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MANAGEMENT OF MICROCLIMATE WITH WINDBREAKS

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ABSTRACT

Windbreaks influence the mean wind flow near the surface and as a result modify the microclimate in the area protected by the windbreak. Within this area there exist two zones, the quiet zone and the wake zone. In the quiet zone, reductions in turbulent transfer reduce the steepness of environmental gradients and as a result, plants growing in the quiet zone are less tightly coupled to the atmosphere above the shelter area. In the wake zone, turbulent transfer is enhanced, environmental gradients are increased and plants in this zone remain tightly coupled. As a result, the physiological response of crops within the two zones may be different. By altering windbreak structure large scale adjustments in microclimate are possible, however, additional research is needed before significant progress can be made in controlling specific microclimate parameters in shelter.

INTRODUCTION

The use of windbreaks to moderate climatic extremes dates back to the 18th century when Scottish agricultural workers used hedges to protect their crops. Since then, windbreaks have been utilized in numerous countries around the world to enhance crop production, reduce soil erosion, control snow drifting, and protect livestock. In the United States, windbreak planting reached a peak in the 1940's when the Prairie States Forestry Project led to the establishment of numerous multiple row windbreaks throughout the Great Plains Region. As larger machinery, center pivot irrigation, and government policies encouraged a fence row to fence row philosophy among farmers, many of these windbreaks were removed. Today, agricultural producers are beginning to utilize more sustainable and ecologically sound production techniques and the value of wind protection is again of interest (22).

This paper addresses four questions: 1) How does a windbreak reduce wind speed? 2) What effect does the reduction in wind speed have on the microclimate in the sheltered zone? 3) How do these changes in microclimate influence crop growth? and 4) Can we manage a windbreak to give the desired microclimate changes? The discussion here is necessarily brief and the reader is referred to the comprehensive review of windbreak technology resulting from the 1986 International Windbreak Symposium (4).

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WINDBREAKS, WIND FLOW AND MICROCLIMATE

In general, wind flows across the land surface in a laminar fashion. As the air flows over the surface, a frictional drag develops slowing the wind near the surface. A rough surface tends to have greater frictional drag, slower wind speeds, and greater turbulence near the surface. A windbreak can be considered as a special case of an increase in surface roughness which, when properly designed, provides an area of reduced wind speed useful for agriculture.

A windbreak is a barrier placed on the surface which obstructs the wind flow and as a result alters the flow patterns both windward and leeward of the barrier. As the wind approaches the barrier the flow is forced up and over the barrier and the streamlines of air are compressed as they pass over the barrier (25). This upward movement begins at some distance from the windbreak and creates a region of reduced wind speed on the windward side of the barrier. The width of this region is proportional to the height of the barrier and is usually expressed in multiples of barrier height (H). This protected area extends 2 to 5 H to the windward. A similar but much larger region of reduced wind speed is created in the lee of the barrier. This region typically extends for a distance of 10-20 H but has been reported to extend as much as 60 H (5).

The size of these protected zones and the extent of the wind reductions within the zones are dependent on the structure of the windbreak (11, 26). In particular, windbreak height and porosity determine windbreak effectiveness. In most cases a windbreak porosity of 40 to 60 percent provides the greatest area of protection. As porosity decreases, less wind passes through the barrier, the area of protection decreases, and more turbulence is generated. In contrast, as porosity increases, more wind passes through the barrier, wind speed reductions are smaller, and less turbulence is generated.

Recent research on windflow patterns behind windbreaks has suggested that the area of microclimate influence is considerably smaller than previously believed. McNaughton (15) has proposed that while the absolute reductions in horizontal windflow at the greater distances from the windbreak may be real, there is an increase in turbulence beginning at a distance of approximately 8 H leeward. Using the terminology of Raine and Stevenson (21), McNaughton (15) has described a quiet zone (within 8 H) where wind speed is reduced, turbulent transfer is less efficient, and environmental gradients of heat, vapor pressure and carbon dioxide are reduced; and a wake zone (beyond 8 H) where wind speed is also reduced but where turbulent transfer is enhanced and environmental gradients are increased. The boundary between these zones is dependent on windbreak characteristics, particularly height and porosity, and on atmospheric stability (16).

As a result of wind speed reductions and changes in turbulent transfer the microclimate in the protected zones is altered. The magnitude of microclimate changes for a given windbreak depends on the existing atmospheric conditions and on the windbreak's height, porosity, orientation to the sun and the time of day.

In general, daytime air temperatures within 8 H (the quiet zone) of a medium porous barrier tend to be several degrees Celsius warmer than temperatures in the open. Between 8 H and 24 H (the wake zone) daytime air temperatures are several degrees cooler. Night temperatures near the ground are generally 1-2 degrees warmer in the protected region (up to 30 H). However, on very calm nights, temperature inversions may occur and sheltered areas may be several degrees cooler (1, 25).

Average soil temperatures in shelter are slightly warmer (15, 25). However, soil temperatures in areas adjacent to an east-west field windbreak are higher on the south side due to radiation reflected by the windbreak. On the north side, soil temperatures, especially in the early spring are lower due to shading by the windbreak.

Rainfall over most of the sheltered area is generally unaffected except in the area immediately leeward of the barrier. This area may receive slightly less moisture due to interception by the windbreak. In contrast, snow accumulations leeward of dense windbreaks will add significant moisture to the area adjacent to the barrier. If the windbreak is more porous, snow distribution in sheltered areas is more uniform and may be a significant factor in determining increased yields (23).

Relative humidity in the quiet zone is slightly higher than in open areas depending on windbreak porosity (15, 25). Windbreaks with a porous lower level allow more air to pass through, decreasing humidity levels on the leeward side. Humidity in the wake zone may be slightly lower as a result of increased levels of turbulent transport (15,16).

Recent reviews by McNaughton (15,16), Heisler and Dewalle (11), and Argete and Wilson (1) have discussed the relationships between windbreaks, wind speed, and microclimate in detail and the reader is referred to these original works for a more complete discussion.

PLANT RESPONSE TO SHELTER

Wind influences plant growth and development in several major ways (7, 8, 9) all of which may be modified by shelter. One concept that is useful in explaining plant response to shelter is that of coupling (17). Exchange processes between single leaves and the atmosphere or between plant canopies and the atmosphere are controlled by the gradients that exist in the immediate environment above the leaf or canopy. When these gradients are modified by shelter, plant processes within the sheltered zone may become uncoupled (15, 17).

In the quiet zone we expect conditions to be uncoupled as the canopy is isolated from the atmospheric conditions above the sheltered area. In contrast, conditions in the wake zone become more strongly coupled as turbulence increases the concentration gradients. In either case we can expect to see the exchange rates for heat, water vapor and carbon dioxide altered (9, 14, 15, 16).

Plant temperature in shelter generally increases, particularly in the quiet zone where the rate of heat transfer from a plant is reduced by decreased temperature gradients. This can be an advantage as small increases in plant temperatures may have substantial positive effects on the rate of growth and development of the crop.

The influence of windbreaks on plant water relations is complex. Transpiration rates may be either decreased or unaffected by shelter depending on atmospheric resistance and saturation vapor pressure deficit. However, if the leaf surfaces are damaged, transpiration may increase (9). Evaporation rates from crops are reduced in shelter (14), water use efficiency in the quiet zone is enhanced (6, 9), and as a whole plant water stress is reduced (9). However, sheltered plants tend to be bigger and have larger leaf areas and under conditions of limited soil moisture may actually suffer greater water stress than exposed plants (9).

Wind also influences plant growth directly by the mechanical manipulation of plant parts. This movement may increase radial enlargement, reduce stem elongation (12), or affect cellular composition (2). The effect may be manifested via a hormonal pathway or may result from direct damage to the plant tissue. Indirectly, wind blown soil contributes to leaf or stem abrasion and may result in increased water loss due to cuticular damage (8).

CROP RESPONSE TO SHELTER

While the influences of wind and shelter on individual plant processes are only partially understood, the net effect of shelter on total crop yield is positive (3, 7, 13, 24, 25). The reasons vary with crop, windbreak design, geographic location, moisture condition, and cultural practice. This should be expected since final crop yield is the culmination of a series of interacting factors present during the growth and development of the crop (See Figure 1). As Sturrock explains, the relationship between shelter and crop response is a complex and dynamic system, subject to continual change as a result of changes in macroclimate, windbreak efficiency and the protected crop (24).

This is not to imply that the relationship between shelter and crop production is completely understood. On the contrary, the literature contains numerous examples of contradictions (7, 13, 24, 25). While some of these contradictions are relatively easy to understand, others present interesting questions which must be addressed through additional research. For example, if the findings of McNaughton (15, 16) are correct then there should be differences in the physiological and morphological response of plants in the quiet and wake zones. To date no studies have been conducted with this objective in mind, however, a comparison of several of our past studies suggests that this could be a valuable approach.

In 1981 and 1982 Ogbuehi and Brandle (18,19) published a series of articles concerning the response of soybeans to sheltered conditions. The sheltered soybeans were characterized by a significantly lower leaf area

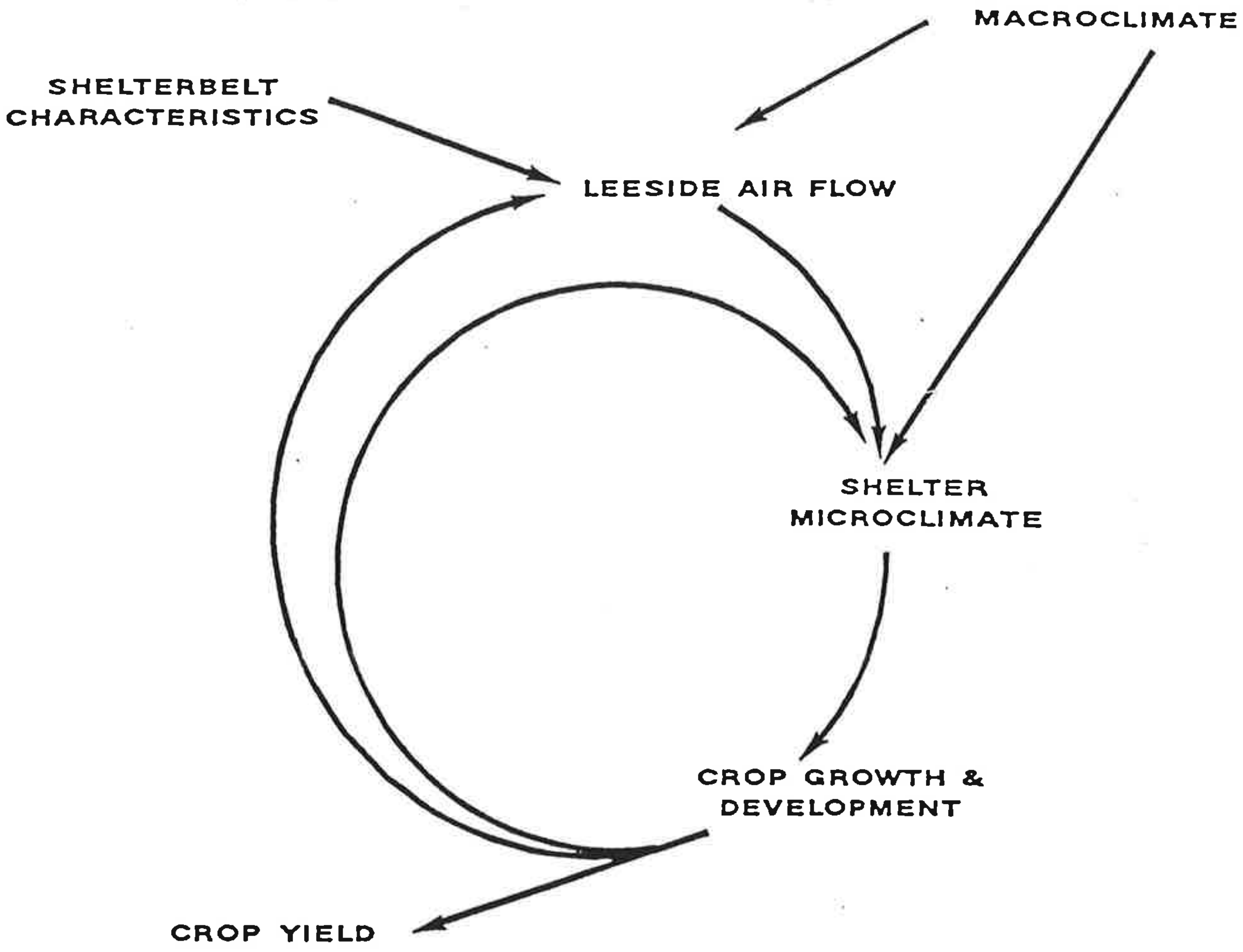

Figure 1. The interrelationships affecting shelter response of crops as proposed by Sturrock.

density, and smaller leaf size in the uppermost portions of the canopy in comparison with those grown in exposed plots. Consequently, there was a greater penetration of the incident photosynthetically active radiation to lower canopy strata in sheltered soybeans. With greater light penetration, photosynthetic rates at lower levels of the canopy were increased and final yields within the sheltered zone were increased 23 percent. The increase in total yield could be attributed to the increased yields in the lower levels of the canopy.

In 1984, Hans and Brandle (10) initiated a study designed to determine if the canopy structure changes seen in soybeans would occur in alfalfa. Results after 3 years of data collection indicated no significant differences in leaf to stem ratio, total biomass, or canopy structure. Both studies were conducted within 10 H of the windbreak in areas considered to be totally protected. Wind speed in the sheltered area averaged 54 percent of open wind speed for the soybean study and 60 percent for the alfalfa study. These differences in wind speed did not appear to be of such a magnitude as to account for the different responses and at that time the lack of significant differences was attributed to the high level of variability in the alfalfa samples.

A reevaluation of these two studies indicated several subtle but important differences between the sheltered conditions. Both studies had been conducted in windbreaks systems established in 1964 and believed to have similar zones of protection. No previous studies had shown any difference in response between the two systems even though the windbreaks are composed of different species. The soybean study was conducted behind a two row green ash (*Fraxinus pennsylvanica* L.), Austrian pine (*Pinus nigra* Arnold), and eastern redcedar (*Juniperus virginiana* L.) windbreak with a porosity of approximately 40 percent (18). The alfalfa study was conducted behind a Scots pine (*Pinus sylvestris* L.), eastern redcedar windbreak with a porosity of approximately 30 percent (10).

Reevaluation of the plots with particular reference to the findings of McNaughton (15) indicated that while the soybean study was well within the quiet zone at 2-6 H the alfalfa study, which was located at 7-8 H, was most likely on the border between the quiet and wake zones. This is even more likely given the lower porosity of the conifer windbreak and the tendency of lower porosities to reduce the extent of the quiet zone (16, 20, 27).

Several observations recorded in Hans' daily log also support the idea that his plots were located at the border between the quiet and wake zones. He observed that an increase in alfalfa height occurred between 2 and 5 H, that the wave action of the alfalfa canopy was more uniform closer to the windbreak, and that there appeared to be an increase in the turbulent motion of the alfalfa in the vicinity of the study plots. While not definitive, these observations would indicate that plot location may have been a factor in the results of the alfalfa study.

Finally, preliminary data from an alfalfa yield study conducted during the summer of 1990 at Cut Knife, Saskatchewan indicated that maximum yield benefit occurred at between 2 and 4 H leeward of a single row caragana (*Caragana arborescens* Lam.) windbreak with a porosity of approximately 40 percent. Yields at 8 H, 15 H, and 25 H did not differ from the open field yields (Kort and Brandle, unpublished data).

What are the consequences of these observations?

First of all the alfalfa study needs to be repeated and the results verified. Second, detailed microclimate measurements need to be made including measures of turbulence in the sheltered areas. Third, vegetational sampling for both alfalfa and soybeans needs to be done to determine if there are differences in canopy structure between the quiet and wake zones. Finally, the influences of windbreak porosity on the size and magnitude of the quiet and wake zones needs to be determined under field conditions.

The concerns raised by McNaughton (15,16) have been based primarily on theoretical grounds, reevaluation of existing studies and wind tunnel models. He acknowledges that under field conditions microclimate responses are confounded with vegetational changes in the sheltered zone. If verified these observations would be one of the first confirmations of the impact of the quiet and wake zones on the effects of windbreaks on crop production.

MANAGEMENT OPTIONS

Do we know enough about the relationship between windbreaks and microclimate to make specific recommendations? The answer is both yes and no.

We can and do design windbreaks to meet specific objectives. By adjusting species selection and plant spacing we can manipulate windbreak porosity. We can spread snow across a field (high porosity) or store it in a relatively small area (low porosity). We can optimize protection across a large grain field (moderate porosity) or provide maximum wind reduction for highly sensitive specialty crops (moderately low porosity). We can and do utilize windbreaks for wind erosion control. To a lesser extent we can select the type of windbreak for various types of crops. We can and do take advantage of the microclimates that are created.

We can't create a specific microclimate. We can't adjust porosity and control the size of the quiet or wake zone. We have not selected or developed specific crop varieties to utilize the advantages provide by windbreaks. We have not determined if the standard cultural practices utilized in unprotected fields are best for sheltered areas.

SUMMARY

Windbreaks alter the microclimate in the sheltered area and this microclimate can be utilized to the advantage of agricultural production. Within limits it is possible to manage the microclimate response by manipulating the porosity of the windbreak. Additional research is needed to determine how porosity effects the size and magnitude of the quiet and wake zones within the sheltered areas. Detailed microclimate measurements under field conditions need to be made to determine the relationship between theoretical models, physiological processes, and final crop yields under sheltered conditions.

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