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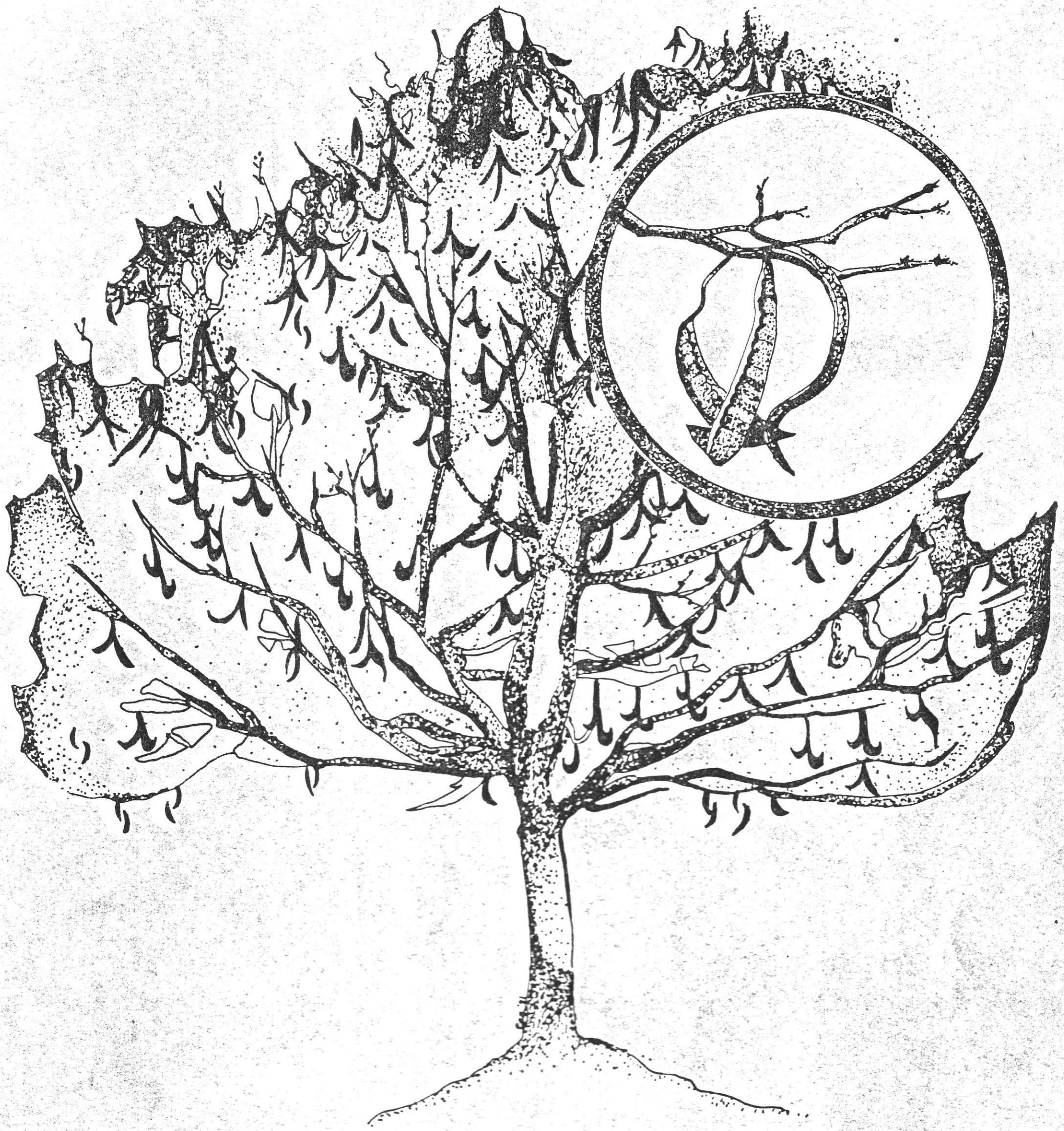

Tree Crops for Energy Co-Production on Farms

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THE ROLE OF MICROCLIMATE IN ENERGY USE EFFICIENCY[1]

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Introduction

The relationship between microclimate and energy use efficiency is a difficult one to generalize. In each situation different factors are of varying degrees of importance. The purpose of this report is to offer some general considerations concerning the relationship of shelterbelts and microclimate to energy use efficiency. By utilizing various characteristics of the microclimate of shelter a landowner may reduce the energy needed to grow crops, raise livestock, heat or cool the farmstead and maintain the farm working area.

Before we examine the benefits of shelter to these aspects of farm operation we must examine the physical changes in microclimate related to shelter from the wind.

Effects on Microclimate

The main effect of shelter is to reduce surface windspeed (Marshall 1967). Almost all other effects are secondary, a consequence of the reduction in windspeed. The effectiveness of a windbreak is dependent primarily on its height, density, width and length. Roughness of the ground surface and atmospheric stability also play a role in determining effectiveness. A dense windbreak will protect an area 10 to 15 times its height (H) downwind. By decreasing the density to 50 per cent the area protected downwind can be extended to 20 to 25 times its height. In either case the degree of protection is a function of the distance from the windbreak. As the density of a windbreak increases, turbulence in the lee of the windbreak is created due to the air overtopping the barrier. By increasing the porosity some wind penetrates the barrier and prevents the overtopping and turbulence (Marshall 1967, Rosenberg 1974, van Eimern et al. 1964).

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Air Temperature

Air temperature is a function of the amount of sensible heat transferred from the soil or plant surface to the air. The dissipation of this heat is influenced by turbulent mixing of the air. Reductions in turbulence will cause that parcel of air near a warm surface to become heated. Since the effect of shelter is a reduction in wind velocity and consequently a reduction in turbulent mixing, daytime air temperatures tend to increase in sheltered areas. However, night time temperatures tend to be cooler because of the formation of inversion layers in the sheltered zone (Rosenberg 1974). In general the degree of temperature variation is determined by windbreak permeability, soil moisture, cloudiness and net radiation. Windbreaks tend to increase the range of temperature within a 24 hour period.

Soil Temperature

The influence of shelter on soil temperature has been extensively reviewed by van Eimern et al. (1964) and others (Bates 1911, Caborn 1957, Rosenberg 1965). Bates (1911) suggested that the magnitude of increase in soil temperature was a function of many factors including depth, season, time of day, soil moisture, crop cover and others. Rosenberg et al. (1963) reported an increase in soil temperature of 1^o to 2^oC under uniform crop conditions during both day and night.

Humidity

The literature on the influences of shelter on humidity must be viewed with caution. Not only do many of the reports deal only with relative humidity with no temperature considerations (Bates 1911, Caborn 1957, Rosenberg 1965) but many other factors are also ignored (van Eimern et al. 1964). In general, absolute humidity and relative humidity are greater in shelter, both by day and by night (Bagley & Gowen 1960, Rosenberg 1965, Rosenberg 1974).

Soil Moisture and Evapotranspiration

The effects of shelter on soil moisture are exceedingly complex (Caborn 1957). In general, two types of effects need to be considered: 1) the influence of the windbreak on the distribution of precipitation and 2) the influence of the windbreak on evaporation (Marshall 1967).

In areas where the majority of the annual precipitation occurs in the form of snow, the distribution of the snow is important. Windbreaks help control this distribution. The degree of distribution across a protected field is proportional to the height, width and density of the windbreak. The best distribution is obtained with permeable windbreaks somewhat open at ground level (Stoeckeler 1962).

Windbreaks also affect the distribution of rain due to the formation of a rain-shadow zone on the leeward side of the windbreak. The size of this zone depends on the wind velocity and the height and density of the windbreak (Caborn 1957).

Dew formation may be increased in a narrow band 2-3H on the leeward side of a windbreak. The agricultural significance of dew may be limited even though some moisture may be absorbed through the leaf surface (Caborn 1957).

Besides influencing addition of moisture to the soil profile, windbreaks influence the removal of water by their influence on evaporation. Changes in windspeed, temperature and atmospheric gradients influence evaporative rates (Caborn 1957, Rosenberg 1974, van Eimern et al. 1964) and as a consequence atmospheric evaporative demand is decreased on the leeward side of a windbreak (Frank et al. 1974, Marshall 1967, van Eimern et al. 1964). Theoretically this should make more water available to plants for growth.

While the physical changes in microclimate due to shelter are fairly well established, the biological responses to these changes are less clearly defined.

Effect on Crop Production

Yields of wheat, rye, barley, oats and corn increased when protected by 40 year old cottonwood and boxelder windbreaks in North Dakota, South Dakota and Nebraska (Stoeckeler 1962). Shelter has also been shown to increase yields of forage crops such as alfalfa (Bates 1944, Trenk 1948), timothy (Trenk 1948), red clover (Trenk 1948) and crested wheat grass (Quayle 1941).

Increased yields of tomatoes and beans (Bagley 1964, Bagley & Gowen 1960), dry beans (Rosenberg et al. 1963) and soybeans (Frank et al. 1974) have been reported when protected by slat-fences. Radke et al. (1970, 1973) demonstrated increases in the yields of soybeans protected by temporary corn windbreaks. George (1971), however, indicated that in North Dakota yields of wheat were inconsistent and showed no significant differences when sheltered with slat fences. Likewise, Skidmore et al. (1974) found no consistent increases in wheat yields in Kansas.

In sugar beets the total weight of roots and beets increased in shelter of slat-fences but the top weight was unaffected and the sugar content of the beet actually decreased (Rosenberg 1966). During three different growing seasons, Brown and Rosenberg (1970, 1971) found that the benefits of annual windbreaks on the yields of sugar beets were much more pronounced during dry years than during years of adequate rainfall.

The inconsistency of these results has led other investigators to conclude that the amount of measurable benefit in crop yield is dependent on the severity of growing conditions (McMartin et al. 1974, Pelton 1967, Skidmore et al. 1974, van Eimern et al. 1964). In addition, the use of crop yield as an indicator of shelter-effects involves the sum of too many variables over too long a period to give consistent results. Changes in microclimate undoubtedly affect the development of the plant.

Therefore, the emphasis of research should be to determine how these small changes affect plant processes at various stages of development.

Winterkill and Wheat Yields

The effects of wind protection on winter wheat survival and yield in Eastern Nebraska have been observed periodically over the past 15 years. In many years weather conditions in Eastern Nebraska are such as to prevent extensive damage to the wheat crop due to winterkill. As a consequence, the value of wind protection in the production of winter wheat is often overlooked. However, in three of the last five years temperatures during October to February have averaged 4° to 8°F below normal. Table 1 illustrates the yields of winter wheat in sheltered and exposed areas and the temperature deviation from normal during each of these years (October to February). During the 1976-77 and 1978-79 growing seasons yields from sheltered plots were significantly greater than exposed plots. Yield increases were sufficient to more than compensate for the land lost to trees (Brandle 1980).

By increasing production on a smaller area the microclimate changes occurring as a result of shelter have increased our energy use efficiency, i.e. more grain produced per unit of fuel consumed.

Soybean Production in Shelter

Conflicting reports exist concerning the effects of shelter on soybean production and its relationship to plant water status (Frank et al. 1974, Radke et al. 1970, 1973). A recent study (Ogbuehi 1980) has shown that under rainfed conditions soybean yields increased 20 - 26 per cent as a consequence of an increase in water use efficiency. Furthermore, plants in shelter had higher CO_2 exchange rates and greater stomatal conductance at equivalent relative canopy heights in comparison to exposed plants. A study of the canopy structure indicates a greater leaf area development in shelter resulting in greater light interception. Longer internodes of sheltered soybean plants allowed greater spatial separation of leaves, lower canopy area density, deeper penetration of light to lower canopy strata and consequently greater utilization of available light.

Again modification of the microclimate has provided a greater energy use efficiency. In this case the benefit is not only greater grain production per unit fuel consumed but also more efficient use of available solar radiation.

Effects on Livestock Operations

The value of windbreaks for protection of cattle on range and pasture land is well established (Cross 1974, Zaylskie 1966). Livestock need protection from winter storms, especially in the Northern Plains States. Johnson (1947) estimated an average 33 per cent savings in winter feed requirements for stock with wind protection. Nebraska sandhills ranchers maintain that protective tree plantings greatly reduce livestock losses due to freezing temperatures, blizzards and the inaccessibility

Table 1. Comparison of annual yields of winter wheat, sheltered and exposed, with the deviation from the average monthly temperature (October - February).

	Yield (bu/A)		Temperature (°F)
Year	Sheltered	Exposed	Deviation from Normal
1975-76	57.3	56.7	+ 3.30
1976-77	38.0	31.7	- 4.34
1977-78	*	*	- 6.68
1978-79	47.1	33.3	- 8.02
1979-80	46.6	43.8	- 0.38

* No yield data available

of feed (Cross 1974). The list of personal testimonies could go on at length.

While the value of windbreaks to ranchers and cattle producers is unquestioned, some scientists question their economic value in feedlot operations. Again personal testimony is overwhelmingly pro-windbreak. In Cuming County, Nebraska over 95 per cent of the feedlots are protected by over 2,065 acres of windbreaks (Cross 1974). Producers are convinced that cattle which are provided protection spend more time eating and less time bunched up for warmth. Protected cattle will gain more weight per unit of feed because less feed is required.

In contrast, Bond & Laster (1974) concluded that windbreaks provide little benefit "to winter growth or to feed efficiency of feedlot cattle in the Midwest". Their study showed conclusively that cattle provided with wind protection spent more time in protection than at the feed bunks and as a consequence gained less than those without protection.

At the University of Alberta a group of animal physiologists have been working extensively on the relationship between cold weather and energy requirements of cattle (Christopherson 1973, Christopherson & Thompson 1980, Young & Christopherson 1974, Webster 1970). Their findings indicate that the critical temperature (that temperature below which animals experience cold) of feedlot cattle is usually below an equivalent still-air temperature of -20°F. They indicate that even in Canada long periods of -30° to -20°F are unusual. However, practical feedlot data indicate poorer feed efficiencies and consequently a reduced rate of weight gain during the winter months at temperatures above the critical temperatures of the animals (Young & Christopherson 1974). They concluded that while generation of heat for body warmth may be required during stress periods it is not the major cause of an increase in feed requirements. The primary reduction in productivity results from physiological changes reducing digestion efficiency and arises from prolonged exposure to cold. Furthermore prolonged exposure to cold reduced apparent digestibility of dry matter 1.3 per cent units for each 10^{o}F drop in the average ambient temperature.

For example, a ration which has a dry matter digestibility of 70 per cent at 50^{o}F would offer 12 per cent less nutrients to the consuming animal at -10^{o}F than at 50^{o}F. Temperature fluctuations of this magnitude are relatively common throughout the Great Plains Region. Christopherson (1973) also showed that it is these abrupt changes in temperature which produce irregular feeding patterns in cattle and the resulting reduction in rate of weight gain.

The use of windbreaks to reduce windspeed alters the microclimate of the feedlot. As a result, ambient air temperatures are moderated and less feed is required for each unit of weight gain. Energy is conserved as a result of lower feed requirements as well as from reduced feed distribution demands. Again we have produced more of a given product while reducing our total energy usage, i.e. greater energy use efficiency via a modification of the microclimate.

Effects on Home Heating and Cooling

The value of windbreaks and other tree plantings in reducing home heating and cooling costs has only recently been revived. Recent investigations have illustrated the vast potential in energy savings of utilizing the microclimate changes due to shading and wind reduction.

Home Heat Exchange

Heat loss from a home occurs through three major processes: radiation transmission, heat conduction, and air infiltration (DeWalle & Farrand 1975).

The transmission of solar radiation through windows can be a valuable asset in winter and a significant liability during the summer. The amount of solar radiation penetrating a window can be controlled by judicious placement of trees. In addition, trees can also be used to influence the amount of solar radiation striking any surface of the building. Obviously it would be advantageous to maximize solar radiation during the heating season and minimize it during the cooling season.

The conduction of heat through solids is controlled by the thermal properties and thickness of the materials involved. Still air has one of the lowest rates of conductivity of materials found in the home. Thus, the value of insulation is related to the many small pores filled with air. Some materials such as glass have very high levels of conductance and therefore heat conductivity through windows is extremely high. Heat conduction can account for 35-50 per cent of the total heat loss of a structure.

The best opportunities to control conduction losses are to reduce the temperature gradient across the barrier and to reduce the rate of heat movement through the barrier. The latter can be controlled relatively easily by insulation material but the temperature gradient itself is somewhat more difficult. Inner surface temperatures are largely controlled by the interior air temperature. Thus the gradient can be partially reduced by lowering the interior temperature. Outer surface temperatures are controlled by wind, air temperature and solar radiation. By reducing the wind velocity we can reduce the air turbulance and in turn enlarge the layer of still air next to the outer surface. In addition we have seen that a reduction in windspeed will also increase the air temperature in shelter due to a reduction in turbulent mixing. Again the judicious use of deciduous trees for shade will reduce surface temperatures in the summer and reduce cooling demands. During the winter solar radiation can be important in reducing heating demands by raising the outside surface temperature and reducing the temperature gradient. It should be apparent that these two processes can be conflicting and that a balance must be struck to maximize the utilization of the microclimate.

Heat loss by air infiltration is the process most directly affected by reductions in windspeed. Air infiltration is the movement of air through cracks, windows, doors or other openings. It is caused by pressure gradients between the inside and outside of a building. As wind velocity increases, the outer surface of a structure facing the wind will experience an increase in pressure and air will be forced into the building through available openings. On the leeward size of the building pressure is reduced and air moves from the building to the outside. Temperature gradients also contribute to this air movement. A severe combination of high wind and low temperature may cause the air in a home to be replaced as often as twice per hour. In most situations from 20-35 per cent of the heat lost by a building is lost by air infiltration (DeWalle and Farrand 1975).

Air infiltration through windows, doors and cracks can be reduced by diminishing the pressure of the wind by means of a windbreak. A study at Princeton University (Mattingly & Peters 1975) has indicated reductions in air infiltration rates as high as 60 per cent. The study was conducted with condominiums with common walls which tended to decrease the relative importance of the air infiltration factor and thus the importance of wind protection is underestimated.

Table 2 gives hypothetical data from four typical homes in Nebraska. Data were compiled from the AGNET system (Bodman et al. 1980) and values from the Princeton study were used to estimate expected reductions in air infiltration rates (Mattingly & Peters 1975). Three situations were considered: 1) No protection, 2) Protection by a single row of conifers - 40 per cent reduction in air infiltration and 3) Protection by a single row of conifers and a 7 foot high board fence - 60 per cent reduction in air infiltration. Potential savings of 13

Table 2. Effect of wind protection on the home heating costs and heat loss due to air infiltration of four Nebraska homes.

Degree of Protection	Infiltration Heat Loss		Annual Heat Cost	
	BTU/HR	% of Total	$/yr	% Saved
w/o protection	21325	33	325	---
w/tree windbreak	12795	23	283	13%
w/tree windbreak & 7 foot barrier	8530	16	261	20%
w/o protection	32730	41	537	---
w/tree windbreak	19638	29	448	16%
w/tree windbreak & 7 foot barrier	13092	22	404	25%
w/o protection	38827	65	335	---
w/tree windbreak	23296	53	248	26%
w/tree windbreak & 7 foot barrier	15530	43	203	39%
w/o protection	52152	74	393	---
w/tree windbreak	31291	63	279	29%
w/tree windbreak & 7 foot barrier	20860	53	220	44%

to 44 per cent were realized. In 1980 dollars these savings range from $64 to $173 per year.

Snow Management

Proper snow management by windbreaks is an integral part of any windbreak system. For field windbreaks the objective is to spread the snow evenly across the protected area and open deciduous species are most desirable.

For use with livestock operations the windbreak systems must be designed to prevent snow drifts in the feedlots and alleys. Poorly designed systems may actually cause more harm than good. If snow is allowed to build up in the pens access to feed may be denied and the increased moisture may cause mud problems. In designing systems for feedlots care should be taken to provide enough room for snow deposition and proper drainage for melting snow.

In the protection of the farmstead itself care must be taken to prevent snow build up in drives, against doors or windows and in other work areas. In fact, shelter which is designed to protect the farmstead should take into consideration the working areas of the farmyard. Storage areas for machinery and equipment should be protected and the design of the windbreak should be such as to minimize snow removal efforts.

Windbreaks designed to protect farmsteads and feedlots are usually multiple row. There is normally a row of shrubs or low growing evergreens on the windward side with one or more rows of deciduous trees and one or more rows of tall coniferous species completing the windbreak. This will provide adequate snow stoppage as well as provide plenty of space for snow deposition. The amount of space needed for snow storage varies with geographic location and an adequate number of rows should be provided to provide sufficient storage.

One other aspect of snow management must be considered. Even though we have been primarily concerned with the individual farm situation we should consider the use of "living snow fences" for the protection of roadways. By proper placement and design the amount of snow removal necessary to provide access to the farmstead can be minimized and the resulting energy savings realized.

In summary by utilizing the various aspects of microclimate created by shelterbelts we can increase the amount product produced, reduce the amount of energy needed to perform various tasks and maximize the efficiency of the energy it is necessary to use.

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