijkl})^2}{\underset{jkl}{\Sigma\Sigma\Sigma} n_{jkl}}$$

$$\Sigma y^2 = \underset{ijkl}{\Sigma\Sigma\Sigma\Sigma}(Y_{ijkl}^2) - \frac{(\underset{ijkl}{\Sigma\Sigma\Sigma\Sigma} Y_{ijkl})^2}{\underset{jkl}{\Sigma\Sigma\Sigma} n_{jkl}}$$

$$\Sigma xy = \underset{ijkl}{\Sigma\Sigma\Sigma\Sigma}(X_{ijkl})(Y_{ijkl}) - \frac{(\underset{ijkl}{\Sigma\Sigma\Sigma\Sigma} X_{ijkl})(\underset{ijkl}{\Sigma\Sigma\Sigma\Sigma} Y_{ijkl})}{\underset{jkl}{\Sigma\Sigma\Sigma} n_{jkl}}$$

The resulting computations are as shown.

Location	d.f.	Σx^2	Σxy	Σy^2	d.f.	$\Sigma d_{y.x}^2$
Manhattan	94	486.08	-145.598	1503.6712	93	1460.0612
Akron	99	931.56	456.875	3090.3874	98	2866.3173
			Within		191	4236.3785
			Regression Coefficient		1	199.3348
Common	193	1417.64	311.277	4594.0586	192	4525.7133
Total	194	1420.79	329.249	4696.4517	193	4620.1527
			Adjusted location means		1	94.4394

The within and the common terms are obtained by addition, and the regression coefficient and the adjusted means by substraction.

Testing the b (slope) values for significance

$$F = \frac{199.3348}{22.651} = 8.80^{**}$$

Testing the adjusted means for significance

$$F = \frac{94.4394}{23.571} = 4.01^{**}$$

ANNUAL CROPS AS WIND BARRIERS

by

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This study was conducted for the purpose of determining the percent reduction in wind velocity to the leeward side of an annual crop barrier. Some research has been done on the snow spreading abilities of narrow two-row annual crop barriers spaced 50 feet apart, but no information was available on the wind velocity reduction potential of annual crop barriers.

Previously the barrier with the highest reduction was arbitrarily selected as the most effective barrier. It has been realized that a barrier with a little porosity will have a lower maximum percent reduction than a solid barrier, but it will extend its percent reduction further to the leeward side of the barrier. Taking this into account an effectiveness index was formulated. The effectiveness index is the summation of percent reduction times leeward distance in barrier heights. Effectiveness index weighs the percent reduction according to its leeward distance from the barrier. For example, a 20 percent reduction at 20 H (H is leeward distance in barrier heights) carries the same weight as a 80 percent reduction at 5 H.

To determine the density of the annual barriers a "density meter" was constructed. The meter assumes a direct relationship between porosity to wind velocity and porosity to sunlight. Sunlight was reflected through the barrier and the amount of light passing through was measured with photocells. The meter was calibrated so that the ratio of the amount of light through a barrier to the amount of light without any barrier could be used on a calibration chart to determine the relative density. The effectiveness index method showed that Kochia was the most effective barrier. A Kochia barrier has a density of 83 percent and could be spaced 12 H apart. It is hard to keep the Kochia plants from blowing away; therefore, Kochia is not recommended for barrier use. Two-rows of sudangrass spaced 14 inches apart were also very effective in reducing wind erosion. They have a density of 60-70 percent and can be spaced 7.5 to 8.0 H across a field. Sudangrass weathers fairly well unless the barrier is filled with snow.

Grain sorghum and forage sorghum were susceptible to lodging, but selected hybrid varieties may be more resistant to weathering. Other crops that may be more effective barriers than those tested include *Sorghum almum* and Kenaf (*Hibiscus cannabinus*).