Optimum Windbreak Spacing in Great Plains Agriculture

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OPTIMUM WINDBREAK SPACING IN GREAT PLAINS AGRICULTURE

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ABSTRACT—Integer programming techniques were used to determine the optimal windbreak pattern for corn and soybean production over a 70-year planning horizon. Field windbreaks provide numerous benefits to agricultural producers, including increased crop yields, erosion control, and wildlife habitat. However, windbreaks involve costs of establishment, maintenance, removal, localized yield reductions, and a loss of income resulting from cropland dedicated to windbreaks. As with any farm investment, windbreaks must be economically viable if they are to be adopted by producers. In addition to the direct costs of establishment, maintenance, and removal, yield increases must be large enough to replace opportunity costs of yield losses due to cropland removed from production and yield reductions in the area immediately adjacent to the windbreak. The economic viability of windbreaks is examined here by comparing the yield benefits resulting from climatic protection to total costs. A key question in determining economic viability is how closely windbreaks should be spaced. Assuming a conservative growth rate and tree height (20 feet in 40 years), the optimal spacing was approximately 386 feet, or 13 times the height of the windbreak. The net return results for the optimum pattern were 7.61% and 9.23% over unprotected production for corn and soybeans, respectively, assuming windbreak maturity is reached at 40 years. Net returns increased as the time required for windbreaks to reach maturity decreased. For taller windbreaks, the optimal spacing remains at 13 times windbreak height, but the absolute distance between windbreaks increases and the number of windbreaks required for optimal protection decreases.
Introduction

Windbreaks or shelterbelts are frequently observed in rural areas of the Great Plains. They have long been recognized as leading to increased crop yields and increased livestock weight gains. In the 1930s major installations of windbreaks were made to reduce soil erosion in the area largely termed the “dust bowl” (Droze 1977). Windbreaks have been shown to lead to higher yields in field crop production primarily due to the reduction in wind speed and the resulting changes in microclimate (Baldwin 1988; Kort 1988; McNaughton 1988; Brandle et al. 2004). During the 1960s and 1970s many field windbreaks were removed to accommodate large irrigation systems. The adoption of minimum tillage practices to control wind erosion further reduced the perceived value of field windbreaks, resulting in more windbreak removals and field consolidation.

More recently, an increase in environmental concerns has led to the adoption of various conservation programs such as the Conservation Reserve Program (CRP), the Wetlands Enhancement Program, and the Riparian Buffer Initiative. Windbreaks are an important element in the CRP, and cost-share programs for their establishment are available. While the windbreaks planted in the 1930s were eight to ten rows wide and removed considerable land from production, modern field windbreaks are typically one or two rows wide and have significantly lower establishment, maintenance, and removal costs (Brandle et al. 1984, 1992). These narrow windbreaks have been shown to be equally effective in altering microclimate in the sheltered areas (Cleugh and Hughes 2002; Zhou et al. 2004). While Brandle et al. (1984, 1992) have addressed the economics of field windbreaks, the issue of profitability of windbreaks remains an important consideration of producers considering establishing a field windbreak system. Specifically, producers are interested in determining the optimal number and spacing of field windbreaks on a field.

Objectives and Scope of Analysis

The objective of this analysis was to optimize crop field windbreak layout for corn and soybean considering crop yield enhancement benefits, direct costs (establishment, replanting, maintenance, and removal), and opportunity costs resulting from reduced crop acres as well as reduced yields on cropland adjacent to windbreaks. Without design optimization, a danger exists that a windbreak installation decision will be rejected when, with optimal design, the project may be profitable.
The analysis of optimum windbreak layout or spacing was evaluated for a range of corn and soybean prices. In addition, the base analysis was completed assuming 40 years before windbreak maturity was reached and additional analyses were completed assuming 30 and 20 years to reach maturity.

The paper proceeds to first discuss the general counteracting economic forces influencing windbreak spacing. This is followed by a general description of the integer programming model and the construction of average-year yields and costs. The economic assumptions are presented, followed by a detailed description of crop yields for the windbreak-protected zones. The results described the optimum solutions for various crop prices and maturity assumptions.

**Windbreak Cost and Benefits**

The optimum windbreak spacing in corn and soybean production was analyzed by implicitly considering all alternative configurations of spacing, each with its distinctive level of crop production and distance between windbreaks. Crop production for each configuration is influenced by yield benefits derived from wind protection. Zero production in the area dedicated to windbreaks, and reduced crop production from cropland immediately adjacent to windbreaks, are opportunity costs involved with each windbreak.

The yield benefit occurs both windward (upwind of the windbreak) and leeward (downwind of the windbreak). On the leeward side, yield is reduced immediately adjacent to the windbreak (generally within $1H$ where $H$ = height of the windbreak), returns to a level equal to an unprotected field at approximate $1H$, increases to a maximum between $7H$ and $8H$, and gradually declines to the level of an unprotected field between $15H$ and $20H$. A similar but much smaller pattern is found on the windward side, with the maximum yield increase at approximately $2H$, returning to levels of an unprotected field between $4H$ and $5H$ (Stoeckeler 1962; Baldwin 1988; Kort 1988). For both the windward and leeward sides of a windbreak, yields are greater than under no windbreak protection except for the intervals immediately adjacent to the windbreak (see Fig. 1). These yield relationships coupled with the cost of windbreaks (direct establishment, replanting, maintenance, and removal cost), along with reduced production in the area immediately adjacent to the windbreak and zero production in the windbreak area (the area planted to trees), are instrumental in determining the optimum distance between windbreaks. The relative profitability of the crop may also impact optimum layout, and the optimal layout may differ for different crops.

Windbreak effects are proportional to the height of the windbreak (Caborn 1957; Brandle et al. 2004) and distances away from the windbreak are expressed
in terms of windbreak height \((H)\). For example, if a windbreak is 3 ft tall, \(10H\) is 30 ft, and if the windbreak is 30 ft tall, \(10H\) is 300 ft. More importantly, the influence of a windbreak at the same relative position windward or leeward of the windbreak (for example, \(10H\)) on wind speed, microclimate and ultimately crop yield are similar, regardless of whether the height of the windbreak is 3 ft or 30 ft (Van Eimern et al. 1964; McNaughton 1988).

Optimizing windbreak spacing (distance between windbreaks) involves two counteracting aspects in addition to the necessity to consider the direct costs for establishing windbreaks. One reflects the decreasing yield benefits secured from windbreak protection moving leeward and windward from the windbreak. Reducing the distance between windbreaks reduces areas of relatively lower yield benefits, resulting in more windbreaks and higher average yields. However, shorter spacing, or shorter distance between windbreaks, involves relatively more area in non-crop-yielding windbreak area as well as relatively more area devoted to windbreak-adjacent strips that incur reduced production. In addition, optimum windbreak spacing is complicated by the necessity to consider both windward and leeward yield impacts simultaneously. This is to guard against possible illogical configurations from ending leeward intervals related to one windbreak and windward intervals of the next windbreak.

**Integer Programming Model**

An integer programming model was constructed to determine the optimum windbreak layout. Programming variables for (1) a 20-ft-wide windbreak space, (2) 21 windbreak-impacted intervals, and (3) non-windbreak-impacted intervals were treated as integers. The intervals were defined in terms of windbreak height, in this case 20 ft units. The purpose of integer programming was to restrain two potential outcomes. The first was to guard against solutions involving non-integer numbers of windbreaks. Windbreaks are defined here as having a width equal to windbreak height (20 ft), and a fractional windbreak is inconsistent with that requirement. Next, a solution involving fractional numbers of the protected intervals was not permitted. For the windbreak-impacted intervals a fractional solution implies a partial interval but partial intervals should have yield benefits technically different than for a full interval. In addition, a fractional width requires a different machinery width than that for a full interval, which can be inconvenient, time consuming, and costly.

The model was constructed and optimized on an “average year” basis assuming a 70-year windbreak life. The uneven flows of costs over the 70-year period for windbreak establishment, replanting, maintenance, and removal were
Figure 1. Cross section of crop yield windward and leeward of a field windbreak.
first discounted and then amortized over the period to secure the annual direct cost for the windbreak. These costs are on a per windbreak basis. For a given field size, as distance between windbreaks decreases, windbreak direct costs increase.

A crop yield function for corn and soybean for each interval of increasing distance both windward and leeward from the windbreak was included in the model. The crop yield function is described in detail later in this paper. The yield benefits of windbreak protection begin in year 7 but the full yield benefit of the windbreak is realized only at windbreak maturity, or year 40 of the 70-year life. For the two intervals immediately adjacent to the windbreak, the yield declines similarly begin at year 7. Annualized yields for the 70 years for each interval were calculated by (a) discounting each of the 70-year yields and (b) annualizing or amortizing the present value secured from (a). This process, using a 4% interest rate, is more exact than using a simple average because the timing of the yield changes are considered. The indirect cost of space devoted to windbreaks was endogenized in the model given zero crop yields in space devoted to the windbreak and reduced production intervals adjacent to the windbreak. This opportunity cost must be more than matched by yield benefits on the resulting production area to cover the direct costs of windbreak establishment and maintenance.

The program included an integer activity for a windbreak linked with integer activities of annualized yield-producing activities corresponding to 20 ft intervals moving leeward and windward from the windbreak. The linkage requires previous (closer to windbreak) integers to be employed before subsequent ones can be engaged. The optimal solution specifies the number of windbreaks and the intervals between windbreaks. An activity for no windbreak production is also included in the event that windbreak establishment is unprofitable. The yield function for the leeward side declines within the first $1H$ (1 times the height of the windbreak), increases until $6H-8H$, and then declines until $15H$, at which point the windbreak effectiveness is zero. For the windward side, yields decline in the first interval, reach a windward maximum in the second interval, and decline for the next four intervals before reaching the no-impact point. The programming output secures the net return, number of windbreaks (for an assumed field length), and which windward and leeward intervals are optimal.

Mixed intervals were permitted in the programming model. This means there was no restriction that all windbreaks must have an equal number of intervals. This aspect becomes operational when, for the last interval selected, some windbreaks may include a different number of intervals than others in order to complete field length in an orderly manner.
Economic Assumptions

The programming model is developed on an "average year" basis. However, as previously described, an annualization procedure using 4% was used to develop the annual cost of windbreaks as well as the annual yield for the changing yields over the 70-year life. Hence, average year does not represent simple averages in either case.

A real dollar setting is assumed in the model. Windbreak costs and crop prices are not inflated for the period. Similarly, no technological changes influencing crop yields are assumed. Consistent with treatment of these variables is the use of a real interest rate, assumed to be 4%.

The initial establishment cost was $228.00 per acre of windbreak for converting cropland to trees, which included a $2.00 per acre site preparation cost. With government cost sharing (USDA Natural Resources Conservation Service), this cost was reduced to one-half, or $114.00 per acre. Tree costs were $0.53/tree and $0.30/tree for planting. The number of trees in a windbreak depends on the spacing between trees. In our analysis, each windbreak is 2,178 ft long, trees were assumed to be 8 ft apart, giving a total of 272 trees per windbreak.

Replanting (without government cost sharing) was assumed to be required (5%) for each of years 2-5. A constant annual cost of $1.00 per acre for 70 years was required for weed control and maintenance. Last, a removal cost was included which was $495 per acre at year 70. The annualized result, assuming 50% cost sharing for establishment only, was $9.38 per acre, found by discounting all costs (site preparation, tree cost, tree planting, replanting, maintenance, and removal) to year zero and annualizing it to a constant per year basis. Many windbreaks qualify for the Conservation Reserve Program payments for a 15-year period. This aspect was not included in the analysis, but if included would result in greater profitability for windbreak establishment.

For corn and soybeans, the operating cost of production for all inputs (except windbreaks) was assumed to be $175 and $115, respectively. This cost excludes machinery, ownership, and land. These costs are derived assuming eastern Nebraska production cost estimates (Selley et al. 2001). Harvest costs are not varied in response to yield changes nor in response to the proportion of land in windbreaks versus in production. Hence, net returns (objective function) refers to gross returns less operating cost. A "base" price for corn and soybean was set at $2.50 and $6.00 per bushel, respectively, and the assumed yields for nonprotected production were 100 bu/ac and 30 bu/ac, respectively.

The model requires (a) an annualized cost for windbreak establishment, maintenance, and removal, (b) the "stepped" yield functions windward and
leeward from the windbreak, (c) cost of crop production, (d) prices of products, and (e) area required of a windbreak. The analysis is oriented to the Great Plains because it uses relationships applicable across the entire region.

Forty years are required to reach maturity and full effectiveness of a windbreak. Hence, the yield benefits of a windbreak cannot be incorporated into the model assuming immediate maturity. The windbreak begins to impact yields at year 7, thus non-windbreak yields are assumed for the first 6 years. A linear yield relationship with time for each interval is assumed beginning with year 7 until maturity is reached at the 40-year period. For all intervals, the 6 years of no-yield effect, the 34 years of linearly increasing yields (decreasing in the intervals adjacent to the windbreak), and the 30 years of mature windbreak benefits are used to derive an annualized yield for the entire 70-year period for each interval.

A number of management choices are important to the success of windbreaks. The choice of species (here, eastern redcedar, *Juniperus virginiana* L.) and height-width (each 20 ft) of the windbreak and each interval are important and are predetermined in the analysis of this paper. The 20 ft height assumption is a conservative assumption of mature height and most appropriate for the drier areas of the Great Plains. In wetter areas, tree heights will increase interval width and reduce the number of windbreaks required for full protection of the field. Thus, both direct costs and opportunity costs associated with the windbreak scenarios will be lower than those assumed in this analysis. Because windbreak benefits are proportional to height, the level of protection and the resulting crop response in each interval will remain constant. The choice of crop is important because crops differ in their yield response to wind protection (Baldwin 1988; Kort 1988).

**Yield “Intervals”**

Fifteen protected intervals were included in the integer program to linearize the leeward increasing-declining yield impacts with distance from the windbreak (Kort 1988). Similarly, six protected intervals were included for the windward side of the windbreak. The intervals and yield levels at maturity are shown graphically in Figures 2 and 3 for corn and soybeans, respectively. The intervals are numbered from 1 to 24 beginning with interval 1 with no protection benefits, followed by increasingly less distant intervals from the windbreak on the windward side. The windbreak is located in interval 8 (with zero yield) followed by 15 protected intervals on the leeward side. Last, interval 24 is included to signify the end of protection benefits for the leeward side.
Figure 2. Corn yields by 20 ft intervals at year 40.

Figure 3. Soybean yields by 20 ft intervals at year 40.
Each interval refers to a 20 ft width. For intervals 7 and 9, yields are assumed to decline from 100% of unprotected yield in years 1-6 to 50% of unprotected yields for both corn and soybeans at year 40 and remain at that level until year 70. Intervals 7 and 9 involve competition from the adjacent windbreak, but yield declines begin only in year 7 when the windbreak reaches sufficient size to impact yields. Yield benefits for both corn and soybeans increase to interval 12 for the leeward side, remain at that level through interval 14, and then decline. For the windward side, yield benefits are greatest in interval 6 and decline until interval 2 is reached. The leeward and windward yield functions demonstrate that there is an optimal microclimate condition at particular distances from the windbreak. These yields can be compared to no-windbreak yields of 100 bu/ac and 30 bu/ac, respectively. The pattern of yields under windbreak establishment for both protected sides demonstrates an increasing-decreasing function with distance from the windbreak. Programming selects the optimal configuration that is likely to include intervals in the declining-yield portion of the function. This is because yields in that portion will still be above the average for a shorter spacing range that only includes the highest yields (intervals 6 to 12-13-14). Further, as more intervals are selected (greater distance between windbreaks) the proportion of windbreak acreage to production acreage declines. This also holds for the relative proportion of lower-producing intervals 7 and 9.

The yields at windbreak maturity are shown in Table 1. A longer-term benefit of windbreaks is reduced erosion (Tibke 1988). Data are lacking on the differences in yields caused by wind and water erosion between a windbreak and non-windbreak setting over a long time frame; however, yield losses due to erosion are well documented (Tibke 1988) and practices that improve erosion control will have a positive economic benefit. Were long-run soil retention assumptions on yields included, the economic benefit of windbreaks would be greater, although the impact on windbreak spacing is unclear. No carbon-storage aspects resulting from windbreak establishment were considered in the study. It would add to the net return on the windbreak investment but would not be expected to impact optimum windbreak numbers. Also, the value of the windbreaks as wildlife habitat has not been included but is another desirable value for many landowners.

At windbreak maturity (years 40-70) the peak yields are shown in Table 1 as 123.10 bu/ac and 38.58 bu/ac, respectively, for corn and soybeans in intervals 12-14 on the leeward side. Yields decline with greater distance from the windbreak until yields reach 104.2 bu/ac and 31.56 bu/ac at interval 23 for corn and soybeans, respectively. For the windward side, yield maximums occur at interval 6 and decline with distance from the windbreak.
TABLE 1

CORN AND SOYBEAN YIELDS BY INTERVAL AT YEAR 40
AND AVERAGE YIELDS BY INTERVAL FOR THE 70-YEAR PERIOD

<table>
<thead>
<tr>
<th>Interval</th>
<th>CORN (bu/ac)</th>
<th>SOYBEANS (bu/ac)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>At year 40-70</td>
<td>70-year annualized yield</td>
</tr>
<tr>
<td>1</td>
<td>100.00</td>
<td>100.00</td>
</tr>
<tr>
<td>2</td>
<td>108.40</td>
<td>103.42</td>
</tr>
<tr>
<td>3</td>
<td>111.55</td>
<td>104.70</td>
</tr>
<tr>
<td>4</td>
<td>115.75</td>
<td>106.41</td>
</tr>
<tr>
<td>5</td>
<td>118.90</td>
<td>107.69</td>
</tr>
<tr>
<td>6</td>
<td>121.00</td>
<td>108.55</td>
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<tr>
<td>7</td>
<td>50.00</td>
<td>79.65</td>
</tr>
<tr>
<td>8</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>9</td>
<td>50.00</td>
<td>79.65</td>
</tr>
<tr>
<td>10</td>
<td>115.75</td>
<td>106.41</td>
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<tr>
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<td>108.97</td>
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<td>123.10</td>
<td>109.40</td>
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<tr>
<td>13</td>
<td>123.10</td>
<td>109.40</td>
</tr>
<tr>
<td>14</td>
<td>123.10</td>
<td>109.40</td>
</tr>
<tr>
<td>15</td>
<td>122.05</td>
<td>109.40</td>
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<tr>
<td>16</td>
<td>119.95</td>
<td>108.97</td>
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<td>17</td>
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<td>116.80</td>
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<td>104.20</td>
<td>102.56</td>
</tr>
<tr>
<td>24</td>
<td>100.00</td>
<td>100.00</td>
</tr>
</tbody>
</table>

Note: Interval 1 is the windward interval that experiences no protection value. Interval 8 is the windbreak and interval 24 is the leeward interval that experiences no protection value. Intervals 7 and 9 represent the area of competition between the windbreak and the adjacent crop.
The mature windbreak yields are only achieved for years 40-70, yet annualized yields for the entire 70-year period are required for the average-year programming analysis. These are also shown for each interval in Table 1. Clearly, the time required to achieve the yield enhancement benefits that result from windbreak establishment must be considered in analyzing the optimum configuration. This is accomplished by discounting yields for the entire 70 years and annualizing these yields for the average-year-basis model. It can be noted that soybean yields are relatively more responsive to the climatic advantages of windbreaks than corn. Thus, this different response may result in different optimal strategies between the two crops.

The yield responses for years 7-40 differ by interval. All intervals have identical non-windbreak-protected yields for years 1-6 (100 bu/ac for corn and 30 bu/ac for soybeans). Also, after windbreak maturity is reached at year 40, yields for all intervals are maintained at year 40 levels through year 70 (Table 1). The year 7-40 yield response for intervals 7 and 9 (immediately adjacent to the windbreak) shows linearly declining yields reaching 50% of non-windbreak-protected yields in year 40. In Figure 4 this response (interval 9) is shown for leeward corn production. Shown also is the corn yield response for interval 23, which receives the least windbreak influence. Its yield at year 40 is only slightly higher (104.2 bu/ac) than non-windbreak protection. The intervals with the greatest windbreak protection relative to windbreak competition are intervals 12-14. Beginning at 100 bu/ac in year 6, the yields reach 123.1 bu/ac in year 40. Other yield responses by interval lie in between those shown in Figure 4 but are not included in Figure 4.

Using the 70-year annualized yields of Table 1 as a perspective, the optimizing process determines how many “sets,” including the optimal associated intervals, should be selected to maximize net returns for a given field length. A set can be defined as a windbreak along with its associated windward and leeward intervals. A number of configurations of windward and leeward intervals are possible to accompany a windbreak. In total, for a given field length, there are a large number of potential challengers to the optimal set/interval choice. For example, starting from the set that includes all protected intervals (2-23), would eliminating, say, interval 2, with only a minimum yield advantage over no protection, be more profitable because more sets of intervals 3-23 could be employed? In considering this, more sets also involve a greater number of intervals 7-9 with zero or reduced production.

If the model selected windbreak protection, the model required both intervals 7 and 9 to be employed but allowed choices for the remaining intervals. Failing to do this could conceivably result in only intervals 8 to, say, 21 being
Figure 4. Leeward corn yields for years 1–70 for three intervals.
selected, thereby eliminating windward effects when in reality they occur. Conceivably the optimal strategy could have selected an interval set with logical errors for leeward and windward matching points, but this did not occur. Had this been the case, additional matching constraints would have been required in the model.

In this analysis, the number of windbreaks should be viewed in reference to a 5,280-ft-long field. For example, 12 windbreaks using 22 intervals, each 20 ft in width exactly, uses 5,280 feet. To place each interval on a 1 acre basis, a 2,178-ft-wide field is assumed. Thus, in total, the results are in reference to 264 acres and expressed on a per acre basis. Interval width is assumed to be equal to windbreak height. If windbreak height changes, the length of each windbreak segment is changed so as to retain the 1 acre basis for each interval.

Corn and soybeans are conventionally produced in a rotation framework. Rotations have economic advantages over continuous cropping due to yield enhancement, cost reductions, and risk benefits. Programming windbreaks for each crop independently could result in solutions that may be different for corn and soybeans. In such a case a problem arises because rotations are practiced by growing one crop on cropland previously dedicated to another crop. The estimation of the sensitivity of net returns to windbreak numbers is a useful analysis in a case where the optimum number of windbreaks differs between crops. This may allow a compromise solution to be selected where an equal number of windbreaks are used for each crop. A method of endogenizing the equal number issue would be to combine the corn and soybean net returns by interval and allow the programming solution to select the optimal number of common windbreaks.

Results

Base Price Results

For corn at $2.50/bu, the optimal solution for the 264 acres resulted in a net return of $21,306 ($80.70/ac) compared to a no-windbreak solution of $19,800 ($75.00/ac). This represents a 7.61% increase. For soybeans at $6.00/bu, the relative increase is greater (9.22%), from $17,160 ($65.00/ac) for no windbreaks to $18,743 ($71.00/ac) for the optimal solution. The greater relative increase is due to the stronger yield benefits from wind protection for soybeans compared to corn (Brandle et al. 2004).

At the assumed base price for corn ($2.50/bu), the 13 windbreaks used intervals 2-21 while 4 of the 13 windbreaks involved intervals 2-22. Hence the total length used was $20 \times 20 \times 13$, or 5,200 ft, plus the additional interval for
4 windbreaks (80 ft), or a total of 5,280 ft. At the assumed base soybean price in the analysis ($6.00), 13 windbreaks also were established. Also, in this case 13 windbreaks used intervals 2-21 (20 intervals) while 4 of the windbreaks involved intervals 2-22 (21 intervals). Thus, the potential for the results not to match for rotation purposes did not occur in this analysis at the base prices.

The optimum results for corn in terms of net returns ($21,306; $80.70/ac) is on an annualized yield basis. However, this masks an important aspect relating to how returns change with respect to time as the windbreaks mature. For years 1-6, when no yield impacts are observed but areas of cropland are placed into windbreaks, net returns are $18,703 ($70.84/ac) compared to non-windbreak production of $19,800 ($75.00/ac). In years 40-70, however, net returns under windbreak production rise to $25,105 ($95.09/ac). Between year 6 and year 40, net returns under windbreak production increase linearly. At year 12 net returns from the windbreak setting equal the net returns under the no-windbreak setting. The approximately $4.16 per acre lower return for years 1-6 under windbreak establishment must be considered as a cash-flow sacrifice even though it is more than made up for in later years.

**Parametric Results**

The optimal number of windbreaks for varying corn prices in $0.25/bu increments is presented in Table 2. Windbreak establishment was optimized at corn prices of $1.50/bu and higher in $0.25/bu increments. At $1.50/bu, returns did not cover costs for any configuration, whereas at $1.75/bu, 15 windbreaks were found to be optimal. At $2.25/bu 14 windbreaks were optimal while at $2.50 the optimal number decreased to 13 and remained at 13 until a $6.50/bu corn price. At $6.50/bu and higher, windbreak establishment was constant at a level of 12.

For soybeans (Table 2), nearly the same general results were observed. At $3.50/bu, production did not yield positive net returns. At higher prices, windbreak establishment occurred, and as soybean prices increased, the optimum number of windbreaks declined. The phenomenon of the decreasing optimum number of windbreaks under higher product prices reflects an increased net-return opportunity cost caused by a greater sacrifice in returns from reduced production in the windbreak area and intervals immediately adjacent to the windbreak. This opportunity cost increases with higher product prices. In the case of corn, as prices were increased to unrealistically high levels, no windbreaks were selected. For soybeans, however, 12 windbreaks still were selected.
TABLE 2
OPTIMUM NUMBER OF WINDBREAKS FOR A 1-MILE-LONG FIELD
(MIXED LENGTHS PERMITTED)

<table>
<thead>
<tr>
<th>Price per bushel ($)</th>
<th>Optimum number</th>
<th>Price per bushel ($)</th>
<th>Optimum number</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.50</td>
<td>No production</td>
<td>3.50</td>
<td>No production</td>
</tr>
<tr>
<td>1.75</td>
<td>14</td>
<td>3.75-4.25</td>
<td>15</td>
</tr>
<tr>
<td>2.00-2.50</td>
<td>13</td>
<td>4.50-4.75</td>
<td>14</td>
</tr>
<tr>
<td>2.75-10.00</td>
<td>12</td>
<td>5.00-8.25</td>
<td>13</td>
</tr>
<tr>
<td>10.50 and higher</td>
<td>0</td>
<td>8.50 and higher</td>
<td>12</td>
</tr>
</tbody>
</table>

Forced Windbreak Analysis

Table 3 shows the impact on corn net returns of forcing the number of windbreaks from zero to the level at which net returns fall below no protection. The comparable impacts are presented in Table 3 for soybeans. The range of the number of windbreaks for which returns exceed a no-windbreak situation is large, attesting to the strong economic impacts derived from windbreaks. It can be noted that because of the large number of alternative windbreaks that have net returns greater than unprotected production net return, differences among them are relatively small. The differences average roughly $150 per one unit change in windbreak numbers for both corn and soybeans.

Analysis of 20- and 30-Year Maturity

Economic impacts resulting from windbreak establishment are enhanced under the assumption that windbreak maturity is reached prior to 40 years. For this reason, additional analyses were completed assuming maturity was reached at both 30 and 20 years. These assumptions result in higher annualized lifetime yields under windbreak protection because maximum yields are
### TABLE 3

**ESTIMATED NET RETURNS FOR CORN AND SOYBEANS FOR DIFFERENT WINDBREAK LEVELS IN A 1-MILE-LONG FIELD**  
(MIXED LENGTHS PERMITTED)

<table>
<thead>
<tr>
<th><strong>CORN</strong>*</th>
<th><strong>SOYBEANS†</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Number of windbreaks</strong></td>
<td><strong>Net returns ($)</strong></td>
</tr>
<tr>
<td>0</td>
<td>19,800.00</td>
</tr>
<tr>
<td>1</td>
<td>19,924.62</td>
</tr>
<tr>
<td>2</td>
<td>20,049.24</td>
</tr>
<tr>
<td>3</td>
<td>20,173.86</td>
</tr>
<tr>
<td>4</td>
<td>20,298.48</td>
</tr>
<tr>
<td>5</td>
<td>20,423.10</td>
</tr>
<tr>
<td>6</td>
<td>20,547.72</td>
</tr>
<tr>
<td>7</td>
<td>20,672.34</td>
</tr>
<tr>
<td>8</td>
<td>20,796.96</td>
</tr>
<tr>
<td>9</td>
<td>20,921.58</td>
</tr>
<tr>
<td>10</td>
<td>21,046.20</td>
</tr>
<tr>
<td>11</td>
<td>21,170.82</td>
</tr>
<tr>
<td>12</td>
<td>21,295.44</td>
</tr>
<tr>
<td>13</td>
<td>21,306.88</td>
</tr>
<tr>
<td>14</td>
<td>21,258.43</td>
</tr>
<tr>
<td>15</td>
<td>21,182.17</td>
</tr>
<tr>
<td>16</td>
<td>21,067.52</td>
</tr>
<tr>
<td>17</td>
<td>20,927.26</td>
</tr>
<tr>
<td>18</td>
<td>20,754.96</td>
</tr>
<tr>
<td>19</td>
<td>20,571.03</td>
</tr>
<tr>
<td>20</td>
<td>20,375.40</td>
</tr>
<tr>
<td>21</td>
<td>20,159.74</td>
</tr>
<tr>
<td>22</td>
<td>19,935.19</td>
</tr>
<tr>
<td>23</td>
<td>19,710.63</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Corn price = $2.50/bu.
†Soybean price = $6.00/b
realized earlier in the 70-year life of the windbreak. The exceptions to this are
the two intervals immediately adjacent to the windbreak where the decline is
similarly met earlier. The optimum windbreak number was found unchanged
(13) for corn for maturity at year 30. However, compared to the 7.61% increase
for corn over no-windbreak production (40-year maturity), net returns increase
11.60% over no-windbreak production when a 30-year maturity is assumed. For
soybeans, optimal returns increase to $19,260 ($72.95/ac) under the assump­
tion that the windbreak reaches maturity at 30 years. This represents a 12.24%
increase compared to no protection. The optimum number of windbreaks was
the same for soybean (13) as was the case for corn.

Under a 20-year maturity assumption, the optimum number of wind­
breaks remains the same (13) for corn as for the 40- and 30-year scenarios.
Net returns, however, increase to $22,116 ($88.77/ac) or 11.70% over the non­
protected scenario. For soybeans the optimum windbreak number increases
to 20 with a 17.94% increase in net returns compared to nonprotected produc­
tion. It should be noted, however, that for the 20-year maturity assumption for
soybeans, there is relatively little difference in net returns for 20 windbreaks
($20,238; 76.66/ac) versus 13 windbreaks ($19,914; $75.43/ac). This attests to
a very “flat” net return function for soybean for varying windbreak levels under
the 20-year maturity assumption.

Conclusions

Under assumed base prices of $2.50/bu and $6.00/bu for corn and soy­
beans, respectively, the optimized windbreak patterns were found to increase
net returns 7.61% for corn and 9.22% for soybeans. These increases are relative
to a no-windbreak production setting. When placed on a 1-mile-long basis, the
optimum results involve 13 windbreaks for both corn and soybean production.
In both cases the net returns are largely similar over the 12-15 range. Thus, where
corn and soybeans are grown in rotation, there is no incompatibility resulting
from significantly different optimum interval-spacing between the two crops.

The optimum interval-spacing for corn involved all six protected intervals
on the windward side of the windbreak and either 13 or 14 of the 15 protected
intervals for the leeward side. For soybeans, an identical result was found.

The optimum number of windbreaks declines as crop prices increase.
This occurs because the opportunity costs of reduced production from the
windbreak area and intervals immediately adjacent to it increase as crop prices
increase. At the base crop prices, however, the differences in net returns from
alternative numbers of windbreaks forced into the programming model are relatively small.

The results suggest that windbreak establishment deserves careful consideration by producers. While some producers are establishing windbreaks, widespread adoption has not materialized. The expected monetary benefits determined here under the study assumptions suggest that factors other than economic considerations are important to the decision-making process. If additional acres are to be protected by new field windbreaks, these factors need to be identified and addressed.

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References


