GRASS BARRIERS FOR WHEAT PRODUCTION IN SOUTHWEST SASKATCHEWAN

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Wind has long been considered a bane to farming in the Brown and Dark Brown soil zones of southwest Saskatchewan. Blowing dust from rampant wind erosion in an all-too-often occurrance. Strong hot summer winds cause tremendous moisture stress to crops -- particularly in dry years when crops are already drought-stressed. Perennial vegetative windbreaks have been advocated as a way to reduce near-surface windspeeds both to control wind erosion and to improve crop yields through better water conservation and decreased incrop evaporative stress.

Water Conservation Effect of Windbreaks

In southwest Saskatchewan, approximately 1/4 to 1/3 of annual precipitation falls, principally as snow, between October and April. Retaining this snow on the field with barriers offers the greatest potential for increasing available water for dryland crops (de Jong and Steppuhn 1983). Staple and Lehane (1955) noted that spring wheat yields were approximately proportional to the amount of snow deposition leeward of arboreal shelterbelts. Tall cereal stubble has been shown to retain 20 to 100% more snow water than conventional short stubble (Nicholaichuk et al. 1986) which has resulted in an additional 1 to 5 cm of soil water in the spring (Kachanoski et al. 1985, Bauer and Tanaka 1986). Stubble wheat yields have been increased by 40 to 150 kg/ha for each additional centimetre of available soil water present at seeding (Bauer and Tanaka 1986, Bauer 1972).

Table 1 lists soil water gains for an open field and for a field sheltered by double-row tall wheatgrass (TWG) windbreaks spaced 15 m apart in Montana (Black and Siddoway 1976). The TWG barriers substantionally increased water conservation between harvest and seeding for a continuous wheat and a fallow-wheat rotation. A 9 m spacing for TWG barriers was found to be narrower than neccessary and a 18 m spacing proved too wide for even snow distribution in years without abundant snow.

Following soil wetting, the TWG barriers system significantly reduced soil drying rate over a 4 day period compared to the soil surface outside of the barriers (Aase and Siddoway 1976). There was no difference in soil water losses after 10 days of elapsed drying time. TWG barriers would increase water conservation when relatively small, intermittent showers predominate.

Incrop Effect of Windbreaks

Barriers modify windspeed and flow patterns and this in turn influences the incrop microclimate. Marshall (1967) reviewed numerous studies and summarized the incrop microclimatic changes (Figure 1). The barrier-microclimate relationships shown in Figure 1 are not necessarily representative of a particular situation but do give an idea of the magnitude and direction of microclimatic factors relative to perpendicular distance from the windbreak.

Table 1 Eight-year average soil water gains and storage efficiencies, with and without TWG barriers, for continuous spring wheat and spring wheat-fallow rotations in Montana (Black and Siddoway 1976).

		Within TWG barriers		Open field	
Cropping sequence	Precipitation (cm)	Soil water gain (cm)	% of Precipitation	Soil water gain (cm)	% of Precipitation
Continuous Wheat harvest to seeding (9 months)	17.1	9.9	58	5.3	31
Wheat-Fallow harvest to spring (9 months)	17.1	10.2	59	5.3	31
summerfallow (5 months)	22.1	1.5	7	1.5	7
2nd winter (7 months)	17.3	2.5	15	2.3	13
fallow period (21 months)	56.7	14.2	25	9.1	16

The altered microclimate leeward of the barriers has generally found to be advantageous for crop growth because of lower evaporative stresses. At Swift Current, Pelton (1967) erected a 2.4 m tall fence after emergence of spring wheat. Over a 5 year period, sheltered dryland grain yields were 23 to 47% greater than yields from an open field. In a similar but shorter two-year study in North Dakota, Frank et al. (1977) reported the yield of sheltered irrigated spring wheat was 22% more than unsheltered irrigated wheat but the yield of sheltered dryland wheat was 22% less than unsheltered dryland wheat. Skidmore et al. (1975) determined the incrop windbreak microclimatic effects were greatest at intermediate moisture stress compared to low and high moisture stresses. Selles et al. (1986) observed that strips of 40 to 60 cm tall standing stubble improved the incrop microclimate in the early stages at crop growth. Soybeans grown between simultaneously-seeded maize barriers had increased water use efficiency and greater yield than soybeans grown in the open field (Radke and Hagstrom 1973).

Perennial Vegetative Windbreak Effects

For perennial windbreaks used in climates where snow constitutes a significant proportion of annual precipitation, the benefits of increased overwinter water conservation are interwoven with growing season microclimatic effects. The better soil water regime downwind of the barriers is attributed not only to increased snow trapping but also to reduced evaporation (van Eimern 1964, Marshall, 1967). However, vegetative barriers also compete with the crop for water and nutrients.

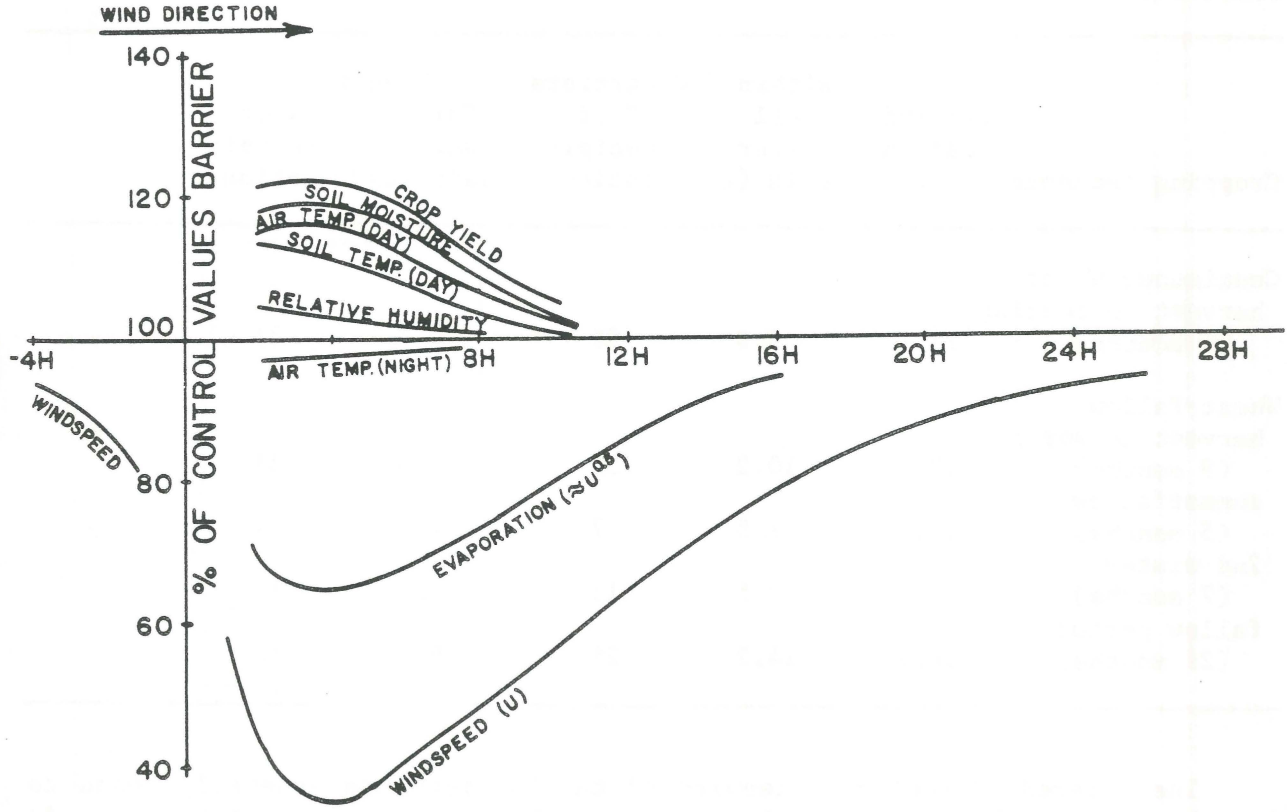

Figure 1. Summary diagram of the relative effects of a windbreak on microclimate at different multiples of windbreak height away from the windbreak (Marshall 1967).

After taking into account the field area occupied by the shelterbelt, wheat yields from fields with windbreaks of single-row shrubs or trees have ranged from slightly better than unsheltered yields (Staple and Lehane 1955) to slight less (McMartin et al. 1974). The greatest yield benefit of shelterbelts occurred in relatively dry years. Numerous studies from the steppes of the USSR have reported grain yield increases of fields with shelterbelts over open fields to be 100% or more in drought years (van Eimern et al. 1964). The area of reduced grain yields due to competition from the shelterbelt for water and nutrients typically extends laterally 1 to 2 times shelterbelt height (McMartin et al. 1974) but may reach four times shelterbelt height (Greb and Black 1961).

Greb and Black (1971) investigated winter wheat-fallow production in

Colorado using tall annual crops planted during the fallow period for windbreaks. Winter wheat grown within 46 to 66 cm tall double-row sorghum-sudangrass stalk barriers yielded nearly 300 kg/ha more than that grown in an open field. Winter wheat and winter rye forage yields grown within a TWG barrier field system were 60% more than open field production in Colorado (Snyder et al. 1980).

TWG windbreaks produced better early-season growth of winter wheat compared that grown in unsheltered fields (Aase and Siddoway 1974). Table 2 summarizes yields for winter wheat and spring wheat produced within a double-row TWG barrier system with a 15 m spacing and in an unsheltered field in Montana (Aase et al. 1976). On a whole field basis, some of the yield advantage of the TWG barrier production system would be lost to compensate for the 10% of land area occupied by the perennial grass windbreaks.

Table 2 Spring and winter wheat grain yields as affected by applied nitrogen, cropping rotation, and TWG barriers in Montana.

		Crop-Fallow			Continuous Cropping		
	Actual N Applied (kg/ha)	Open Yield (kg/ha)	TWG Yield (kg/ha)	TWG % of Open	Open Yield (kg/ha)	TWG Yield (kg/ha)	TWG % of Open
winter wheat	0	1852	2275	123	1002	1476	147
(1970-74)	34	2183	2554	117	1600	2077	130
spring wheat	0	1461	1536	105	741	804	109
(1968-72)	34	1887	1769	94	1016	1226	121

adapted from Aase et al. (1976).

Wind Erosion Effects of Windbreaks

Perennial vegetative windbreaks have long been used as an effective measure against wind erosion. Windbreaks not only reduce surface windspeeds to non-erosive velocities but permeable windbreaks also decrease the gradient of velocity with height. Decreasing the velocity gradient may actually be more effective for reducing wind erosion than lowering windspeeds (van Eimern et al. 1964). Finally, the soil tends to be wetter between windbreaks and this also decreases the wind erosion hazard (Aase and Siddoway 1976).

Arboreal shelterbelts are usually planted 100 to 400 m apart so there is some risk of wind erosion when strong winds are nearly parallel to the windbreak. Windbreaks with a narrower spacing still retain some erosion control for winds parallel to the rows. Aase et al. (1985) measured windspeeds at a height of 30 cm between TWG barriers and in an adjacent open field. Average windspeeds within the barrier system ranged from 39% of open field values for winds perpendicular to the barrier strips to 80% of open field windspeeds for winds parallel to the the TWG barriers. They concluded TWG barriers perpendicular to prevailing wind direction decreases wind erosion potential by 93.4% compared to an unsheltered field.

OBJECTIVES

The objectives of this study were:

1) Establish the feasibility of producing spring and winter wheat within an Altai wild rye (AWR) and a tall wheatgrass (TWG) barrier system in southwest Saskatchewan.

2) Investigate the effects of perennial grass barriers on water conservation.

3) Investigate the effect of perennial grass barriers on growth of spring and winter wheat.

MATERIALS AND METHODS

The study was established at the Swift Current Research Station on Swinton silt loam soil, a Brown chernozem. The study was conducted on eight 180 x 180 m blocks. On two of these blocks, barrier strips of tall wheatgrass (<u>Agronpyron</u> <u>elongatum</u> Beauv.), variety Orbit, were seeded. On another two of the blocks, barrier strips of Altai wild rye (<u>Elymus</u> <u>angustus</u> Trin.), variety Prairieland, were seeded. Seeding was performed on May 6, 1976 using a prototype single-row seed drill at a rate of 65 to 85 seeds per metre of row. All grass barrier strips were seeded 15 m apart in a north-south direction. The grass barrier strips consisted of two rows seeded as close together as practical. One TWG barrier block and one AWR barrier block had been cropped to spring wheat the previous year while the other grass barrier blocks had been summerfallowed. The remaining four blocks were open. Two of these blocks had been cropped the previous year while the other two had been summerfallowed.

Each block with grass barriers were paired with an adjacent open block which had the same cropping history. From 1976 to 1979 a spring wheat-fallow rotation was followed. Two grass barrier-open block pairs were cropped while the other two pairs were fallowed. This pattern reversed the next year such that each year only one AWR barrier block and one TWG barrier block were cropped. In the establishment year of 1976, the grass barrier blocks which had been fallow were seeded to wheat between the strips immediately after the grass barriers had been seeded. For these years, a plot consisted of one entire block.

In fall, 1979 the experimental design was changed substantially. The study land area was divided into two groups. Each group consisted of one TWG block and two nearby open blocks. Four treatments were randomly assigned within each TWG block. The plots for each treatment were laid out between two TWG barriers. These plots were 30 x 180 m and, thus, included one complete TWG barrier. The four treatments were: a) continuous spring wheat receiving fall tillage with a wide blade, b) continuous spring wheat receiving no fall tillage, c) continuous winter wheat receiving preseeding tillage, and d) continuous winter wheat seeded directly into standing stubble from the previous year's crop. The two open blocks in each group were divided into 6 plots of 60 x 180 m. Two of these plots were randomly assigned to a spring wheat-conventional fallow rotation alternating annually so that one of the plots was cropped each year. Similarily, two other plots were randomly assigned to a winter wheat-chemical fallow sequence. Treatments for the remaining two open plots were continuous spring wheat not receiving fall tillage and continuous winter wheat direct seeded into standing stubble. After the transition year of 1979-80, the two three-block groups were treated as replicates for use of analysis of variance to make multi-year comparisons of the continuous rotations. Otherwise, statistical comparisons were accomplished using a t-test treating areas associated with subsamples as the fundamental experimental unit.

Soil water was determined gravimetrically for the 0-15, 15-30, 30-60, 60-90, and 90-120 cm depths from soil samples taken in October and in April or early May. From 1977 to 1981, six soil cores were taken at each sampling on open plots. On the TWG barrier plots, three soil cores were taken near the barriers and an additional three soil cores were taken midway between the barrier strips. After 1981, three soil cores were taken at each sampling time on open plots. Late winter snow surveys and spring soil sampling were performed in the vicinity of fall soil sampling. Available water was calculated using bulk densities and 40 bar wilting point water content determined from a separate set of soil samples taken in 1979.

Fertilizer nitrogen and phosphorus for spring wheat were applied at recommended rates based on soil nitrates to 60 cm and $NaHCO_3$-extractable phosphorus to 15 cm from October soil sampling. An average application rate was used for all continuous spring wheat treatments. For winter wheat, phosphate was applied at 22 kg/ha at seeding and the nitrogen requirement was broadcast at recommended rates based on soil nitrates to 60 cm from October soil samples. As with spring wheat, one average fertilizer rate was used for all continuous winter wheat rotations. For both spring and winter wheat, all phosphate was drilled with the seed as monoammonium phosphate (11-51-0) and all additional fertilizer nitrogen was broadcast in the spring as ammonium nitrate (34-0-0).

Spring wheat varieties were Neepawa in 1977 and Canuck afterwards. The winter wheat variety was Norstar throughout the study. Seeding rates were consistently 66 kg/ha. Preseeding tillage was performed with a heavy duty cultivator equipped with sweeps and an attatched rodweeder. All seeding was done with a hoe press drill except a prototype offset disc drill (Swift Current Zero-Till Disc Drill) was used for the direct-seeded continuous winter wheat treatments.

All plots were sprayed with 2,4-D in late fall or early spring to control winter annual weeds. Broadleaf weeds were controlled incrop with bromoxynil (Torch) or a bromoxynil/MCPA mix (Butril M) at recommended rates as required. Incrop grassy weed control was accomplished with diclofop methyl (Hoe-Grass) at recommended rates as required. Weed control for chemical fallow treatment relied on several spray applications of glyphophate/dicamba/2,4-D (Roundup/Banvel/2,4-D) mix at recommended rates as required. Conventional fallow received several operations with a heavy duty cultivator and/or a rodweeder.

From 1977 to 1981 whole plot yields were taken. From 1982 to 1984 yields were estimated from two 4 x 30 m swaths per plot. Four 5 x 30 m swaths per plot were used in 1985. These swaths were harvested with a full-size combine. In the TWG barrier system, the swaths were made midway between the barrier strips. In 1980, detailed spring soil water and 5.4 square metre grain yield measurements were made on a transect eastward from the grass strips to determine the effect of grass barrier competition.

Windrun and evaporation were measured in the 1980 growing season. A standard anemometer and an Ogo-Pogo evaporimeter were installed at a height of 0.75 m at one location midway between TWG barriers and at another location in an adjacent open block. Soil temperatures midway between TWG barriers and in an adjacent open block were measured in the 1983 growing season. Precipitation was measured daily approximately 650 m from the study area.

RESULTS

Comparison of Grass Species for Vegetative Barriers

Observations of crop growth within the AWR and TWG barriers soon showed the AWR was a much stronger competitor to the crop than the TWG. Figures 2 and 3 plot 1980 spring soil water and wheat yields, respectively, against distance from grass barrier for spring wheat. The AWR withdrew soil water for 2 to 3 m to each side of the barrier strip. By comparison, the TWG caused less soil water depletion and this depletion extended less than 1 m from the barrier strip. Analysis of soil nitrates from detailed spring soil sampling revealed neither grass species was significantly affecting nitrate levels adjacent to the barrier strip (data not shown). Wheat yield trends generally followed those of available soil water. Grass barrier competition effects on soil water and grain yields for winter wheat were very similar to spring wheat (Nicholaichuk 1981).

The strongly competitive nature of the AWR relative to TWG made it unsuitable for a perennial vegetative windbreak. Consequently, the AWR barriers were dropped from the study after the 1980 wheat harvest.

Snow and Water Conservation

The TWG barriers were very effective for snow trapping. In the establishment year, the TWG attained a height of approximately 30 cm. The TWG was well established by fall, 1979. After then, the TWG grew 1.2 to 1.5 m tall yet the strong stems did not lodge in any year. New stems grew up through the standing stems of the previous year. Volunteer TWG filled in any sparse areas in the barrier strips. The porosity of the barrier was nearly ideal for production of long low snow drifts which would eventually fill the 15 m interval between the strips.

Figure 4 shows snow trapping characteristics for spring wheat stubble. Since there was no significant difference between the continuous wheat with and without fall tillage within the TWG barriers, these treatments were averaged. Overwinter precipitation was defined as rain and melted snow between fall and spring soil sampling. Overall, snow water equivalent of the late-winter snowpack within the TWG barriers was 83% of overwinter precipitation versus 32% for open field conditions. However, much of this snow water did

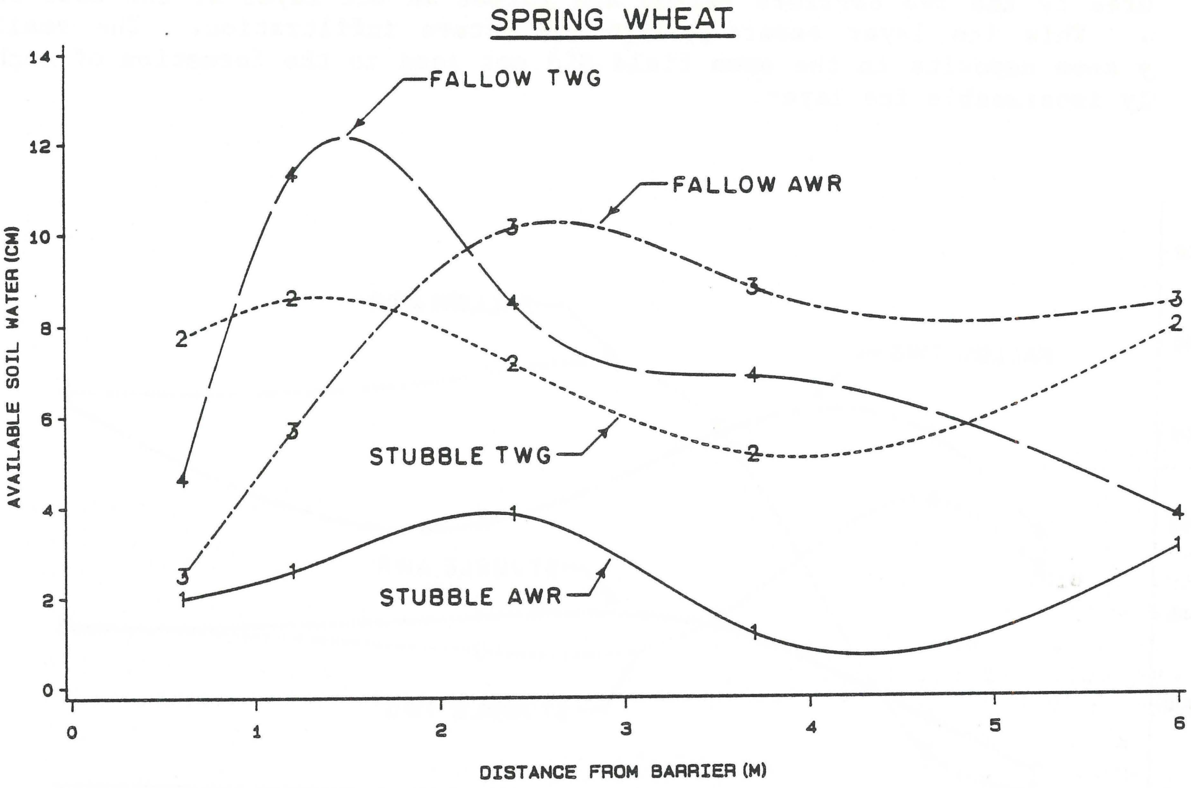

Figure 2. Effect of grass barrier on available soil water with distance from the barrier for spring wheat.

not enter the soil since overwinter soil water gains between spring and fall soil sampling averaged only 1.6 cm more than the unsheltered field. Over the winters of 1981-82 and 1983-84, the TWG barrier system had significantly ($P < 0.05$) more soil water gain than the open stubble. There was no significant difference in overwinter soil water gain for the other winters.

Snow trapping charateristics for winter wheat stubble are shown in Figure 5. Since there was no significant difference between the continuous wheat with and without preseeding tillage within the TWG barriers, these treatments were averaged. Overwinter soil water gains for the winter of 1983-84 refer to soil summerfallowed in 1983. Since snow water equivalent and snow depth were not measured that winter on open fallow, the values shown on Figure 5 are for nearby spring wheat stubble. Excluding 1983-84, average snowpack depth and snow water equivalent within the TWG barriers (23.7 and 6.3 cm, respectively) were approximately twice those of the open field (11.3 and 2.9 cm, respectively). Despite the additional snow captured within the TWG barriers, overwinter water gains were dissapointingly small. Overwinter water gains with the TWG barrier system averaged 6.1 cm which was 0.1 cm less than the open field. Over no winter period was there a significant difference between open field soil water gain and that for the TWG barrier system. During the mild winters of 1980-81 and 1982-83 there were several midwinter thaws. In these years, the open field situation was more favourable for overwinter soil water gain. The probable reason for this behavior is that the extra early snows captured by the TWG barriers melted and formed an ice layer at the soil surface. This ice layer severely retarded future infiltration. The smaller early snow deposits in the open field did not lead to the formation of such a nearly impermeable ice layer.

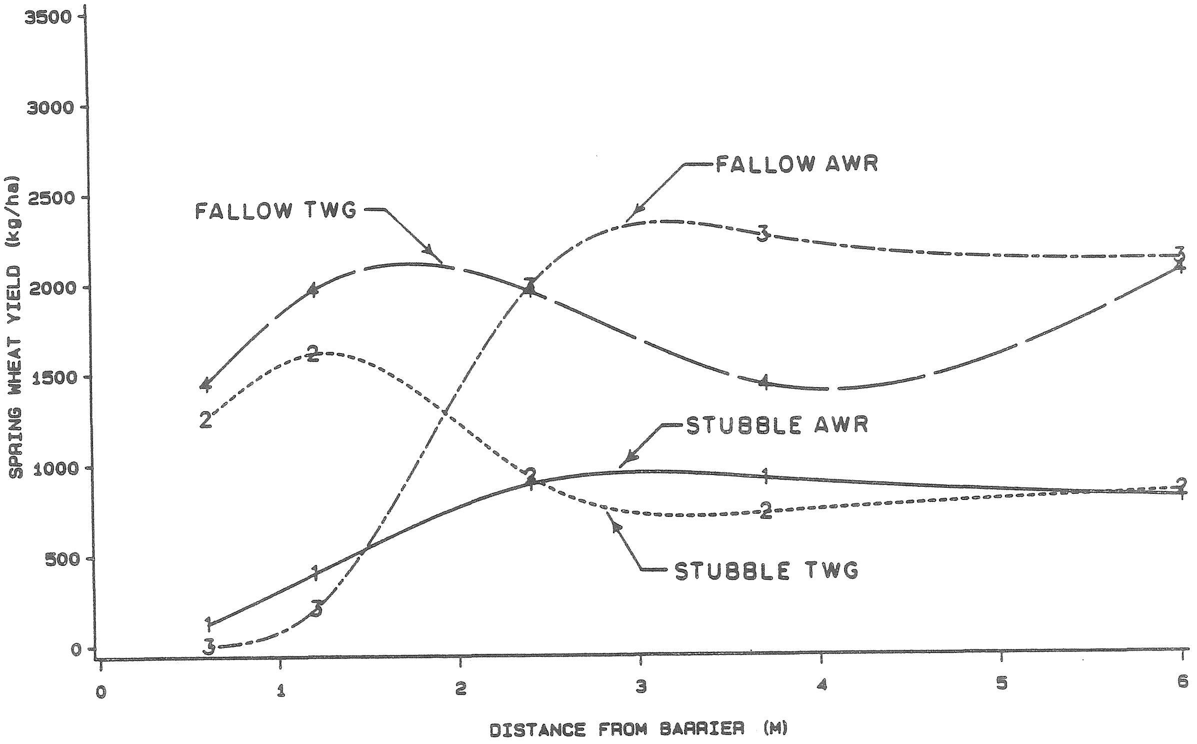

Figure 3. Effect of grass barrier on spring wheat yield with distance from the barrier.

Without snowcover, winter wheat production is very risky in southwest Saskatchewan because of the danger of winterkill from excessively low soil temperatures. Steppuhn and Nicholaichuk (1986) concluded winter wheat requires approximately 10 cm of dry snowcover to protect the plants from winterkill. Snow depths within the TWG barrier system exceeded 9.6 cm 5 years out of 6 compared with 3 years out of 6 for the open field.

Table 3 summarizes water conservation characteristics for continous spring wheat and spring wheat-fallow rotations. The TWG barrier system had its greatest effect on water conservation during the overwinter period immediately following cropping. From the spring of the summerfallow year until the next spring, the TWG barriers did not increase water conservation. Water conservation characteristics were similar to those found in Montana (Table 1). However, in Montana the overwinter water gains on wheat stubble were larger with the TWG barrier system. The soils in the Montana study were coarser textured (sandy loam) than those in this study (silt loam) and probably had better infiltration of snowmelt.

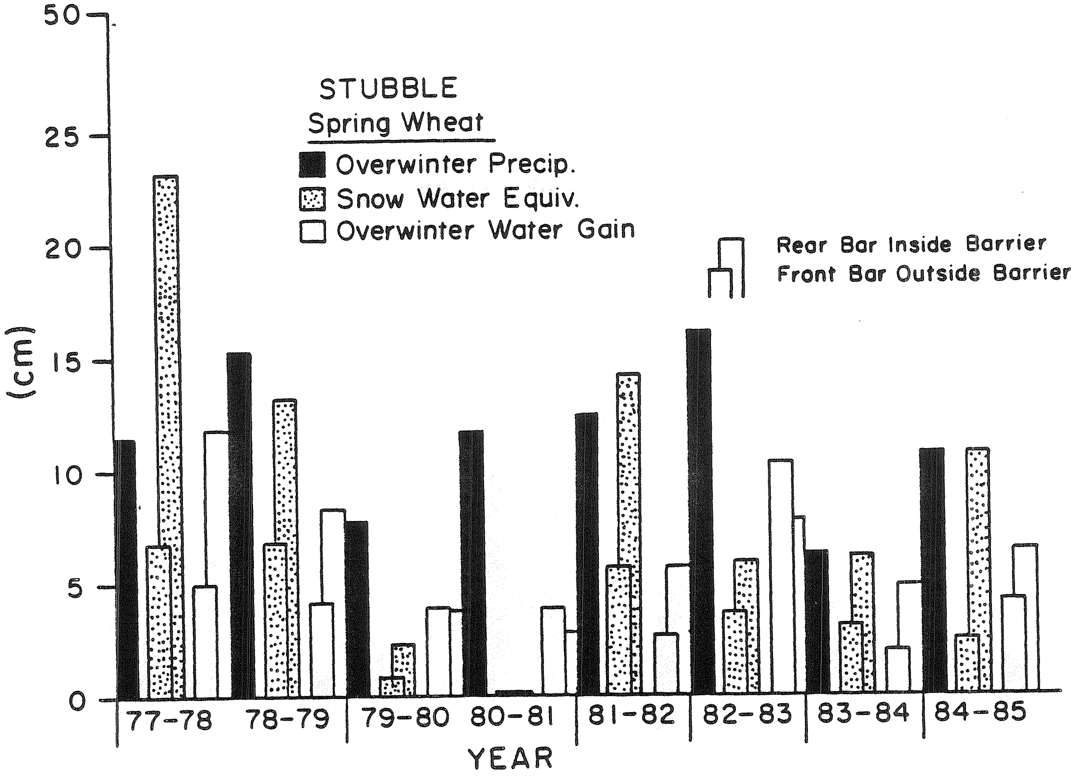

Figure 4. Overwinter water conservation characteristics, within and outside TWG barriers, for continuous spring wheat.

Table 3 Average soil water gains and storage efficiencies, with and without TWG barriers, for continuous spring wheat and spring wheat-fallow rotations.

Period	Precipitation (cm)	Within TWG barriers Soil water gain (cm)	Within TWG barriers % of Precipitation	Open field Soil water gain (cm)	Open field % of Precipitation
Continuous Wheat					
Oct.-April (6 yrs data)	10.9	5.2	48	4.5	41
Wheat on Fallow					
1st winter (2 yrs data)	13.4	5.8	43	5.0	37
summerfallow[1] (3 yrs data)	16.1	0.4	3	0.1	0
2nd winter (3 yrs data)	11.5	3.3	29	3.7	32
fallow period[2] (2 yrs data)	41.9	10.1	24	8.8	21

notes: [1] spring to fall sampling dates.
[2] fall of harvest year to spring of next crop year.

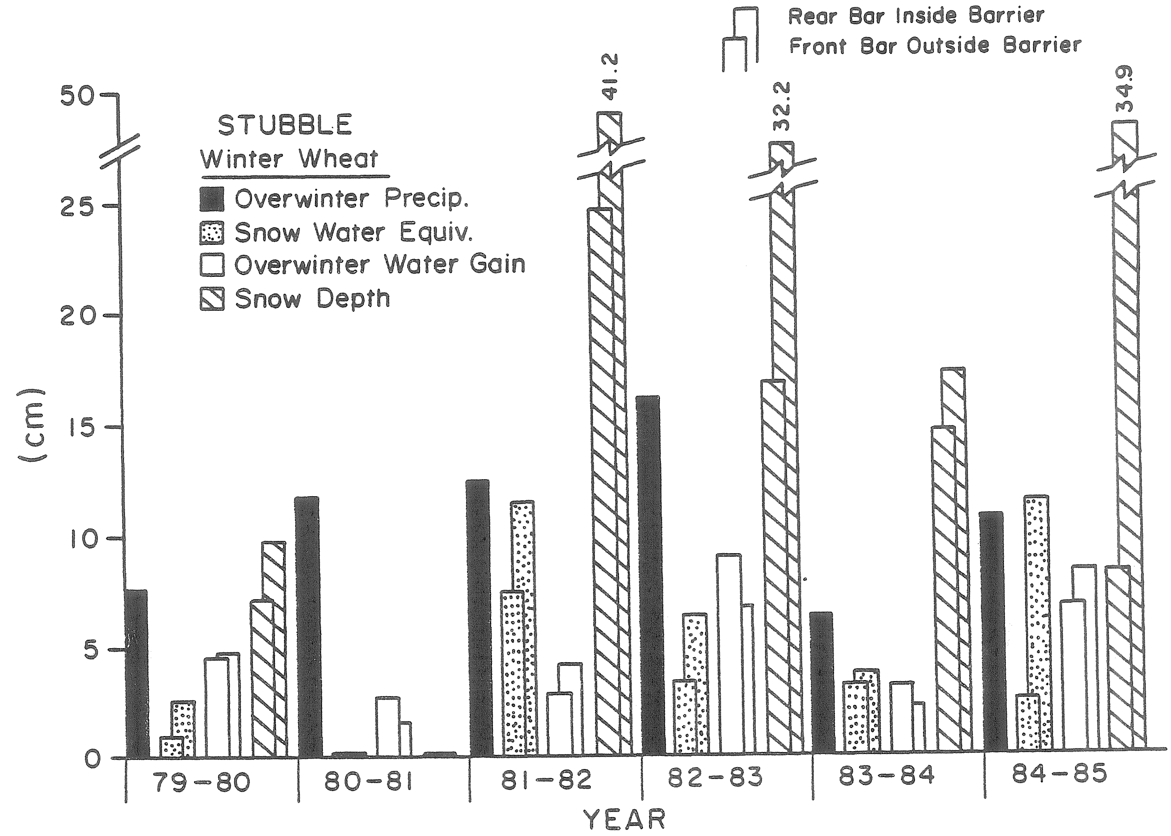

Figure 5. Overwinter water conservation characteristics within and outside TWG barriers, for continuous winter wheat.

Wind Erosion and Microclimate

No quantitative measurements were made of wind erosion but at several occaisions there was evidence of wind erosion on the open field, particularly the open conventional fallow. There was no visual evidence of soil erosion within the grass barriers.

Over the growing season of 1980 windrun was 17% less and evaporation as measured by the evaporimeter was 25% less within the grass barriers than in the open area. Surface soil temperatures were 0.34 °C greater midway between the TWG barriers than in the open field. Soil temperatures in the two areas were not different 5 cm or more below the surface. These results are similar to those reported for TWG barriers by Black and Siddoway (1976) and followed trends in windbreak effects found by other researchers (see Figure 1). It is believed the main benefit of these microclimate changes occurs during crop establishment (Nicholaichuk 1981).

Yields

Spring wheat yields are listed in Table 4. For the years when whole plot yields were taken for the TWG barrier system, the yields were increased by 10% to account for the land occupied by the TWG barrier. There were no evidence of any difference between fallow wheat yields for the open field and TWG barrier system. However, especially in 1977 and 1978, the TWG barriers did not have the height or density of fully-established barriers. Any benefit arising from better water conservation and microclimate improvements was roughly balanced by TWG competition with the crop. In Montana, fertilized fallow spring wheat yields tended to yield slightly less within TWG barriers (Table 2). Fallow spring wheat yields within the more competitive AWR barriers averaged 20% less than within the TWG barriers (data not shown).

Considering all years, there were no significant differences in continuous wheat yields between the TWG barriers and the open field (Table 4). The trend was for somewhat higher continuous wheat yields with the TWG barrier system. A similar trend was found in Montana (Table 2). In the drought years of 1984 and 1985, continuous wheat yields within the TWG barriers were significantly ($P < 0.02$) greater than the open field. This latter behavior indicated the water conservation and microclimatic benefits of vegetative barriers at higher crop moisture stress outweighed TWG competition.

In 5 years out of 6, the TWG barrier treatment including fall tillage had slightly higher yields than the TWG barrier treatment not receiving fall tillage. The fall tillage would destroy some of the lateral TWG roots and, thereby, reduce competition with the crop the next year.

The TWG barrier system was a successful drought mitigation technology. Continuous stubble wheat yields remained approximately the same proportion of open field fallow yields during the dry years of 1984 and 1985 as during the years with more favourable moisture conditions (Table 5). The unsheltered continuous wheat yields dropped substantially relative to open fallow wheat yields in 1984 and 1985.

Table 6 summarizes winter wheat yields. TWG barrier system yields have been adjusted when appropriate so there is no allowance for the 10% of field area occupied by the barrier strips. General yield trends were similar to those of spring wheat. With only two years of data and different fallow methods, no inferences can be made as to the effect of TWG barrier system on fallow winter wheat yields. In Montana, winter wheat on fallow within TWG barriers outyielded its open field counterpart (Table 2).

In 1984, winter wheat on open conventional fallow yielded significantly ($P < 0.05$) less than on conventional fallow within the TWG barriers. This difference can be explained by some winterkill in the open conventional fallow where there was no mechanism of retaining an insulating snowcover. Steppuhn and Nicholaichuk (1986) concluded TWG barrier systems are viable practice for extending the range of winter wheat into areas where winter wheat production with tilled seedbeds is risky because of winterkill.

The stubble winter wheat yields were larger within the TWG barriers than in the open field (no significant differences). The magnitude of this increase was very similar to that found for spring wheat but was less than that reported for fertilized stubble winter wheat in Montana (Table 2). The winter wheat in Montana made better use of winter precipitation because of better snowmelt infiltration characteristics of that soil. As with spring wheat, the windbreak benefit was much greater in the drought year of 1985 than in the wetter years of 1981 and 1982. In 1980, increased winterkill on the open continuous treatment was responsible for much of the yield differential be-

Table 4 Spring wheat yields within and outside a TWG barrier system.

Year	Growing season precip.[1] (cm)	Crop-Fallow Yields			Continuous Crop Yields				
		Open field (kg/ha)	TWG system (kg/ha)	% of open field	Open field (kg/ha)	TWG/fall tillage system (kg/ha)	% of open field	TWG/no fall tillage system (kg/ha)	% of open field
1977	19.9	3247	3261	100	-	-	-	-	-
1978	11.9	1906	1896	99	-	-	-	-	-
1979	13.7	1479	2016	136	-	-	-	-	-
1980	15.9	1851	1603	87	783	895	114	824	105
1981	19.6	2456	-	-	1617	1785	110	1728	107
1982	24.4	2993	-	-	2528	2641	104	2444	97
1983	18.7	2635	-	-	1682	1662	99	1616	96
1984	10.0	1445	-	-	343	884	258	747	218
1985	7.3	1238	-	-	654	833	127	1023	156
Mean	15.7	2139	2194	103[2]	1267	1450	114	1397	110

notes: [1] May-June-July precipitation.
[2] based on 1977-80 yields only.

Table 5 Continuous spring wheat yields, with and without a TWG barrier system, relative to open fallow yields.

		Continuous Crop			
	Open Fallow (kg/ha)	TWG System[1] (kg/ha)	% of Open Fallow	Open Stubble (kg/ha)	% of Open Fallow
All years 1980-85	2103	1423	67	1267	60
Normal to wet years 1980-83	2484	1699	69	1652	67
Dry years 1984-85	1342	872	65	499	37

notes: [1] average of fall bladed and no fall tillage.

tween the TWG barrier system and the open field. In three out of four years, winter wheat receiving preseeding tillage outyielded direct-seeded winter wheat. This fall tillage reduced TWG competition. Seeding winter wheat into a tilled seedbed is not recommended in Saskatchewan because of winterkill concerns (Saskatchewan Agricultural Services Co-ordinating Committee 1987). However, within TWG barriers, this production practice outperformed direct seeding both within and outside the barriers.

After three years of continuous winter wheat, the decision was made to fallow the land because of a serious grassy weed problem. Black and Siddoway (1976) abandoned their continuous spring and winter wheat rotations after five years because of a buildup of grassy weeds. Long-term continuous wheat rotations, especially of winter wheat, may not be feasible with normal herbicide applications.

Table 7 gives the efficiencies with which the wheat made use of available spring soil water reserves plus growing season precipitation. The stubble wheat grown within the TWG barriers made more efficient use of available water resources than open field stubble wheat. This suggested the improved microclimate stemming from the wind reduction between the TWG barriers increased water use efficiency. For stubble winter wheat, a better stand resulting from less winterkill also improved water use efficiency. Efficiencies of use of available water were lower on fallow within TWG barriers than for the open field. This was probably due to nonproductive water use by the TWG barriers.

Table 6 Winter wheat yields within and outside a TWG barrier system.

		Crop-Fallow Yields			Continuous Crop Yields				
Year	Growing season precip.[1] (cm)	Open field chemical fallow (kg/ha)	TWG/conv. fallow system (kg/ha)	% of open field	Open field (kg/ha)	TWG/ preseed tillage system (kg/ha)	% of open field	TWG/direct seeding system (kg/ha)	% of open field
1980	13.3	1874	1761	94	257	595	232	473	184
1981	18.1	2876	-	-	1578	1574	100	1464	93
1982	21.3	2265	-	-	2263	2306	102	2484	110
1983	18.2	2521	-	-	fallow[2]	fallow[2]	-	fallow[2]	-
1984	9.7	2352	1952	83	1366[3]	-	-	-	-
1985	8.0	1760	-	-	985	1505	153	1210	123
Mean	14.8	2275	1857	88[4]	1271[5]	1495	118[5]	1408	111[5]

notes:
[1] April 1 to July 15 precipitation.
[2] fallowed to control grassy weeds.
[3] conventional fallow yield.
[4] based on 1980 and 1984 yields only.
[5] based on 1980-82 and 1985 yields only.

Table 7. Use efficiencies of available water resources by wheat with and without TWG barriers.

		TWG barriers		Open Field	
Rotation	Growing Season Precip.[1] (cm)	Avail. Soil Water[2] (cm)	Use Efficiency[3] (kg/ha/cm)	Avail. Soil Water[2] (cm)	Use Efficiency[3] (kg/ha/cm)
Cont. S. Wheat[4] (6 yrs)	14.9	7.5	61	5.8	56
Fallow S. Wheat[5] (3 yrs)	13.8	14.5	59	14.0	63
Cont. W. Wheat[6] (4 yrs)	14.0	8.1	65	6.8	60
Fallow W. Wheat (2 yrs)	9.9	11.2	90	13.8	92

notes:

[1] spring soil sampling to July 15 precipitation for winter wheat, May-June-July or May soil sampling date to July 31 precipitation for spring wheat.

[2] available soil water in 1.2 m soil profile at spring sampling.

[3] grain yield/(available spring soil water plus growing season precipitation).

[4] average of fall bladed and no fall tillage for TWG barriers.

5 1978-1980 only.

6 average of direct seeded and seeded into tilled seedbed for TWG barriers.

Practical Aspects of TWG Barrier Systems

Since establishment in 1976, the TWG barriers have required no maintenance and no fertilization or weed control beyond that coming as a side effect of adjacent wheat production. Similar performance has been noted in Montana for TWG barriers established in 1967 (Steppuhn et al. 1988). TWG windbreaks offer a high degree of permanency.

Tillage right up to the barrier strip in the fall before seeding increased spring and winter wheat yields by reducing competition from the strip. Seeding right to the TWG barrier strip is recommended to minimize weed growth between the TWG and the wheat crop.

Double-row TWG barriers on 15 to 18 m spacing occupy about 10% of the field area. Based on further experience, single-row TWG barriers are now recommended (Snyder et al. 1980). Single-row barriers on a 15 to 18 m spacing occupy approximately 5% of the field area. Insofar as practical, the barriers should be both perpendicular to winter winds and, to reduce risk of water erosion, perpendicular to the land slope.

The principal disadvantage of TWG barrier system is the inconvenience of farming operations and of fitting equipment widths to barrier widths. Synder et al. (1986) estimated the additional cost of farming around and with a TWG barrier system to be an additional 5% of variable costs (seed, fertilizer, herbicide, and machinery costs). Needless to say, seeding the TWG barriers must be done with great care to ensure the barrier strips are truly parallel throughout their length.

Steppuhn et al. (1988) estimated the initial investment cost of establishing a single-row TWG barrier at $12/ha. Over a 20 year period at a 12% annual interest rate this is equivalent to a cost of $1.25/ha per year.

Without considering any return to management, the additional net revenue of a TWG barrier wheat production system over that from open field production is:

$$\text{additional net revenue} = [\text{TWG system net revenue}] - [\text{open field net revenue}]$$

Using the cost assumptions discussed above this additional net revenue for a single-row TWG barrier on a 15 m spacing can be expressed as:

$$ANR = [\ (1-0.05)*Y_b*P-(1.05*VC+1.25)\ ] - [\ Y_o*P-VC\ ] \qquad .....(1)$$

where: ANR = additional net revenue on whole field basis ($/ha),
Y_b = wheat yield within TWG barrier strips (t/ha),
P = wheat price ($/t),
VC = variable costs of open field wheat production ($/ha),
Y_o = wheat yield in open field (t/ha).

Equation (1) was solved for TWG barrier system wheat yields which had equal net revenue to open field wheat production (i.e., ANR=$0) for a number of combinations of wheat prices, variable production costs, and open field wheat yield. The break-even ratios of barrier system yield to open field yield are presented in Table 8. The break-even ratios decrease as wheat prices increase, variable production costs decrease, and/or wheat yield increase.

Considering fallow spring wheat yields reported in this study and in Montana, a spring wheat-fallow rotation within a TWG barrier system does not appear economically attractive relative to open field production. A winter wheat-fallow rotation within a TWG barrier system may provide additional net revenue for soils that normally have good snowmelt infitration characteristics.

Reported yield results suggest an extended spring or winter wheat rotation with a TWG barrier system may be a viable alternative to open field production at present wheat prices and moderate production costs. Any recovery in wheat prices would make a TWG barrier system more attractive. The relative profitability of the TWG barrier system would decrease as the proportion of fallow in the extended rotation increases.

The above economic analysis ignores the value of wind erosion control. The higher a value a producer places on wind erosion control, the lower the relative TWG barrier system yield required to make the such a system attractive.

In southwest Saskatchewan, the wind erosion control, yield benefit at high moisture stress and potential overwinter water conservation provided by a TWG barrier wheat production system would probably be most advantageous for coarse to medium textured soils (sands-sandy loams-light loams) and for solonetzic soils. In these soils wind erosion is a common problem because soils naturally form a soil surface dominated by wind-erodible soil particles and/or low soil productivity often results in insufficient crop residue to protect the soil surface. The crop often undergoes substantial moisture stress because of the low soil water storage within the root zone. The coarse textured soils may best make use of trapped winter snows within the barrier strips because they typically have good infiltration of snowmelt. The extra water from trapped snow may also benefit solonetzic soils by enhancing the leaching of salts, especially sodium, deeper into the soil profile.

The TWG barriers were harvested for seed in the relatively wet year of 1986 (May-June-July precipitation of 20.5 cm). As harvested with a grain combine, yields of clean seed were approximately 3.5 kg per 100 m of double-row barrier. This would be equivalent to 12 kg/ha for single-row TWG barrier system (assuming single-row yields are 1/2 of double row yields). Presently, certified Orbit TWG seed is worth $8.50/kg (Saskatchewan Wheat Pool, personal communication 88/02/02) because of strong demand related to government programs in the United States. Over the long term, seed prices may not remain so high, but it appears safe to assume a producer will at least be able to recoup the costs of barrier establishment by harvesting the barriers for seed in favourable years.

CONCLUSIONS

1) Altai wild rye was not a satisfactory vegetative windbreak because it was a strong competitor with the wheat crop. Tall wheatgrass (var. Orbit) was a very satisfactory vegetative windbreak because of its tall upright growth habit, resistance to lodging, low competiveness, minimal maintenance requirement, durability and robustness.

2) Tall wheatgrass barriers effectively trapped snow between barrier strips. Generally this trapped snow increased water conservation compared to the open field but actual water conservation was dependent on the soil infiltration characteristics for snowmelt. Tall wheatgrass barriers provided satisfactory snow cover to protect winter wheat from winterkill in most years.

3) On stubble, the yield benefit of a tall wheatgrass barrier system increased as crop moisture stress increased. This yield benefit resulted from improved water conservation and better incrop microclimate. The tall wheatgrass barrier system was a successful drought mitigation technology for stubble crops. Fall tillage before seeding increased stubble spring and winter wheat yields by lessening competition from the tall wheatgrass barrier. On fallow, yield reductions due to competition from the tall wheatgrass windbreaks roughly balanced any yield increases due to water conservation and incrop microclimate influences.

4) Wind erosion control is probably the greatest advantage to the tall wheatgrass barrier system.

5) The disadvantages of the tall wheatgrass barriers are: i) the inconveni-

ence in farming operations and fitting equipment widths to barrier intervals, and ii) the land occupied by the barriers (5% for single-row barriers).

6) Relative to open field production, a tall wheatgrass barrier spring wheat production system is most profitable for extended rotations. This relative profitability decreases as the proportion of fallow in the rotation increases. The profitablility of tall wheatgrass barrier winter wheat production system would increase as the ability of the snowmelt to infiltrate the soil increases. The relative profitability is greatest for extended winter wheat rotations providing grassy weeds can be held in check. Harvesting the tall wheatgrass strips could improve the system profitability considerably.

7) In southwest Saskatchewan, wind erosion concerns and moisture stress would make a tall wheatgrass barrier wheat production systems most advantageous for coarse to medium textured soils and for solonetzic soils.

Table 8. Break-even ratios of TWG barrier system yields to open field yields at various wheat prices, variable production costs, and open field yields.

Open Field Yield (kg/ha)	Variable Production Costs ($/ha)	Wheat Price ($/t)			
		50	100	150	200
1000	75	1.16	1.11	1.09	1.08
	125	1.21	1.13	1.11	1.09
	175	1.26	1.16	1.12	1.11
1400	75	1.13	1.09	1.08	1.07
	125	1.17	1.11	1.09	1.08
	175	1.20	1.13	1.10	1.09
1800	75	1.11	1.08	1.07	1.07
	125	1.14	1.10	1.08	1.07
	175	1.17	1.11	1.09	1.08
2200	75	1.10	1.08	1.07	1.07
	125	1.12	1.09	1.08	1.07
	175	1.15	1.10	1.08	1.08

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