Windbreaks and Specialty Crops for Greater Profits[1]

James R. Brandle, Laurie Hodges, and Joel Stuthman[2]

Abstract — Trees and shrubs have an important role to play in today's integrated agricultural systems. Planted as windbreaks, they provide wind erosion control, improve crop yields, and enhance the quality of many wind-sensitive crops. When properly designed, windbreaks can also provide valuable products to enhance the profitability of agricultural operations.

Appearance and quality are major factors in decisions by consumers to purchase specialty crops. Fruits and vegetables with blemishes caused by wind blown soil, abrasion, or sunburn are graded lower and receive lower prices. Many fruit and vegetable crops have shown significant yield increases as a result of shelter. In many cases, vegetables grown in shelter mature earlier, providing marketing advantages to producers in quality and price.

Incorporating fruit or nut trees and shrubs into a windbreak may offer opportunities for additional income. Fresh or dried fruits and nuts, jams, juices, and wine are some of the possible products. While high-quality fruit and nut crops require intensive management, less intensive operations can provide products suitable for local farmer markets or pick-your-own operations.

The integration of woody plants into the agricultural landscape provides habitat for many wildlife species. A diverse agroecosystem is more likely to resist outbreaks of certain insect and rodent pests due to the presence of natural predators. While some wildlife species may be incompatible with production of certain specialty crops for some markets, the presence of wildlife may provide additional income from fee hunting or other recreational activities, especially near urban centers.

The integration of agroforestry practices into sustainable agricultural systems focused on specialty crops requires careful consideration of all aspects of the operation, an understanding of basic ecological principles, and a working knowledge of local conditions and markets.

Introduction

The continental climate of the Great Plains is one factor limiting commercial vegetable production in the region. The climate-related combination of temperature extremes, temperature fluctuation, high winds, high evapo-transpiration, and low, erratic rainfall increases the risk to growers producing high-value, capital-intensive crops such as commercial fresh market fruits and vegetables.

The use of windbreaks to moderate climatic extremes dates back to the 18th century when Scottish agricultural workers used hedges to protect their crops. Today, windbreaks are recognized not only for their influence on microclimate but also for their beneficial effects on crop yield and quality (Baldwin 1988; Brandle *et al.* 1988; Norton 1988). These benefits stem mainly from a reduction in wind speed and a modification of the microclimate in the sheltered zone.

[1] *Paper presented at the Agroforestry and Sustainable Systems Symposium (Fort Collins, CO, August 7-10, 1994).*

[2] *James R. Brandle is Associate Professor of Forestry, Laurie Hodges is Assistant Professor of Horticulture, and Joel Stuthman is a technical writer, University of Nebraska-Lincoln, Lincoln, NE.*

This paper addresses three aspects of windbreaks and specialty crops: 1) How does a windbreak work? 2) What are the benefits to specialty crops? and 3) How can agroforestry practices be incorporated into production systems to enhance total economic return?

Windbreak Mechanics

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 increases surface roughness and, when properly designed, provides areas of reduced wind speed useful for agriculture.

A windbreak is a barrier on the surface that obstructs wind flow and alters the flow patterns both windward and leeward of the barrier. As wind approaches the barrier the flow is forced up and the streamlines of air are compressed as they pass over the barrier (van Eimern *et al.* 1964). 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 extends out 2 to 5 times the height of the barrier. A similar but much larger region is created to the lee of the barrier and typically extends for a distance of 10 to 20 times the barrier height (Caborn 1957).

The size of these protected zones and the extent of the wind reductions within the zones are dependent on the structure of the windbreak (Heisler and DeWalle 1988). In particular, windbreak height and porosity determine windbreak effectiveness. In most cases a windbreak porosity of 40 to 60 percent provides the greatest degree of protection over the largest area. As porosity decreases, less wind passes through the barrier, wind speed reductions are larger, 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, the extent of the protected zone increases, and less turbulence is generated (Brandle 1990).

As a result of wind speed reduction and changes in turbulent transfer, the microclimate in the protected zones is altered. The magnitude of microclimate change for a given windbreak depends on the existing atmospheric conditions; on the windbreak's height, porosity, and orientation; and on the time of day. In general, air temperatures tend to be several degrees warmer in shelter; however, on very calm nights temperatures may be 1 to 2 degrees cooler (Argete and Wilson 1989). Soil temperatures tend to be slightly warmer in shelter (McNaughton 1988), especially early in the season. Rainfall over most of the sheltered area is generally unaffected except in the area immediately leeward of the barrier (van Eimern 1964). 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 determining crop productivity (Scholten 1988). Relative humidity is slightly greater near the windbreak (within 10H, where H is the height of the windbreak) and slightly lower beyond 10H due to an increase in turbulent transport (McNaughton 1988; 1989). Recent reviews by McNaughton (1988; 1989), Heisler and Dewalle (1988), and Argete and Wilson (1989) 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

Wind influences plant growth and development in several major ways (Grace 1977; 1981; 1988) all of which may be modified by shelter. One useful concept in explaining plant response to shelter is that of coupling (Monteith 1981). Exchange processes between single leaves and the atmosphere, or between plant canopies and the atmosphere, are controlled by the gradients of temperature, water vapor, and carbon dioxide that exist between the immediate micro-environment above the leaf or canopy and higher levels of the atmosphere. When these gradients are modified by shelter, plant process within the sheltered zone may become uncoupled and the driving forces for various exchange processes altered.

Near the windbreak, in the area of greatest protection, we expect conditions to be uncoupled as the canopy is isolated from the atmospheric conditions above the sheltered area. In contrast, as we move away from the windbreak, the degree of protection decreases, turbulence increases, and the plant canopy becomes more strongly coupled to the upper levels of the atmosphere. In either case we can expect to see the exchange rates for heat, water vapor, and carbon dioxide altered (Grace 1988; McNaughton 1983; 1988; 1989).

Temperature in shelter generally increases, particularly within 8H of the windbreak. This can be an advantage since small increases in air 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 either decrease or remain the same depending on atmospheric resistance and saturation vapor pressure deficit (Grace 1988). Evaporation rates are reduced in shelter (McNaughton 1983), water use efficiency is enhanced (Davis and Norman 1988; Grace 1988), and as a whole, plant water stress is reduced (Grace 1988). However, sheltered plants tend to be larger and have greater leaf areas, and under conditions of limited soil moisture, may actually suffer greater water stress than exposed plants (Grace 1988).

Wind also influences plant growth directly by the mechanical manipulation of plant parts. This movement may increase radial enlargement, reduce stem elongation (Jaffe 1976), or affect cellular composition (Armbrust 1982). The effect may be manifested by changes in plant hormone levels or may result from direct damage to the plant tissue. Indirectly, wind-blown soil contributes to leaf, stem, flower, or fruit abrasion and may result in increased water loss due to cuticular damage (Grace 1981), decreased fertilization, and loss of quality in the crop.

Specialty Crop Response to Shelter

The effects of wind protection on the production of vegetable, orchard and other specialty crops were reviewed most recently by Baldwin (1988) and Norton (1988) as part of the First International Symposium on Windbreak Technology (Brandle *et al.* 1988). Earlier reviews by van Eimern *et al.* (1964), Waister (1972), Grace (1977) and Sturrock (1984) provide a historical look at the influence of wind on vegetable production. Using these earlier reports as background, we will review current literature and include data from our ongoing studies at the University of Nebraska.

Wind Erosion and Soil Abrasion

Wind erosion and abrasion of young seedlings is a major cause of damage to specialty crops in semiarid areas (Baldwin 1988). Efforts to control wind erosion are usually designed to reduce erosion below the tolerance level of the soil but rarely take into account the tolerance of the crop to damage by wind blown soil (Finch 1988). Many of the vegetable and other specialty crops have extremely low tolerances, making protection of the crop critical to successful production in the region.

Mechanically-Induced Stress

Mechanically induced stress occurs when the above ground portions of the plant are disturbed. Wind is the primary casual agent, and exposures as low as several minutes per day of mild wind (<4 m sec^{-1}) may cause damage in some species. The response can take many forms; the most noticeable are reduced growth of aerial portions of the plant and thickening of the stem. Other manifestations of wind damage include: epinasty, increased chlorophyll concentrations, reduced or delayed flower production, increased susceptibility to fungal disease, enhanced bud dormancy and lower phototrophic and gravitropic responses (Biddington 1986).

Extreme wind events can cause extensive damage to a number of crops. While windbreaks provide little protection against events such as tornadoes, they do provide protection from winds up to 20 to 25 meters per second (50 to 60 mph). For example, on July 8, 1993, a storm with average wind speeds of 40 m sec^{-1} was recorded at the shelterbelt research area of the University of Nebraska-Lincoln, Agricultural Research and Development Center (ARDC) near Mead, Nebraska. Cantaloupe vines in the exposed areas were blown to one side of the raised beds and some plants were partially pulled from the soil by the wind action (fig. 1). In areas sheltered by windbreaks, no such damage was recorded.

Figure 1 — Wind damage to cantaloupe plants in unsheltered areas exposed to winds of 40 m sec^{-1} on July 8, 1993 at ARDC, Mead, NE. Note that the roots have been pulled from the soil.

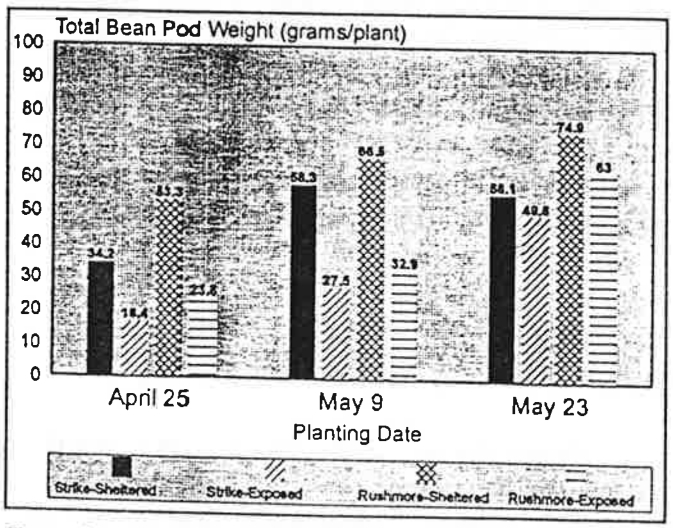

Figure 2 — Preliminary data on yield of sheltered and exposed snap beans from three planting dates at ARDC, Mead, NE. Total bean pod weight per plant is the mean of 51 plants from four replications with two samples per replication. No statistical analysis has been done on the data at this time.

Crop Yield and Quality

Windbreaks increase yields of vegetable and other specialty crops in the order of 5 to 50 percent. Van Eimern *et al.* (1964), Waister (1972), Sturrock (1984), Baldwin (1988), and Norton (1988) provide comprehensive reviews of literature published prior to 1988; however, little information is available from locations in the western United States. In Nebraska, studies on sugar beet indicated increases of 8 percent with shelter, with greater increases in dry years (Brown and Rosenberg 1972). Bagley and Gowen (1960) reported increased yields of up to 60 percent for tomatoes and up to 37 percent for snap beans. Both studies were done behind slat fence barriers with porosities of 50 percent.

On-going studies at the University of Nebraska, Agricultural Research and Development Center (ARDC) on snap bean (Suratman, unpublished data), cabbage and cantaloupe (Zhang and Daningish, unpublished data) indicate increases in early yields. In the case of both spring and fall planted cabbage, average head weight of plants grown in shelter was increased 14 to 18 percent and maturity advanced by 5 to 10 days (Hodges and Brandle 1994).

Preliminary data on early yields of two snap bean varieties from three planting dates indicated a definite advantage for the sheltered crop especially for the first two planting dates (fig. 2). These yield increases and the earliness of the yields have a significant impact on the economic benefits of snap bean production. Using Chicago wholesale prices, sheltered plots had increases in value of over 100 percent for the first two planting dates and 13 to 19 percent for the later planting date (table 1). The increases are most likely due to more rapid rates of plant development as a result of increases in temperature in the sheltered areas (data not presented).

In a three-year study of the effects of shelter on cantaloupe production at ARDC, early yields were increased in 1991 and 1993 but not in 1992. For example, both the early marketable yield and the total yield were greater in shelter for the first five harvest dates in 1993 (fig. 3). Using Chicago whole-

Table 1 — Preliminary data on economic return of snap beans from three planting dates in sheltered (SH) and exposed (EX) conditions.

Planting Date = April 25 Harvest Date = July 4 Price[1] = $14.00/30 lb crate				
Cultivar	Strike		Rushmore	
Treatment	sh	ex	sh	ex
lbs/acre[2]	5,227	2,509	8,154	3,624
# of 30 lb crates/acre	174	84	272	121
$/acre	2,436	1,176	3,808	1,694

Planting Date = May 9 Harvest Date = July 8 Price[3] = $22.00/30 lb crate				
Cultivar	Strike		Rushmore	
Treatment	sh	ex	sh	ex
lbs/acre	8,921	4,182	10,106	5,018
# of 30 lb crates/acre	297	139	337	167
$/acre	6,534	3,058	7,414	3,674

Planting Date = May 23 Harvest Date = July 23 Price[3] = $17.00/30 lb crate				
Cultivar	Strike		Rushmore	
Treatment	sh	ex	sh	ex
lbs/acre	8,573	7,597	11,430	9,618
# of 30 lb crates/acre	286	253	381	321
$/acre	4,862	4,301	6,477	5,457

[1]Prices are based on the Chicago wholesale market.
[2]Based on 69,696 plants per acre.
[3]Price reflects unusual weather conditions in major snap bean growing areas.

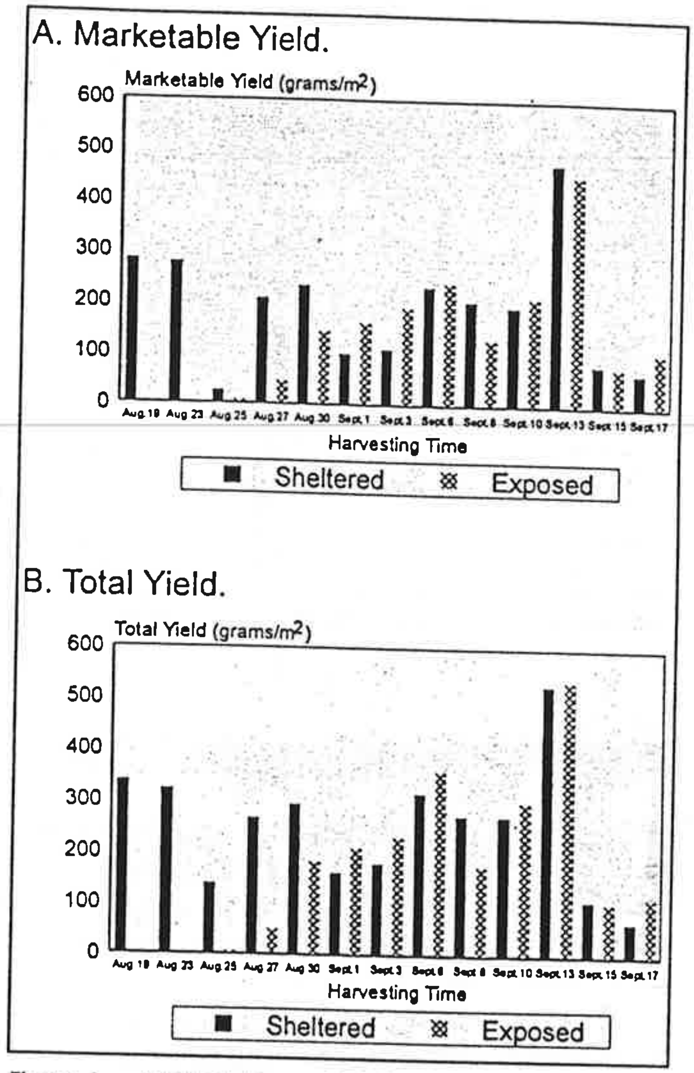

Figure 3 — Marketable and total yield of cantaloupe from sheltered and exposed plots over the 1993 growing season at ARDC, Mead, NE.

sale prices, this translates into a 38 percent increase in value for the 1993 growing season (table 2).

It is somewhat disappointing that additional studies of the effects of shelter on high-value, wind-sensitive crops have not been conducted. These crops could provide significant income to producers in the region if cultural practices were developed to provide protection from wind and wind-blown soil. In this regard, the Department of Forestry, Fisheries, and Wildlife and the Department of Horticulture at the University of Nebraska have developed a cooperative research program to document the impacts of shelter on commercial vegetable production in Nebraska.

Table 2 — Comparison of cantaloupe yield and value from sheltered and exposed plots during 1993 at ARDC, Mead, NE.

Date	Price[1]($)	Sheltered Lbs/acre	Sheltered # 40 lb cartons	Sheltered $/acre	Exposed Lbs/acre	Exposed #40 lb cartons	Exposed $/ACRE
Aug 19	8.50	2,528	63	535	0	0	0
Aug 23	8.50	2,472	62	527	0	0	0
Aug 25	8.50	221	5	42	61	1	8
Aug 27	8.50	1,853	4	391	396	10	85
Aug 30	8.50	2,077	52	442	1,283	32	272
Sep 1	8.50	889	22	187	1,437	36	306
Sep 3	9.50	970	24	228	1,714	43	408
Sep 6	9.50	2,074	52	494	2,146	54	513
Sep 8	9.50	1,833	46	437	1,158	29	275
Sep 10	9.00	1,735	43	387	1,902	47	423
Sep 13	9.00	4,255	106	954	4,057	101	909
Sep 15	9.00	730	18	162	691	17	153
Sep 17	9.00	598	15	135	959	24	216
Totals		22,235	554	4,921	15,804	394	3,568

[1] *Based on weekly reports from the Chicago wholesale market, 12 melons/40 lb carton.*

Agroforestry and Specialty Crops

Agroforestry has been defined as: *an intensive land-management system that optimizes the benefits from the biological interactions created when trees and/or shrubs are deliberately combined with crops and/or livestock.* (Garrett *et al.* 1994)

The definition is such that a wide variety of practices including: riparian vegetative buffer strips, alleycropping systems, silvopastoral systems, windbreak systems, and natural forest/specialty crop systems can be classified as agroforestry practices. In this paper we have limited our discussion to those practices where a windbreak system is modified to produce a product for sale. These products can take many forms. We have divided them into three categories: 1) **crops from windbreaks** - the windbreak produces fruits or nuts which can be sold directly or in some processed form; 2) **windbreaks as crops** - the windbreak is harvested to produce a product such as timber, Christmas trees, or nursery materials; and 3) **protection benefits** - the windbreak produces a condition which has value, such as crop benefits or wildlife habitat. A summary of species adaptable to the Great Plains, and their potential uses are included in table 3.

Crops From Windbreaks

Incorporating fruit or nut trees and shrubs into a windbreak provides additional marketable products such as fresh or dried fruits and nuts, jams, juices, and wine. Brambles such as raspberries and blackberries may be planted in the outer rows of some types of windbreaks, providing fruit for sale at farmers markets, pick-your-own operations or home use. If they are planted as barriers between other crops, they provide supplemental wind protection within the field as well as a marketable fruit.

High-quality fruit and nut crops require intensive management and generally include irrigation systems and high levels of pest control. However, the growing demand for organically produced fruits and vegetables is beginning to add to market value and may provide a local niche for a specialized product. Increasing the degree of on-farm processing also adds value to the product and may provide a greater economic return.

A windbreak is an ideal place to keep bee colonies. Bees are more active in sheltered areas and their hives can be moved to facilitate pollination of various specialty crops. Certain trees, such as black locust (*Robinia pseudoacacia*),

Table 3a — Conifers for use in agroforestry systems in the northern Great Plains[1].

Common name/species	Upland	Bottom Land	Protection Value[2]	Wood Products[3]	Christmas Tree/Nursery Materials	Wildlife Food & Habitat	Comments
Austrian Pine *(Pinus nigra)*	X		Good		X	X	Some disease problems
Balsam Fir *(Abies balsamea)*	X		Good	X	X		Very protected sites
Blk Hls Spruce *(Picea glauca densata)*	X		Excel.	X			
Blue Spruce *(Picea pungens)*	X		Excel.		X	X	
Concolor Fir *(Abies concolor)*	X		Excel.	X	X	X	Protected sites
E. Redcedar *(Juniperus virginiana)*	X	X	Excel.	X		X	Adapted to most sites
Jack Pine *(Pinus banksiana)*	X		Good	X			Very drought tolerant
Norway Spruce *(Picea abies)*	X	X	Excel.		X	X	
Ponderosa Pine *(Pinus ponderosa)*	X		Good	X		X	Drought tolerant
Rocky Mt. Juniper *(Juniperus scopulorum)*	X	X	Excel.			X	Drought tolerant
Scotch Pine *(Pinus sylvestris)*	X		Excel.	X	X	X	Sandy to loamy sites
White Spruce *(Picea glauca)*	X	X	Excel.	X		X	

[1]*Information sources: Dirr (1990), Henderson (1981), Burns & Honkala (1990a)*
[2]*Value as a windbreak species*
[3]*Wood products = timber, posts, poles, chips & fuel wood*

Table 3b — Hardwoods for use in agroforestry systems in the northern Great Plains[1].

Common name/species	Upland	Bottom Land	Protection Value[2]	Wood Products[3]	Biomass[4]	Human Food Products[5]	Wildlife Food & Habitat	Comments
Am. Basswood *(Tilia americana)*		X	Good	X	X	X	X	Wood used for carving
Am. Sycamore *(Platanus occidentalis)*		X	Fair	X	X		X	Wet sites
Black Locust *(Robinia pseudoacacia)*	X	X	Good	X	X	X	X	Excellent fuel wood
Black Walnut *(Juglans nigra)*		X	Fair	X		X	X	Deep well-drained sites
Black Willow *(Salix nigra)*		X	Poor	X	X	X		Flood tolerant
Bur Oak *(Quercus macrocarpa)*	X	X	Good	X			X	Drought tolerant
Boxelder *(Acer negundo)*	X	X	Good		X	X		Tolerates poor soils
Cottonwood *(Populus spp.)*		X	Fair	X	X		X	Very competitive
Green Ash *(Fraxinus pennsylvanica)*	X	X	Excel.	X	X		X	Drought and flood tolerant
Hackberry *(Celtis occidentalis)*	X	X	Excel.	X	X		X	Tolerates High pH
Hickory *(Carya spp.)*	X	X	Fair	X		X	X	
Honeylocust *(Gleditsia tricanthos)*	X	X	Good	X	X		X	Choose thornless variety
Mulberry *(Morus spp.)*	X	X	Excel.		X	X	X	Wood hard and durable
Osage-Orange *(Maclura pomifera)*	X		Excel.	X			X	Drought tolerant, excel. fuel wood
Pin Oak *(Quercus palustris)*	X	X	Good				X	Retains lower branches
Red Maple *(Acer rubrum)*	X	X	Good	X	X	X		
Red Oak *(Quercus rubra)*	X		Fair	X			X	Fast growing oak
Siberian Elm *(Ulmus pumila)*	X	X	Good		X			Drought tolerant
Silver Maple *(Acer saccharinum)*		X	Poor	X	X	X	X	Flood tolerant

[1]*Information sources: Dirr (1990), Burns & Honkala (1990b)*
[2]*Value as a windbreak species*
[3]*Wood products = timber, veneer, posts & poles*
[4]*Fast growing species for fuel wood & chips*
[5]*Includes: fruits & nuts, jellies, jams, wine, maple syrup, & pollen for bees (honey)*

Table 3c — Shrubs and small trees for use in agroforestry systems in the northern Great Plains[1].

Common name/species	Upland	Bottom Land	Protection Value[2]	Wildlife Food	Wildlife Habitat	Food Products[3]	Comments
American Plum *(Prunus americana)*	X	X	Good	X	X	X	Spreads by suckering
Autumn-Olive *(Eleagnus umbellata)*	X	X	Good	X	X	X	Fixes nitrogen
Buckthorn *(Rhamnus cathartica)*	X		Good	X	X		
Buffaloberry *(Shepherdia argentia)*	X	X	Good	X	X	X	Tolerates alkaline soils
Chokecherry *(Prunus virginiana)*	X		Good	X	X	X	Well drained sites
Crabapple *(Malus spp.)*	X	X	Fair	X		X	
Elderberry *(Sambucus canadensis)*		X	Fair	X	X	X	Rich moist lowlands
Golden Currant *(Ribes aureum)*	X	X	Fair		X	X	Tolerates a range of sites
Hazelnut *(Corylus spp.)*	X		Good	X	X	X	Used for oils and flavorings
Honeysuckle *(Lonicera spp.)*	X		Good	X	X	X	Susceptible to aphids
Lilac *(Syringa vulgaris)*	X		Good		X		Full sunlight, susceptible to borers
Nanking Cherry *(Prunus tomentosa)*	X		Good	X	X	X	
Peashrub *(Caragana spp.)*	X	X	Excel.		X		Tolerates poor dry soils
Russian-Olive *(Eleagnus angustifolia)*	X	X	Good	X	X		Fixes nitrogen, susceptible to canker
W. Sandcherry *(Prunus besseyi)*	X		Good	X	X	X	Low growing
Serviceberry *(Amelanchier spp.)*	X		Good	X	X	X	
Sumac *(Rhus spp.)*	X		Good	X	X	X	Tolerates dry and alkaline soils

[1]*Information sources: Dirr (1990)*
[2]*Value as a windbreak species*
[3]*Includes: fruits and nuts, jellies, jams, wine*

autumn-olive (*Eleagnus umbellata*), and American plum (*Prunus americana*) are especially attractive to bees and can be included in the windbreak as bee forage to produce honeys with distinctive flavors.

Sugar maple (*Acer saccharum*), the preferred species for the production of maple syrup, is restricted to the eastern edge of the Great Plains. In contrast, boxelder or Manitoba maple (*Acer negundo*) can be found across the region in fence rows, riparian zones and windbreaks. It produces sap with a sugar content of 1.6 to 3.6 percent which can be boiled down to produce syrup with an acceptable flavor (Fox 1992).

A windbreak can also be used as a seed orchard for the production of selected or superior genotypes. Careful species selection at the time of planting may provide future opportunities for the collection of seed for sale to wholesale nurseries. For example, the Nebraska Forest Service currently buys seed from American plum, chokecherry (*Prunus virginiana*), Russian olive (*Eleagnus angustifolia*), bur oak (*Quercus macrocarpa*), black walnut (*Juglans nigra*), sumac (*Rhus aromatica*) and American elderberry (*Sambucus canadensis*) at prices ranging from $0.15 to $25.00 per pound (Bill Lovett, personal communication).

Windbreaks as Crops

Windbreaks can be designed and managed to provide an assortment of wood products while continuing to provide protection for adjacent crops. These types of windbreaks generally require intensive management, and special care must be given to maintain the overall structure of the windbreak since it is this structure that reduces wind speed.

The management of existing multiple row windbreaks (10 rows or more) for timber or fuel wood is similar to that of a small woodlot. In most cases, current species are not the high value timber species, but larger trees such as poplar (*Populus* sp.), ash (*Fraxinus* sp.), and elm (*Ulmus* sp.) can provide lumber for crates and pallets or may be sawn for on-farm use. Cedar (*Juniperus*) and osage-orange (*Maclura pomifera*) are resistant to decay and provide excellent posts and poles. Cedar may be chipped for animal bedding and brings a premium when packaged for the small animal or pet market. Other types of wood chips are used for livestock bedding, landscape and garden mulches, and fuel. In areas near urban markets, firewood can provide additional income.

If the goal is to produce high-quality hardwoods such as walnut or oak, these species will need to be included in the initial windbreak planting design. These types of systems produce nuts within 10 to 20 years and timber within 50 to 75 years. One drawback of these species is that to gain high-quality timber, pruning of the lower branches is required. This decreases nut production and reduces the protective value of the barrier. Protection can be enhanced by including a shrub row in the windbreak to increase density near the ground. Another limitation is the sensitivity of these species to herbicides used in agricultural operations, which may reduce tree growth and quality.

Christmas trees or nursery stock production offer short-term products which also provide wind protection. A system of alternating tree rows with other specialty crops between the tree rows offers the possibility of two types of crops with different cultural schedules. In addition, the trees offer protection for the wind-sensitive crop and provide an economic return when they are sold. These types of systems are very specialized and labor intensive. They require specialized equipment, extensive business skills and a good understanding of marketing; however, by a series of plantings and harvests, both wind protection and tree crops can be realized from an intensively managed agroforestry system.

Protection Benefits

In addition to the obvious protection benefits of windbreaks to crop production, several other aspects of wind protection can provide economic returns. Windbreaks provide outstanding habitat for various kinds of wildlife. The inclusion of woody habitat in agricultural landscapes increases the diversity of bird, mammal, insect, and microbial species which inhabit an area. This greater diversity in both plant and animal species has the potential to increase natural control of pest outbreaks and contribute to the ecological stability of the agricultural ecosystem. With careful planning and management, windbreaks can improve economic return by enhancing insect predators and reducing the need for pesticides.

While some benefits of wildlife are difficult to measure, others are more easily quantifiable. In the United States, billions of dollars are spent each year on wildlife-related recreational activities (USFWS 1993). In the Great Plains, hunting upland game birds is usually more successful in areas with windbreaks or other woody plantings (Lyon 1961). In a Kansas study, over $30 million in annual expenditures were attributed to hunting in and adjacent to windbreaks (Cable and Cook 1990). As urban pressures increase, land available for hunting will continue to decrease. Landowners willing to provide access to their land for hunting or other recreational activities may be able to charge an access fee, providing an economic return.

Summary

Windbreaks provide wind protection for crops and soils, improve crop yield and quality, and increase net economic return. Including selected woody species as part of a windbreak system can provide additional products (timber, fruits and nuts, nursery materials) which can increase the total economic return. The addition of woody species to the agricultural landscape provides habitat for many natural predators, reducing the need for pesticides, and adds other sources of income from wildlife-related activities.

The integration of agroforestry practices into sustainable agricultural systems can provide many rewards. It requires, however, careful consideration of all aspects of the operation, an understanding of basic ecological principles and a working knowledge of local conditions and markets.

Literature Cited

Argete, J.C. and J.D. Wilson, 1989. The microclimate in the centre of small square sheltered plots. Agricultural and Forest Meteorology 48:185-199.

Armbrust, D.V., 1982. Physiological responses to wind and sandblast damage of grain sorghum plants. Agronomy Journal 74:133-135.

Bagley W.T and F.A. Gowen, 1962. Growth and fruiting of tomatoes and snap beans in the shelter area of a windbreak. In: Wilcox, L. (ed.), Multiple Use of Forest Lands, Proceedings Fifth World Forestry Conference, Seattle, WA, August 28 - September 10, 1960. Vol.3 pp 1667-1671.

Baldwin, C.S., 1988. The influence of field windbreaks on vegetable and specialty crops. Agriculture, Ecosystems and Environment 22/23:191-203.

Biddington, N.L., 1986. Mechanically-induced stress in plants. Span 29 (1):38-40.

Brandle J.R., 1990. Management of microclimate with windbreaks. Proceedings, 17th Annual Meeting, Plant Growth Regulator Society of America. August 5-9, 1990, St. Paul, MN, pages 61-69.

Brandle, J.R., D.L. Hintz, and J.W. Sturrock, (eds), 1988. Windbreak Technology. Elsevier Science Publishers, Amsterdam, 598 pages.

Brown, K.W. and N.J. Rosenberg, 1972. Shelter-effects on microclimate, growth and water use by irrigated sugar beets in the Great Plains. Agricultural Meteorology 9:24-263.

Burns, R.M. and B.H. Honkala, Tech. Eds., 1990a. Silvics of North America, Volume 1, Conifers. USDA Forest Service, Agriculture Handbook 654, Washington DC, 675 pages.

Burns, R.M. and B.H. Honkala, Tech. Eds., 1990b. Silvics of North America, Volume 2, Hardwoods. USDA Forest Service, Agriculture Handbook 654, Washington DC, 877 pages.

Cable, T.T. and P.S.Cook, 1990. The use of windbreaks by hunters in Kansas. Journal of Soil and Water Conservation 45:575-577.

Caborn. J.M., 1957. Shelterbelts and Microclimate. Forestry Commission Bulletin No. 29, Edinburgh, UK, 127 pages.

Davis, J.E. and J.M. Norman, 1988. Effects of shelter on plant water use. Agriculture, Ecosystems, and Environment 22/23:393-402.

Dirr, M.A., 1990. Manual of Woody Landscape Plants: Their Identification, Ornamental Characteristics, Culture, Propagation and Uses. Fourth Edition. Stipes Publishing Co., Champaign, IL 61820, 1007 pages.

Finch, S.J., 1988. Field windbreaks: Design criteria. Agriculture, Ecosystems, and Environment 22/23:215-228.

Fox, H., 1992. Agroforestry Program. 1992 Report of the PFRA Shelterbelt Centre, Prairie Farm Rehabilitation Administration, Indian Head, Sask. pages 44-46.

Garrett, H.E., W.B. Kurtz, L.E. Buck, J.P. Lassoie, M.A. Gold, H.A. Pearson, L.H. Hardesty, and J.P. Slusher, 1994. Agroforestry: An Integrated Land-Use Management System for Production and Farmland Conservation. USDA-Soil Conservation Service Report 68-3A75-3-134, 58 pages.

Grace, J., 1977. Plant Response to Wind. Academic Press, London, 204 pages.

Grace, J., 1981. Some effects of wind on plants. In: Grace, J., E.D. Ford, and P.G. Jarvis, (eds), Plants and their Atmospheric Environment, Blackwell Scientific Publishers, Oxford, pages 31-56.

Grace, J., 1988. Plant response to wind. Agriculture, Ecosystems, and Environment 22/23:71-88.

Heisler, G.M. and D.R. DeWalle, 1988. Effects of windbreak structure on wind flow. Agriculture, Ecosystems, and Environment 22/23:41-69.

Henderson, C.L., 1981. Landscaping for Wildlife. Minnesota Department of Natural Resources, St. Paul, MN, 145 pages.

Hodges,L. and J.R. Brandle, 1994. Effects of wind protection on cabbage yield and quality. Proceedings, Nebraska Fruit and Vegetable Growers Conference, February 16-17, 1994. Columbus, NE. pages 41-51.

Jaffe, M.J., 1976. Thigmomorphogenesis: A detailed characterization of the response of beans (*Phaseolus vulgaris* L.) to mechanical stimulation. Z. Pflanezenphysiol. 77:437-453.

Lyon, L.J., 1961. Evaluation of the influences of woody cover on pheasant hunting success. Journal Wildlife Management 25:421-428.

McNaughton, K.G., 1983. The direct effect of shelter on evaporation rates: Theory and an experimental test. Agricultural Meteorology 29:125-136.

McNaughton, K.G., 1988. Effects of windbreaks on turbulent transport and microclimate. Agriculture, Ecosystems, and Environment 22/23:17-39.
McNaughton, K.G., 1989. Micrometeorology of shelter belts and forest edges. Phil. Trans. R. Soc. Lon. Series B 324:351-368.
Monteith, J.L., 1981. Coupling of plants to the atmosphere. In: Grace, J., E.D. Ford, and P.G. Jarvis (eds), Plants and their Atmospheric Environment. Blackwell Scientific Publishers, Oxford. pp 1-29.
Norton, R.L., 1988. Windbreaks: Benefits to orchard and vineyard crops. Agriculture, Ecosystems, and Environment 22/23:205-213.
Scholten, H., 1988. Snow distribution on crop fields. Agriculture, Ecosystems and Environment 22/23:363-380.
Sturrock, J.W., 1984. Shelter research needs in relation to primary production: The report of the national shelter working party. Water and Soil Misc. Publ. No. 59, National Water and Soil Conservation Organization, Wellington, New Zealand, 113 pages.
USFWS (United States Fish and Wildlife Service) and United States Bureau of the Census, 1993. 1991 National Survey of Fishing, Hunting, and Wildlife Associated Recreation. U.S. Government Printing Office, Washington, D.C.
van Eimern, J., R. Karschon, L.A. Razumova, and G.W. Robertson, 1964. Windbreaks and Shelterbelts. WMO Technical Note No. 59, (WHO-No.147.TP.70) Geneva, 188 pages.
Waister, P.D., 1972. Wind damage in horticultural crops. Horticulture Abstracts 42(3):609-615.

USDA Forest Service
General Technical Report RM-GTR-261

July, 1995

Agroforestry and Sustainable Systems: Symposium Proceedings

W.J. Rietveld, Technical Coordinator

Symposium Sponsors

USDA Forest Service
Rocky Mountain Forest and Range Experiment Station
National Agroforestry Center

USDA Soil Conservation Service