

OPTIMUM WINDBREAK SPACING IN GREAT PLAINS AGRICULTURE

by

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Abstract

Integer Programming determined an optimum windbreak pattern for corn and soybean production. Direct costs included windbreak establishment, annual maintenance, and removal. Crop yields were included as a linearized function. The net return results for the optimum pattern were 12 and 16 percent over conventional production for corn and soybean respectively.

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Introduction

Windbreaks or shelterbelts are frequently observed in rural areas of the Great Plains. They have been found useful in providing a better environment for farmsteads and livestock and in the 1930s major installations of windbreaks were made to reduce soil erosion in the area largely termed the "dust bowl." Windbreaks have also been observed to lead to higher yields in field crop production caused by the change in microclimate resulting from reduced wind speed. Many windbreaks have been removed due to their perceived inconvenience and the development of minimum tillage to control erosion. The issue of the profitability of windbreaks is important however, particularly due to the emergence of shorter and narrower windbreaks which involve less non crop area and have lower costs of establishment, maintenance, and removal. There also is increasing environmental interest in windbreaks and governmental cost sharing is available for their establishment. Particularly important to the field microclimate change resulting from windbreaks is the height, density, orientation (to wind direction) and the width of the windbreak. The microclimate is impacted by changes in solar radiation, air temperature, soil temperature, frost occurrence, precipitation (particularly snow), humidity, evaporation, and CO₂.

Objective

The objective of this analysis is to optimize the crop field layout of windbreaks considering their crop yield enhancement benefits, direct costs (establishment, replanting, maintenance, and removal), and space requirements which reduce field acreage available for cropping. Without design optimization a danger exists that a windbreak installation decision will be rejected when, with optimal design, the project may be profitable.

Model and General Procedure

The issue addressed in this paper is to examine the profitability of windbreaks in alternative Great Plains cropping systems by optimizing the field layout (number of windbreaks). The yield benefits of windbreaks first decrease, then increase and finally diminish with distance from the windbreak. This function coupled with the relative cost of windbreaks (establishment costs and area required) determines the optimum distance between windbreaks. The relative profitability of the crop may also impact optimum layout, and the optimal layout may be different between crops.

An Integer Programming model is constructed to determine the optimum layout. The model is constructed on an "average year" basis over an assumed 70 year windbreak life. The flow of costs over the 70 year period for windbreak establishment, replanting, maintenance, and removal are first discounted and then amortized over the period to secure an annual direct cost for each windbreak. An annual return is also determined using a crop yield function depending on windbreak placement. The indirect cost of space devoted to windbreaks is endogenized in the model.

The program includes an integer activity for a windbreak linked with several integers of decreasing-increasing-descending productivity corresponding to "steps" moving away from the windbreak. The linkage requires previous integers to be employed before subsequent ones can be engaged. Specifically this function first declines within the first 1H (1 times the height of the windbreak) increases generally until 6-8H, and then declines until 15H at which point the windbreak effectiveness is zero. An activity for no windbreak production is also included. Another organizational alternative would be to provide for both windward and leeward benefits as opposed to the leeward-only benefits examined here. The analysis here assumes leeward only thus beginning windbreaks are at the edge of the field perpendicular to the prevailing wind.

The model requires a) an annualized cost for windbreak establishment, maintenance, and removal, b) the "stepped" yield function, c) cost of crop production, d) prices of products, and e) windbreak acreage. Governmental cost sharing of 50 percent of the tree purchase-site preparation-establishment cost is assumed. A removal cost at a 70-year time point is also incorporated. Partial replanting (5%/year) is required for the first five years. The analysis is Great Plains oriented using relationships applicable across the entire Great Plains.

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. Thus, a linear increasing yield (except for the first step of 1H or 20 feet) for the 40 year period along with 30 years of mature windbreak benefits are used to derive an average yield for the entire period for each step.

A number of management choices are important to the success of windbreaks. The choice of species (here red cedar) and width (20 feet) of windbreak are important and are predetermined in the analysis of this paper. The choice of crop is important because crops differ in their yield response to wind protection. Corn and soybean are analyzed here. For each, the price was varied to examine the impact of crop profitability on windbreak placement. In addition, at the base level of profitability solutions were found at 50 percent cost sharing as well as zero cost sharing.

Price, Yield, and Cost Assumptions

For corn and soybean the cost of production for all inputs (except windbreaks) was assumed to be \$175 and \$115 respectively. These costs are derived assuming eastern Nebraska production cost estimates (Selley, et al.). A "base" price for corn and soybean was set at \$2.50 and \$6.00 per bu. respectively, and the assumed yields for each (no windbreak) were 100 bu/ac and 30 bu/ac

respectively.

Yield "Steps"

Fifteen intervals or steps were included in the Integer Programs to linearize the declining-increasing-declining yield impacts with distance from the windbreak (Kort, et al.). Each step refers to a 20 foot width. For the first step, yields decline to zero for both corn and soybean at year 40 and remain zero until year 70. Yield benefits for both corn and soybean increase to step 4 and remain constant through step 6. This yield function's peak for these crops, height of windbreak, and width of step is different from the general 6-8H peak previously described. These are shown in Table 1 as 123.10 bu/ac and 38.58 bu/ac respectively for corn and soybean. Declines then occur until yields are 104.2 bu/ac and 31.56 bu/ac at step 15 for corn and soybean respectively. These yields are only realized at year 40 and can be compared to no-windbreak yields of 100 bu/ac and 30 bu/ac respectively. A longer run benefit of windbreaks is reduced erosion. However, data is lacking on the differences in yields between a windbreak and non windbreak setting over a long time frame. Thus, this aspect was not included in the analysis.

Because the above yields are only achieved at year 40-70, average yields for the entire 70 year period are required for the analysis. These are shown for each step in Table 1. Clearly the yield benefits which can only be achieved over a 40 year period temper the yield enhancement benefits that result from windbreak establishment.

It can be noted that soybean yields are more responsive to the climatic advantages of windbreaks than corn. Thus, the different response may be expected to result in different optimal strategies.

Life Cycle Cost

In developing the annual cost of establishment, replanting, maintenance, and removal, the costs at each time point for the 70 year interval were first discounted to time point zero. A 4 percent real discount rate was used. This cost was then annualized over the 70 year period at the 4 percent discount rate. The initial establishment cost was \$228.00 per acre of windbreak which included a \$2.00 per acre site preparation cost. With cost sharing this cost was reduced to one-half or \$114.00 per acre. Tree costs were \$.53/tree and \$.30/tree for planting.

Replanting is required (5 percent) for each of years 1-5. An annual cost of \$1.00 per acre for 70 years is required for weed control and maintenance. Last a removal cost is included which was \$495 per acre. The result, assuming 50 percent cost sharing, was \$9.38 per acre. For no cost sharing the cost was \$14.26. Cost sharing is only available at the establishment stage. Many windbreaks qualify for the Conservation Reserve Program for a 15-year period. This aspect was not included in the analysis.

Results

Mixed Lengths Permitted

In Table 2 the optimal field layout for corn is presented as the price of corn is varied in 25¢ intervals to \$3.00 per bu. The price of corn is then increased by selected amounts until a price of \$100.00 per bu is reached. A one mile field length (5280 ft) is assumed with each strip 20 ft in width, thus a total of 264 "strips" are available for use. At \$1.75 per bu 17 windbreaks are constructed and production occurs in 13 steps while two windbreaks are constructed which have 12 steps. At the base price (\$2.50) a fewer number (6) are constructed with 13 steps but 12 are constructed with 14 steps. As the price of corn increases the number of steps increases so that at \$7.50 and \$10.00 corn prices all steps are used. At extremely profitable prices (\$100), no

windbreaks are constructed due to the high opportunity cost of land in corn production. It can be seen that a no-cost sharing assumption has no effect on the optimal windbreak decision for corn at the \$2.50 base solution.

The pattern of windbreak location for soybean (Table 3) is very similar to corn. At the base price for soybean (\$6.00 per bu) the organization is identical to that for the organization for corn at its base price (\$2.50 per bu). The only major difference between the corn results and the soybean results is that at extremely high product prices the soybean pattern retains windbreaks but this was not the case for corn. Here, as with corn, a no-cost sharing assumption is seen to not change the optimal layout compared to cost sharing.

The optimal solution at the \$2.50 per bu corn price (\$22,297) can be compared to a no-windbreak solution. This return is presented in Table 4 as \$19,800. The optimal solution is 12.6 percent higher than conventional production. For soybean the respective returns for the two alternatives are \$19,956 vs. \$17,160 (Table 5). Here the benefits of a windbreak setting is 16.3 percent over conventional production.

Mixed Lengths Not Permitted

The return estimated at the \$2.50 optimal solution is \$22,297 where a mixture of windbreak lengths was permitted for corn. For soybean the respective return is \$19,956. Tightening this assumption to require all windbreak spacings (number of steps) be identical results in the solution returns presented in Tables 4 and 5, again assuming cost sharing. The solutions cover the range of one to fifteen steps.

For corn the results at a \$2.50 per bu price demonstrate negative returns for the one step and two step solutions. Returns increase until 11 steps and returns remain relatively constant for the 11-

15 step range. Because mixed lengths are not permitted, no solutions have higher returns than the \$22,297 solution previously described. Compared to where no windbreaks are established (Table 4) the return results for steps 11-15 are roughly 10 percent higher.

For soybean the results of the range in spacings are similar. Over the 11-15 spacing range the return results are roughly constant. Because soybean response to windbreak protection is greater than for corn, the relative difference between the returns under no windbreaks and that of the step 11-15 solutions is relatively higher for soybean compared to corn.

Conclusions

Estimated net returns are found to increase by roughly 12 and 16 percent respectively for corn and soybean under the optimal windbreak pattern compared to conventional production. The corn and soybean results are very similar, even though the increased yield response to soybean is higher than for corn. Hence, were these results employed for a corn-soybean rotation which is a common rotation in the region, no organizational problems are encountered. Were the yield response functions more widely different between corn and soybean, one windbreak pattern would be required to be selected which may not optimize one or both crops independently. However, that did not occur in this study.

Table 1. Corn and Soybean Yields by Step at Year 40 and Average Yields by Step for the 70 Year Period.

Step	Corn bu/ac		Soybean bu/ac	
	At Year 40	Average	At Year 40	Average
1	0	28.97	0	8.36
2	115.75	111.36	35.85	34.22
3	122.05	115.91	38.19	35.91
4	123.10	116.67	38.58	36.19
5	123.10	116.67	38.58	36.19
6	123.10	116.67	38.58	36.19
7	122.05	115.91	38.19	35.91
8	119.95	114.39	37.41	35.35
9	118.90	113.64	37.01	35.06
10	116.80	112.12	36.24	34.50
11	114.70	110.61	35.46	33.94
12	111.55	108.33	34.29	33.09
13	108.40	106.06	33.12	32.25
14	106.30	104.55	32.34	31.69
15	104.20	103.03	31.56	31.13

Table 2. Optimal Number of Windbreaks for Corn at Varying Corn Prices for a One Mile Long Field (mixed lengths permitted).

Price/bu	Optimal Number¹
\$1.75	2-12, 17-13
2.00	2-12, 17-13
2.25	6-13, 12-14
2.50	6-13, 12-14
2.50	6-13, 12-14 (No Cost Share)
2.75	8-14, 9-15
3.00	8-14, 9-15
5.00	8-14, 9-15
7.50	16-15, 8 regular
10.00	16-15, 8 regular
100.00	264 regular

¹ The first number refers to the number of windbreaks and the second number refers to the number of steps. Cost sharing is assumed unless none is indicated.

Table 3. Optimal Number of Windbreaks for Soybean at Varying Soybean Prices for a One Mile Long Field (mixed lengths permitted).

Price/bu	Optimal Number¹
\$ 4.00	16-12, 4-13
4.50	2-12, 17-13
5.00	2-12, 17-13
5.50	2-12, 17-13
6.00	6-13, 12-14
6.00	6-13, 12-14 (No Cost Share)
6.50	6-13, 12-14
7.00	6-13, 12-14
7.50	6-13, 12-14
8.00	6-13, 12-14
10.00	6-13, 12-14
15.00	8-14, 9-15
20.00	8-14, 9-15
100.00	8-14, 9-15

¹ The first number refers to the number of windbreaks and the second number refers to the number of steps. Cost sharing is assumed unless none is indicated.

Table 4. Estimated Returns for Corn Using the Maximum Number of Windbreaks of Equal Length at a \$2.50 Per Bu. Corn Price (no mixed lengths permitted).

Spacing - Windbreak Plus	Number of Windbreaks	Returns \$
1 step	132	-15,144
2 steps	88	- 997
3 steps	66	6,827
4 steps	52*	11,746
5 steps	44	14,819
6 steps	37*	17,153
7 steps	33	18,752
8 steps	29*	19,922
9 steps	26*	20,796
10 steps	24	21,447
11 steps	22	21,893
12 steps	20*	22,119
13 steps	18*	22,160
14 steps	17*	22,222
15 steps	16*	22,201
No Windbreak	0	19,800

* A field length of 5280 cannot be evenly divided by the length of the windbreak (20 ft) plus steps (each 20 ft) thus the remaining area is in regular production.

Table 5. Estimated Returns for Soybean Using the Maximum Number of Windbreaks of Equal Length at a \$6.00 Per Bu. Soybean Price (no mixed lengths permitted).

Spacing - Windbreak Plus	Number of Windbreaks	Returns \$
1 step	132	- 9,797
2 steps	88	1,417
3 steps	66	7,693
4 steps	52*	11,632
5 steps	44	14,117
6 steps	37*	15,975
7 steps	33	17,274
8 steps	29*	18,191
9 steps	26*	18,873
10 steps	24	19,390
11 steps	22	19,724
12 steps	20*	19,862
13 steps	18*	19,834
14 steps	17*	19,858
15 steps	16*	19,808
No Windbreak	0	17,160

* A field length of 5280 cannot be evenly divided by the length of the windbreak (20 ft) plus steps (each 20 ft) thus the remaining area is in regular production.

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