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Microclimate Modification by Slat-fence Windbreaks[1]

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ABSTRACT

The influence of windbreaks on the microclimate has been widely studied, but more information is needed on the dynamics of wind barriers and how they modify the microclimate. Meteorological parameters were measured in the spatial vicinity of slat-fence windbreaks of 0, 40, and 60% porosity to characterize microclimate modification by windbreaks of various porosities. The highest daytime air temperature, lowest nighttime air temperature, and generally the greatest vertical temperature differences all occurred in the area of lowest windspeed. However, lowest windspeeds occurred at different locations for the different porosity windbreaks. The water-vapor-pressure and vapor-pressure differences between 40 and 5 cm above the crop surface were greatest at 2H leeward of the solid and 40-percent-open barriers throughout most of the daylight hours, whereas the vapor pressure at 2H leeward of the 60-percent-open barrier was similar to vapor pressure at other leeward positions. The vapor pressure was lower at 12H leeward of all barriers than in the open field.

Bowen ratios indicated that evapotranspiration was greater in the sheltered area than in the open, contrary to our earlier findings of less evaporation from evaporimeters leeward of similar barriers. Possible explanations of this anomaly are lower potential evaporation in the shelter, leaving the plants more passive to transpiration, and unaccounted-for horizontal divergence of sensible and latent heat in the sheltered area.

Additional index words: **Evapotranspiration, Bowen ratio, Microclimatology.**

MUCH of the Great Plains is characterized by hot, dry summer winds, which cause excessive evaporation and create hazards of soil erosion and of mechanical and abrasive damage to plants.

Where irrigated crops are produced in arid and semiarid climates, large quantities of energy are extracted from the air in the form of sensible heat. Greatest amount is associated with higher windspeeds. Under these conditions of high evaporativity, not only is much more water required to meet the evaporative demands, but soil water also must be maintained at higher levels to prevent plants from suffering from moisture stress.

Windbreaks have long been recognized for their value in moderating damaging effects of winds and in reducing evaporation. Numerous investigations of the influence of windbreaks on the microclimate (changes in windspeed, evaporation, air temperatutre, soil temperature, and snow drifting) have been made. However, still needed are investigations of the dynamics of wind barriers, to determine in more detail how they modify the microclimate and energy budget.

PROCEDURE

Slat-fence windbreaks 2.44 m (8 foot) high and 60 m long with 60, 40, or 0% porosities were installed perpendicular to prevailing summer winds (southerly) about midway in a 100 by 200-m field of clipped sudangrass (*Sorghum vulgare sudanese*). The 40-percent porous fence was constructed from 1.3-cm by 3.8-cm by 244-cm slats wired together as commercial snow fences. Two tiers of 1.22-m (4 foot)-high snow fence were used for the 60-percent porous fence. The solid barrier was created by covering the slat-fence with plastic film. Fences were changed periodically and data were obtained for several observation periods using each fence. The barrier field site was surrounded by farmland sufficiently level for furrow irrigation. The southerly approach in the experimental site was unobstructed by trees, buildings, or hills for more than 3.2 km (2 miles).

Open field measurements of windspeed, air temperature, vertical air temperature differences, water-vapor pressure, water-vapor-pressure differences, and soil-heat-flux density were made windward of the barrier and compared with measurements obtained in the sheltered area at 2, 6, and 12H leeward of the wind barrier. Solar radiation, net radiation, and wind direction were observed at one location.

On days when meteorological parameters were measured, the wind blew from the southerly direction at near-right angles to the barrier and exceeded 4.0 m/sec at 1.42-m height during midday hours except where indicated. The soil water tension was less than 10 bars, and the sky was clear to partly cloudy.

The data were analyzed using the Bowen ratio method to give an energy balance to each of the observation stations.

RESULTS AND DISCUSSION

The micrometeorological measurements showed air temperature lowest in the lee of the solid barrier at the station closest to the barrier in the early morning hours, but after sunup, the situation reversed and the 2H leeward station soon had the highest air temperature. The trend of highest daytime and lowest nighttime temperatures in the most protected area also prevailed with the 40-percent-open barrier (Fig. 1), but was less apparent in the sheltered area of the more porous 60-percent-open barrier, even though its sheltered area had higher temperatures during midday hours.

The higher daytime and the lower nighttime air temperatures in the sheltered area result from reduced vertical diffusion and mixing of air. At night, when the surface is cooled by net-outgoing radiation, a calm lowers the temperature. During periods of high-incoming net radiation, the surface usually is heated above air temperature. Therefore, with reduced diffusion, air immediately above the surface tends to be nearer surface temperature than bulk air temperature. However, daytime temperature in some portions of the sheltered area at times equals or drops below open-field temperatures.

Little difference in temperature existed between open-field (—6H) and 6 and 12 barrier heights leeward of the solid barrier. With the 40-percent-open barrier (Fig. 1), daytime temperature was lowest at 6H. In the wake of the barrier, mean vertical windspeed may not equal 0. Hagen and Skidmore (1) observed that where mean vertical component of flow was up, the temperature was higher, and where mean vertical component of flow was down, the daytime

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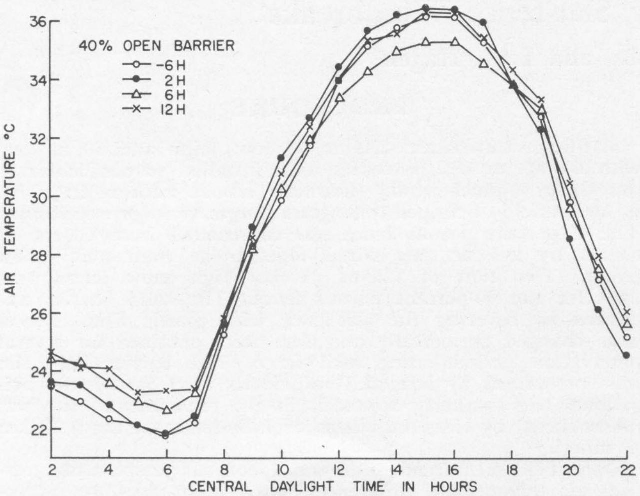

Fig. 1. Diurnal air temperature at 25 cm above the crop at various distances from 40-percent-open, slat-fence barrier. The wind blew at near-right angles to barrier at speeds greater than 4.0 m/sec at 1.42-m height during midday hours.

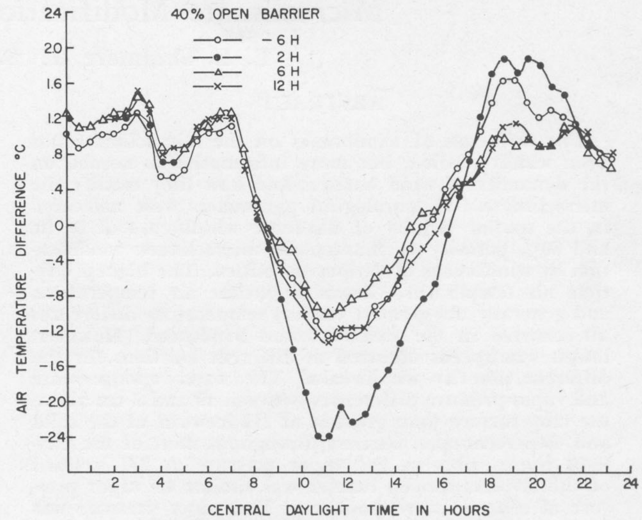

Fig. 2. Diurnal air temperature differences between 40 and 5 cm (t_{40}-t_5) above crop surface at indicated distances from 40-percent-open, slat-fence barrier.

air temperature leeward of the barrier was lower than corresponding open-field temperatures. Woodruff et al. (4) also found leeward air temperature patterns related to the eddy zone produced by the barrier. Where eddy currents were rising near the barrier, a warm zone extending 5 to 10H leeward occurred during the day; beyond 5 to 10H leeward, the daytime air temperature was lower than the open-field temperature.

The temperature difference between 40 and 5 cm above crop surface was generally, but not always, greatest in the sheltered area where windspeed was lowest.

With the 40-percent-open barrier, the temperature difference was greatest at 2H at both midday, when gradient was negative, and late in the day, when gradient was positive (Fig. 2). The temperature difference was least at 6H. Apparently, even though windspeed at 6H leeward of 40-percent-open barrier is low, mechanisms of exchange are high and transfer occurs freely. The temperature differences leward of solid barriers were not so great as differences leeward of more porous barriers. Other data (3) show that neither windspeed nor evaporation is reduced as much by a solid barrier as by one of optimum porosity. So mechanisms for transfer are high with solid barriers. Consequently, the differences are not expected to be so great.

Throughout most of the daylight hours, the water-vapor pressure was greatest at 2H leeward of both the solid and the 40-percent-open barriers, whereas vapor pressure at 2H leeward of the 60-percent-open barriers did not differ greatly from vapor pressure at 6 or 12H leeward positions. For all barriers, vapor pressure was lowest at the 12H leeward position. Diurnal variation of water-vapor pressure for the 40-percent-open fence is illustrated in Fig. 3.

Not only did vapor pressure tend to be highest at 2H, but vapor-pressure difference between 40 to 5 cm above crop surface was always greatest for all barriers at 2H, often exceeding 6 mb. Diurnal vapor-pressure differences for various locations for a typi-

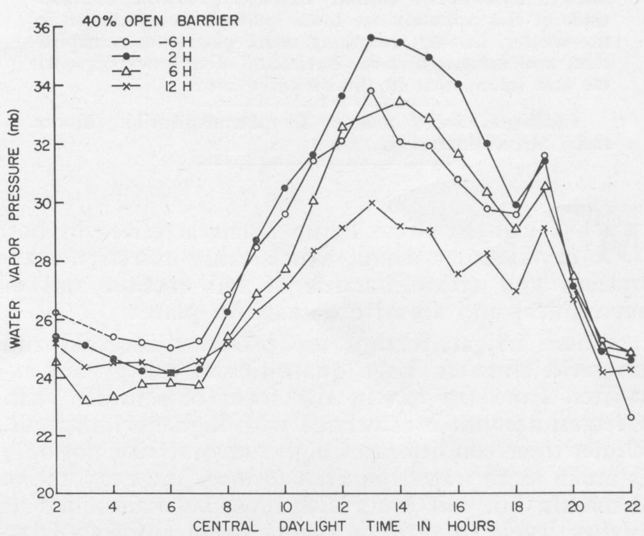

Fig. 3. Diurnal water-vapor pressure at 25 cm above the crop at indicated distance from 40-percent-open, slat-fence wind barrier. The wind blew at near right angles to barrier at speeds greater than 4.0 m/sec at 1.42-m height during midday.

cal day are shown in Fig. 4 for the 40-percent-open barrier. Data of Fig. 4 are representative of the other barriers. Vapor-pressure differences were lower at 6 and 12H positions than in the open field at —6H. However, it is the ratio of the change in temperature with change in vapor pressure that influences the energy budget. That is seen in the Bowen ratio method of determining evapotranspiration as represented by this equation:

$$LE = - \frac{R_n + S}{1 + \gamma \frac{K_h}{K_e} \frac{\Delta T}{\Delta e}} \quad [1]$$

where LE is evaporative flux, R_n is net radiation, S is soil heat flux, γ is psychrometric constant, and ΔT and Δe are changes in temperature and vapor pressure for corresponding change in vertical distance, respec-

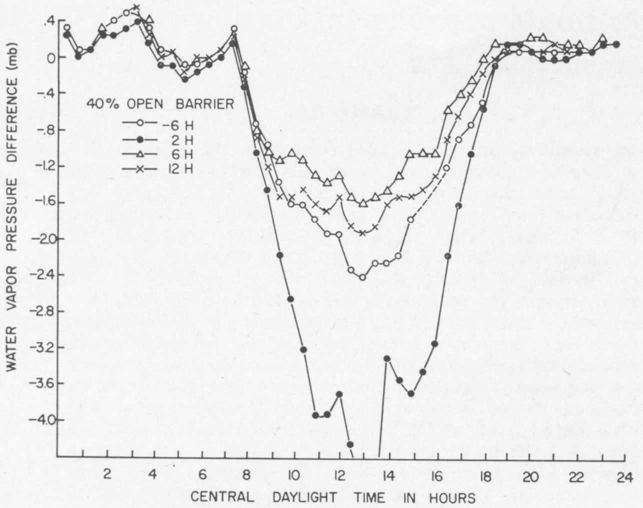

Fig. 4. Diurnal water-vapor pressure difference between 40 and 5 cm (e_{40}-e_5) above crop at indicated distances from 40-percent-open, slat-fence barriers.

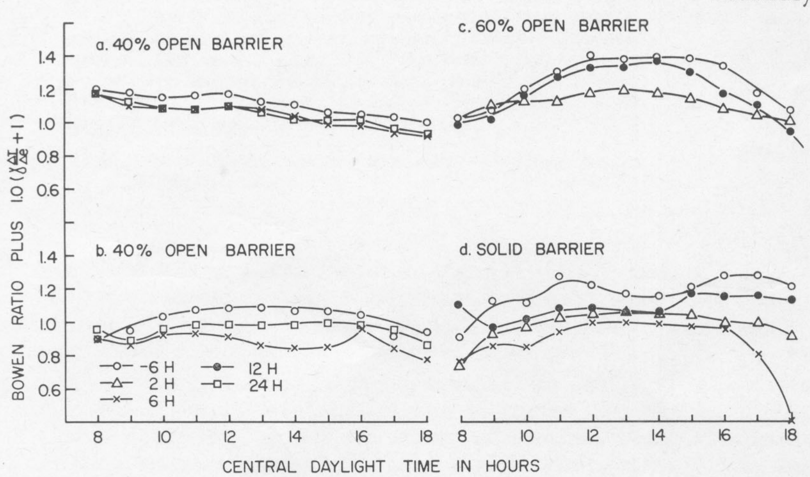

Fig. 5. Bowen ratio plus 1.0 at indicated distances from slat-fence barriers with porosities of 40, 40, 60, and 0% for a, b, c, and d, respectively. Winds were moderately strong for all days except for day represented by "a," which was relatively calm.

tively. Unity of the ratio of heat and water-vapor-transfer coefficients, K_h/K_e, and one-dimensional transport are assumed.

The effect that wind has on $\Delta T/\Delta e$ is not always apparent. It depends somewhat on the wetness of the evaporating surface. Generally, because of increased transfer, an increase in windspeed will decrease both ΔT and Δe, which are usually both negative for conditions of high incoming net radiation; however, if the surface is wet, an increase in windspeed will also increase evaporation rate. The resulting evaporation cooling will lower surface temperature and may even cause a positive temperature gradient; therefore, ΔT should decrease more than Δe. Hence, LE should increase with an increase in windspeed as indicated by equation [1], and conversely, LE should decrease with reduced windspeed.

Variation of the denominator of equation [1], sometimes referred to as the Bowen ratio plus 1.0, is presented in Fig. 5. Bowen ratios are smaller in the sheltered area, where, according to our model, evapotranspiration would be greater. But that is contrary to earlier findings (3) of evaporation from evapo-rimeters leeward of similar barriers. Possible explanations of this anomaly are: first, because of higher potential evapotranspiration in the open field, plants may be stressed and their stomata may be partially closed. The increased canopy resistance to diffusion due to stomatal closure may decrease evaporation, whereas in sheltered areas plants may remain more passive to transpiration.

Rosenberg (2) found that decreased atmometer evaporation in the shelter of a two-tier snowfence was accompanied by increased depletion of soil moisture. Secondly, and probably more important, with the Bowen ratio method, one assumes no horizontal divergence of sensible and latent heat between levels of measurement (one-dimensional transport). That condition is met if the sensors sampling temperature and vapor pressure at two heights are close enough to the surface and close enough to each other so no horizontal divergence occurs between them. However, such a restriction of one-dimensional flow is extremely difficult to meet leeward of an obstacle like a wind barrier.

Hagen and Skidmore (1) found that at 1.2 m (0.5H) above the surface, mean vertical windspeed 2 to 6H and 6 to 12H leeward of a 40-percent-open, slat-fence barrier was +1.8 and −2.1% of the horizontal windspeed at that height windward of the barrier. Even though these nonzero vertical mean windspeeds are small, they account for a lot of mass and energy transfer. Two-dimensional flow makes Bowen ratio data obtained behind wind barriers difficult to interpret and demanding extreme caution.

LITERATURE CITED

1. Hagen, L. J., and Skidmore, E. L. 1971. Turbulent velocity fluctuations and vertical flow as affected by windbreak porosity. Trans. Amer. Soc. Agr. Eng. 14:634-637.
2. Rosenberg, N. J. Microclimate, air mixing and physiological regulation of transpiration as influenced by wind shelter in an irrigated bean field. Agr. Meteorol. 3:197-224, 1966.
3. Skidmore, E. L., and Hagen, L. J. Evaporation in sheltered areas as influenced by windbreak porosity. Agr. Meteorol. 7:363-374, 1970.
4. Woodruff, N. P., Read, R. A., and Chepil, W. S. 1959. Influence of a field windbreak on summer wind movement and air temperature. Kans. Agr. Exp. Sta. Tech. Bull. 100, 24 p.