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EFFECT OF A SOLID WINDBREAK IN A CATTLE-FEEDING AREA

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ABSTRACT

Horizontal wind flow has been measured around a windbreak in a cattle-feeding area using a solid plywood barrier. Wind reduction was greater with the solid barrier than with porous ones reported in literature. Snow-drift pattern around the barrier agreed approximately with the area of measured 50 percent or greater wind reduction. The shape of snowdrifts showed a strong relation to the pattern of streamlines. No air temperature influence from the windbreak was found.

INTRODUCTION

Various kinds of barrier to the wind have a history of a century or more of use in agriculture for comfort or economics. Windbreaks have been used to reduce soil erosion, to protect growing crops from wind breakage or to assist in recharging soil moisture by collecting snow on agricultural land. Highway departments and railroads have used windbreaks, called snow fences, to protect rights-of-way. Users of windbreaks have been interested in causing an effect over the largest possible area from a barrier and there was generally no need to reduce the wind to near zero.

Cattle have always sought shelter from wind, using the natural protection of thickets or ravines. It is hypothesized that cattle will use wind shelters in a feeding or loafing area in the winter and that the animals can be maintained more economically there than in an open area. Shelters have been constructed at the Eastern Oregon Agricultural Research Center, Union site, and the animals spend considerable time near the structure between feeding periods. The size of the area interesting to animals is well established by the manure pattern. A particularly interesting observation is that stock spend as much time on the upwind side of the windbreak, in a small area, as they do the downwind side of the structure. The object of this study is to investigate the environmental variation around the windbreak which may attract animals. The concern is with two aspects of the windbreak:

(a) What is the wind-reducing effect of this solid barrier?

(b) Does the barrier affect nearby or distant air temperature?

For a large area, porous windbreaks are more effective than solid ones. Wang (1963) reported that with a 30 percent dense barrier, the reduction of wind to less than 80 percent extended 12 h[1] leeward. With a 50 percent dense

[1] h is the windbreak height.

barrier, the reduction of wind to 80 percent extended 27 h leeward. With a 100 percent dense barrier, the same wind reduction extended only 15 h leeward.

Chepil (1965) states (from Woodruff and Zingg, 1952) that no matter how strong the wind, the percentage of reduction remains the same with rigid barriers. But he states that Bates (1944) found the percentage of reduction increased slightly with high wind when a porous, resilient barrier was used.

MEASUREMENT AND ANALYSIS

Winter winds at the Union Research Center cause the cattle to face away from the wind and disturb feeding and watering habits. The strength of the wind is shown in averaged winds at the station. The 1975-76 and 1976-77 averages were:

December 1975 . . . 5.06 ms^{-1} January 1976 . . . 5.72 ms^{-1}

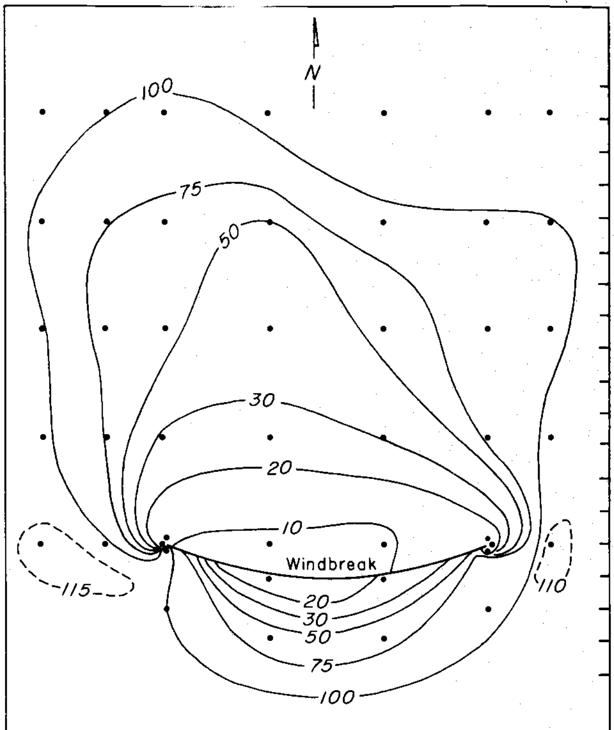
December 1976 . . . 4.69 ms^{-1} January 1977 . . . 5.11 ms^{-1}

The upstream, or reference wind flow, for this study was measured 30.49 meters east of the windbreak. Wind was measured in a grid of 45 locations (see Figure 1) from 4.6 meters upstream of the barrier to 34.6 meters downstream from the end positions of the barrier.

Wind measurements were made with a Deuta portable anemometer mounted on a tripod at 1.4 meters above ground. Six readings at 30-second intervals were averaged to yield a reading at a given point. This method was used throughout for measuring the winds in the grid pattern, the upstream wind, and the wind passing above the barrier.

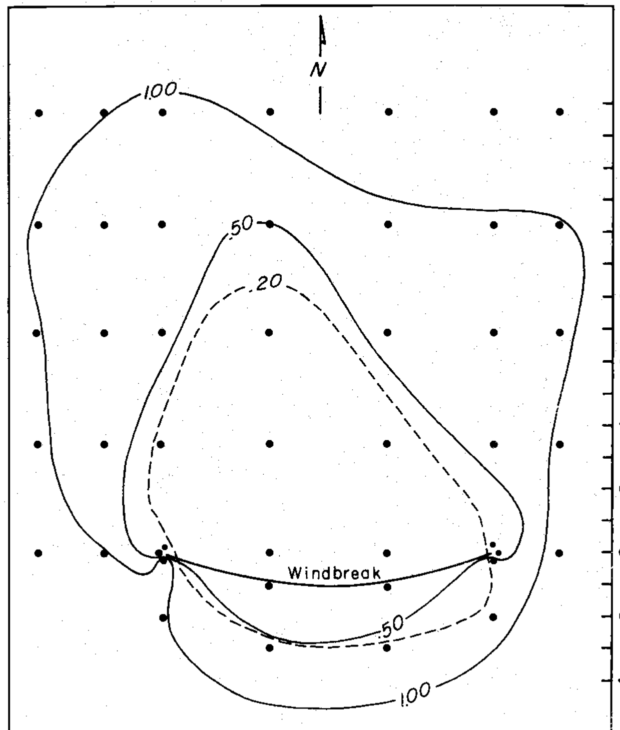
The data were investigated regarding the hypothesis that the decimal fraction wind reduction remains the same at all wind speeds using a rigid barrier. To do this, winds were considered on four days for all grid points. On these days, the rather strong upstream wind speed average was 5.6 meters/second. If the amount of wind reduction caused by a solid barrier is relatively constant, range of wind speed values (as a measure of central tendency) downwind from the barrier should be small. Range of ambient wind speed would be somewhat greater.

Each grid measurement was considered as a percent of the upstream wind. Thus, for any point in the grid, the four days of investigation resulted in a range of wind speed values. These values were expressed as a percentage of the upstream wind. The range of wind speed values was plotted on a grid which showed that all range values on or inside the area enclosed by a dashed line on Figure 2 were 20 or less. Values on the grid outside the 20 percent dashed line were greater. Range in this outer region varied from 22 to 75.



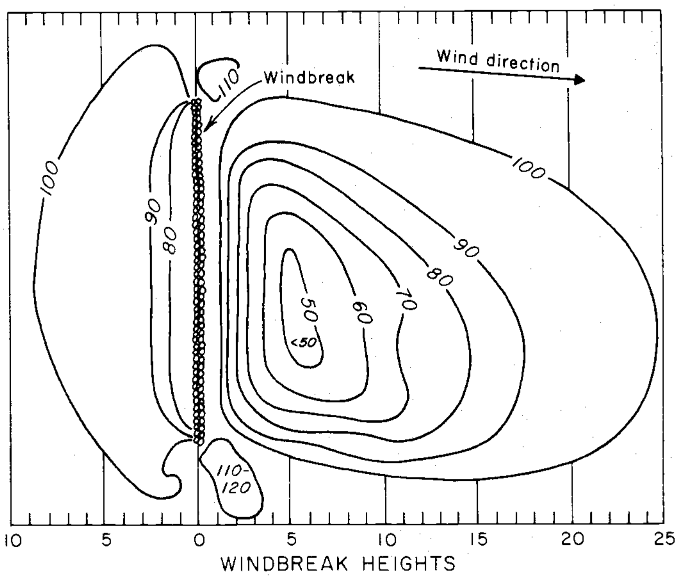
Wind isopleths in relation to a solid windbreak
Isopleths are percentages of upstream wind

Figure 1



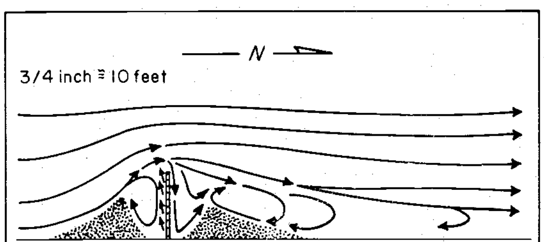
—— Isopleths are percentages of upstream wind
- - - Range of observations within is .20 or less

Figure 2



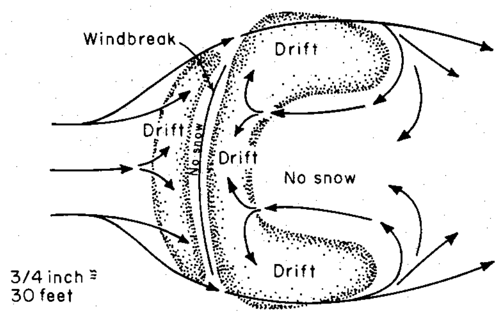
Percentage of normal wind velocity near a windbreak having an average density of 50 percent. (Redrawn from Bates, 1944.)

Figure 3



Cross section of windbreak and snow drifts with probable streamlines

Figure 4a



Top view of windbreak, snow configuration and probable wind pattern

Figure 4b

Solid line isopleths showing areas in the grid having averages of 100 percent or less and 50 percent or less of the upstream wind were imposed on the grid showing the decimal fraction range of values of percentages of wind reduction. In Figure 2, these two sets of isolines are presented. The area of important wind reduction (reduction to 50 percent or less of upstream values) coincides very closely with the region having small ranges, 20 or less.

The range in percent of wind reduction at each grid point by this solid windbreak was often small, which indicates the constancy of barrier influence mentioned by Chepil (1965). However, the range was not small over the entire grid and, therefore, this study does not fully agree with Chepil's conclusion. There is close agreement between the area having a decimal fraction wind range of less than 20 and the area having average wind reduction of 50 percent or greater. This may mean that in the area of the greatest barrier influence, the wind reduction is about the same, no matter how strong the upstream wind flow.

Chepil (1965) reported that dense barriers gave marked wind reduction for short distances on the lee side. In porous barriers, large openings can cause air jetting which may counteract the desired effect.

In working with mature beef animals, a solid wooden barrier was selected because a maximum of wind reduction is desired more than a large area of reduced wind. Such a structure prevents air jetting and was expected to give greater wind reduction than a somewhat porous structure would. The barrier was 2.4 meters high, 24.0 meters long and was curved with a radius of 30.0 meters. The prevailing winter wind at the Research Station blows from the south. The structure was erected on an east-west bearing and was convex toward the wind.

Because there is no warming action from a wind barrier, the only aid it can provide to animals in winter is that of reducing cold stress by reducing the wind-induced chill factor or by absorbing heat which it reradiates in a small area. For this reason, if the maximum benefit to animals is to be derived, it is necessary to bring the wind flow to as near zero as possible. To do so over a few hundred square meters would be beneficial.

Figure 1 shows that a substantial reduction of wind occurs in a narrow band on the windward side of the barrier. Wind reduction, in relation to upstream flow, is, of course, greater on the lee side of the windbreak and covers a much larger area. Wind as low as 10 percent of the upstream wind is found in a narrow band (90 percent reduction) immediately to the lee of the barrier and a reduction of 50 percent is found downstream to a distance of 10 barrier heights (10 h). The largest area of protection downwind occurs when the wind flows perpendicular to the barrier.

Wind flow over the barrier was measured at heights of 15 centimeters and 75 centimeters above the barrier. Measurements were made at the two heights at the end of the barrier and at two positions, each one-third the barrier length in from the ends. Observations of over-the-barrier flow were not on the same days as surface wind measurements.

Wind speed for the four positions over the barrier were calculated as percentages of the upstream wind speed. There is slight evidence of air drag over the structure. The average wind at 15 centimeters above the structure was 99.6 percent of the upstream wind. The effect of constriction on the flow and resulting venturi effect show at the 75 centimeter height where wind speed averages 107.5 percent of upstream flow.

Observations in the grid area were made on six different days from January into early March. To avoid having just one weather regime in which conditions of temperature, wind, and stability might be the same, the six days were chosen rather randomly in time instead of six consecutive days. However, observations were made when it was expected that the wind would be about 4.2 meters/second or stronger because lesser winds usually do not cause a severe chill factor for cattle. Wind values were recorded at each grid point as a percentage of the upstream wind flow. Values indicated in Figure 1 are the averages of the six days. That is, for a given point, the observed wind was divided by the upstream wind at that time; this percentage was calculated for each day for that point; then the six percentage values for that point were averaged and that value was plotted for that point of the grid. The isotachs of Figure 1, therefore, depict an average distribution of wind reduction around the barrier.

The Figure 1 pattern of wind reduction is quite similar to that shown in Figure 3. The windbreak in Figure 3 is one having an average density of 50 percent. It gives a 30 percent to 40 percent wind reduction downwind to 10 h. The solid barrier at the Experiment Station caused a 50 percent reduction out to 10 h. The porous windbreak in Figure 3 gives evidence of the greatest total area of effect. The upstream effect is similar in pattern for both the solid and the 50 percent porous barriers, but the wind reduction is somewhat greater for the solid barrier.

Near each end of the solid barrier, an area has 110 percent to 115 percent of the upstream wind. At each end of the porous barrier reported by Bates (1944), there was an area of 110 percent to 120 percent of the normal flow.

The standard deviation of the percent wind reduction at observation points both upwind and downwind from the windbreak gives an indication of how the variation of wind reduction behaves with distance from the solid barrier. Greater turbulence at the boundary between reduced air flow and the ambient flow accounts for the larger variation with increasing distance from the windbreak. This deviation is as follows:

Distance	Standard deviation of % wind reduction
4.5 m upwind	18
.6 m upwind	04
2.4 m downwind	10
10.8 m downwind	14
18.6 m downwind	08
26.4 m downwind	28
34.2 m downwind	25

These data show that variation in wind reduction increases very rapidly upstream from the windbreak, but the variation is relatively small downwind to about 8 h (20 meters). Beyond 8 h, there is a considerable increase in variation.

Strong eddies probably occur at the ends of the windbreak. This appears in the great variation of speed, which ranges from 9 percent to 115 percent of upstream flow in a distance of .7 meter at the west end of the barrier. Changes of such great magnitude are of interest in a meteorological sense but are beyond the scope of discussion in this paper. The eddies and the strong wind associated with them at times influence the behavior of the animals because they do not congregate at the ends of the structure and particularly avoid the windward side of the structure near its ends.

The area of 50 percent or greater wind reduction on the lee side of the windbreak is triangular. The apex is 26.5 meters (about 11 h) downwind, north of the barrier. There are about 312 square meters of area with a wind reduction ranging from 50 percent to as great as 90 percent below the upstream speed. Approximately 56 square meters on the windward side of the windbreak have wind reduction of 50 percent to 80 percent of the upstream value.

Snow Pattern

An unused windbreak in the same animal lot with one used by the Experiment Station stock was observed for the configuration of snowdrifts associated with it on January 31, 1979. These drifts were entirely undisturbed. The distribution of snow was compatible with measured winds and their reduction. The shape of the drifts gave evidence of some turbulence, and depth of drifts clearly showed the result of reduced horizontal wind speed. The greatest snow deposit, with respect to depth, was in the regions of greatest measured wind reduction and the depth of the drifts tapered away to a feather edge in the direction of greater measured wind movement. In an area of barrier-caused turbulence, beginning at an estimated 2 h from the barrier and extending downwind to about 10 h, snow was not deposited.

Figure 4a is a cross section of the windbreak and associated snowdrifts, and it shows the region of turbulence. Wegley, et al. (1978) suggested similar wind streams and turbulence in relation to windbreaks. The upstream snowdrift was slightly deeper and was smaller horizontally than the drift on the lee side of the barrier. Figure 4b, a top view of the windbreak and snow configuration, shows no snow was deposited for approximately 1 meter on both sides of the windbreak. At an estimated 5 meters downstream from the structure, a large bare area defined a region of turbulence in the air flow just downstream of the region of greatest wind reduction.

The sharp peak on the drifts and their distance from the windbreak suggest some weak upward motion on both sides of the respective peaks. This seems to locate some eddies depicted in Figure 4a. During the day, some very weak vertical motion occurs near the surface of the south side of the wooden wall forced by solar heating of the wall.

In the snow-free area beside the wooden wall, there was weak horizontal air movement. This probably helps keep the surface free of snow. The area of the snowdrift on the windward side of the barrier is known to be a favored position for cattle which have been observed around another, identically designed, windbreak. Cattle frequent this location even in a time of strong upstream windflow.

An eddy flow such as depicted over the right portion of the lee drift in Figure 4a has been suggested by Gandemer (1978) and also by Wegley, et al. (1978). Such a "return" flow near the surface seems necessary to form the drift where it is and with the shape it has.

Wind Shear

Figure 4b shows the horizontal distribution of snow. The two side drifts are seen to extend much further downstream than the principal drift shown nearer the windbreak in Figure 4a. The side drifts appear to be generally no more than 30 centimeters deep and run out to a feather edge. Horizontal wind shear, as shown by wind of 115 percent of upstream flow

$$\text{shear} = \frac{\partial V}{\partial n}$$

passing the end of the barrier and reduced flow in the lee of the barrier, causes curvature of streamlines. There is positive shear in relation to the east and negative shear related to the west end of the structure. The shear is strong. With an upstream wind of 8.94 meters/second, at a distance of 8 meters downstream from the end of the barrier, the shear is

$$\sim \frac{2.24 \text{ ms}^{-1}}{3.96 \text{ m}} = .56 \text{ s}^{-1}$$

This results in rapid turning of streamlines downwind of the structure as shown in Figure 4b.

Vertical shear results from flow passing the top of the windbreak. It is less strong, but it results in turbulent flow as shown in Figure 4a downwind from the windbreak.

The large bare area, centrally located downstream from the windbreak in Figure 4b, also seems to indicate a region with a shallow "return" wind near the surface.

Air Temperature

Air temperatures were measured and recorded immediately on the windward and the lee sides of the windbreak. Also, temperature was recorded at 12 h downstream from the windbreak. The air temperature measurements were made with thermographs in shelters. The instruments were 1.5 meters above ground. Temperatures were read and compared for the three locations at 12 noon.

In periods of strong wind, the animals occupy a certain region on the windward side of the windbreak as well as on the lee side; hence, it seemed possible that some warming was occurring from isolation on the wood surface. If there were a temperature increase from solar warming of the wall, it would be evident at noon.

Twenty-three days in February and March in 1977 and 1978 were selected for temperature comparison. Temperatures were averaged for 12 noon for each location.

	Point of temperature measurement		
	Windward side	Lee side	12 h downstream
Mean temperature	10.7°C	10.5°C	10.0°C
Standard deviation	5.6	6.0	6.1

Clearly, there is no evidence of useful localized warming. The 0.2°C difference from the windward- to lee-side of the structure is within the error of sampling. If there is a small warming effect from the wooden wall, it is essentially the same on the two sides of the wall. Because the downstream temperature at a distance of 29 meters averaged only about 0.6°C different from temperatures near the structure, it seems clear that no warming resulted from the wooden structure; therefore, warming did not affect the animal behavior on the upstream side of the windbreak.

SUMMARY AND CONCLUSION

A solid windbreak causes marked reduction of wind downstream. For livestock comfort, a solid windbreak may be more effective than a porous one because wind reduction by a solid barrier is shown to be greater than by porous barriers reported by other writers (Wang, 1963; Bates, 1944). At the Experiment Station, winds were reduced 50 percent to 90 percent. A porous barrier influences a larger area. A solid windbreak also has an important wind reduction effect on its windward side. The measured area of wind reduction is well portrayed by a pattern of snowdrifts, both on the windward and leeward sides of the windbreak.

The comfort afforded to animals by a solid wooden windbreak is probably not related to any heat accumulated and reradiated by the structure. Any substantial amount of heat on the structure is rapidly dissipated in a strong wind. Therefore, a maximum of wind reduction is desirable and necessary if a windbreak is to be effective, because the comfort or attractiveness afforded to animals by the windbreak is mostly the result of wind chill reduction. Wind chill reduction is large in the region where wind flow is reduced to 50 percent or less of upstream flow.

It is an observed fact that cattle spend considerable time on the windward side of the windbreak, even on days of strong ambient wind. We believe this behavior is explained by the large percentage of wind reduction, 50 percent or more, in a small region on the upstream side of the windbreak.

ACKNOWLEDGMENTS

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