MANAGING SNOW TO EXTEND THE AREAL RANGE OF WINTER WHEAT PRODUCTION

by

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SNOWCOVER INSULATION

It is well known that snow provides excellent temperature insulation. Measurements in Europe have shown that each centimeter thickness of a 10-cm snowcover will maintain an average temperature difference of 1.1°C (Shul'gin, 1957). The effect decreases with snow depth, as indicated in Table 1.

Table 1. Difference in temperature between air and soil, as a function of snowcover thickness, USSR (Shul'gin, 1957).

Thickness of snowcover cm	Difference between air and soil temperature per cm of snow °C
0-10	1.1
11-20	0.7
21-30	0.5
31-40	0.4
41-50	0.3
51-60	0.2
61-70	0.1
71-80	0.1

The insulative value of a snowcover is related to its low heat transfer characteristics. Usually, in winter when a snowcover is at a temperature below freezing, heat flows by conduction from the soil to the atmosphere. The heat flux (q) through snow depends on the temperature gradient (dT/dz) and the thermal conductivity (k) of that particular snow:

$$q = -k \, dT/dz.$$

As a property of the snow, k varies with snowpack density, liquid water content, impurities, albedo, etc.

Snow is composed of varying fractions of air, ice and liquid water. The approximate thermal conductivity, k, and density of each component is:

Component	density	k
	g/cm^3	W/(m K)
air	0.00125	0.025
ice	0.92	2.2
liquid water	1.00	0.57

Presented at the 54th Annual Meeting of the Western Snow Conference, April 14-17, 1986, Phoenix, Arizona.

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Geiger (1961) calculated the composite thermal conductivity of snow to lie in the range from 0.025 to 1.61 W/(m K) for densities between 0.1 and 0.8 g/cm^3. The good insulative characteristics of snow can be attributed to the low k values of its entrapped air. Usually, air comprises over 60% of the snow volume and generally transfers little energy by convection.

Consequently, a snowcover reduces soil heat loss and modifies temperatures of the soil beneath it (Table 2). The extent to which a snowcover affects the penetration of a freezing front into a soil depends on the snow thickness, the vegetative cover and the temperature history. Frost depths are also governed by soil water content. A dry soil tends to freeze deeper and faster (but thaws more rapidly) than a wet soil, primarily owing to differences in heat capacity (Willis, et al., 1961).

Table 2. Mean monthly temperature of bare soil and of snow-covered soil, USSR (Shul'gin, 1957)

Soil	Mean Monthly Temperature, °C				
	Nov	Dec	Jan	Feb	Mar
Snow-covered$^+$	-2.0	0.3	-1.6	-3.0	-1.6
Bare	-3.2	-9.7	-13.9	-13.6	-8.1

$^+$ Snowcover 40 cm deep

SNOWCOVER AND WINTER WHEAT SURVIVAL

Overwintered wheat, seeded in late summer or early fall, has the opportunity of utilizing soil water reserves enriched by the spring snowmelt before the onset of desiccating summer conditions. The plants, however, must first survive the low temperatures. The survival of seedling wheat depends upon the ability of these plants to cold acclimate or "harden off". For instance, when growth starts in the early fall, winter wheat will not survive subfreezing temperatures any better than spring-seeded wheat (Fowler et al., 1983). However, when grown under cool fall temperatures, winter wheat will rapidly cold acclimate. At the beginning of September, the minimum survival temperature for Norstar winter wheat in Saskatchewan averages -3°C (Figure 1). By the end of October, Norstar typically survives temperatures of -19°C.

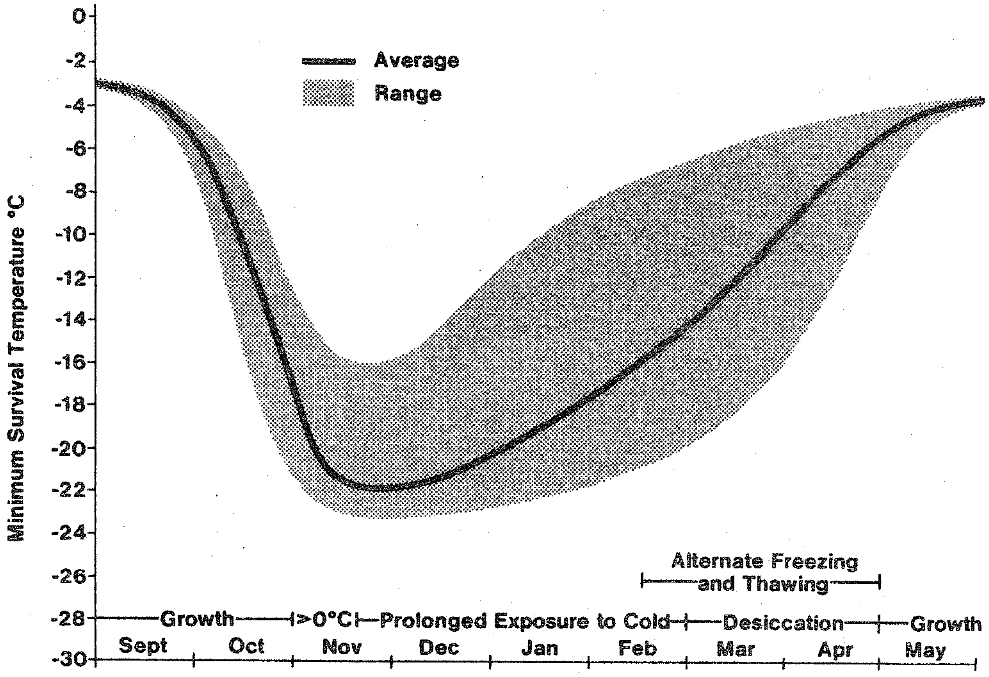

Figure 1. Changes in cold hardiness of Norstar winter wheat grown in Saskatchewan during the September - May period. The primary factors responsible for these changes are shown at the bottom of the graph (Fowler et al., 1983).

The tolerance of a particular winter wheat variety for cold temperatures stems from its genetic inheritance. A field survival index (FSI) was used by Fowler and Gusta (1978) to compare relative survival between different varieties. The FSI represents a variety's winter survival potential. Differences in FSI's reflect average percent differences expected in field survival. The FSI's for varieties Norstar and Sundance (Table 3) equal 514 and 494, respectively, and indicate an expected survival difference of 514-494 = 20 or 20% favoring Norstar. The FSI for each variety shown in Table 3 was derived from field trials involving different levels of winter stress. Fowler et al., (1981) observed that under Saskatchewan conditions the main limiting winter stress is low temperature. Thus, the temperature (LT-50) at which 50% of a cold-acclimated plant population is killed correlates closely with the FSI's listed in Table 3.

Table 3. Field Survival Indices (FSI) and survival tempratures (LT-50) of selected winter wheat varieties (Fowler and Limin, 1986).

Variety	Area of adaptation or initial release	FSI+	LT-50‡ °C
Cappelle Desprez	France	306	-14
Blueboy	North Carolina	358	-16
Yorkstar	New York	360	-16
Fredrick	Ontario	368	-16
Nugaines	Washington	376	-16
Gaines	Washington	389	-17
Besostoja 1	USSR	401	-17
Centurk	Nebraska	433	-18
Cheyenne	Nebraska	445	-19
Winalta	Alberta	463	-19
Sundance	Alberta	494	-20
Norstar	Alberta	514	-21
Alabaskaja	USSR	527	-21

+ The higher a varieties's FSI the greater its ability to survive winter field stress.

‡ Temperature at which 50% of a cold acclimated population is killed in a controlled freeze test.

The ability of a snowcover to moderate ambient temperatures for overwintering wheat plants has been acknowledged by many authors, including Vasil'yev (1956), Willis et al. (1961), Aase and Siddoway (1979), Fowler (1983) and Brun et al. (1986). The insulative effect of snow can be vary large. In 1983, Fowler reported midwinter temperature differences of 10°C at a soil depth of 5 cm, for snow-bare fallow fields compared to adjacent stubble fields covered with 10 cm of snow: -21°C for the bare fallow and -11°C for stubble. Small differences in a snowcover effect large deviations in overwinter stress. In fact, a 10°C spread in winter stress, because of minor variations in snowcover over a distance of a few meters, is greater than the entire range of potential low temperature hardiness, 7°C, of the Table 3 winter wheat gene pool.

As a snowcover deepens, its insulative value also increases, often beyond the protection necessary for the complete survival of a given variety. Fowler and Gusta, (1979) analyzed the data from 64 field trials in Saskatchewan during 1972-77 to identify the minimum FSI required for 100% survival under dry snowcovers of varying depth. Varieties with a wide range of FSI's were included in these trials (Table 3). The derived average minimum values presented in Table 4 suggest that a variety-FSI greater than 650 is required to ensure an undamaged stand on bare summerfallow; clearly few wheat varieties could survive. With 5 cm of snow, the winter hardiness requirement declines, but the risk for most varieties is still high. Under a 10 cm snowcover, varieties with FSI greater than 430 such as Winalta, Sundance, Norstar and Alabaskaja stand a good chance for complete survival.

Table 4. Minimum variety field survival indices (FSI) required for undamaged stands 9 out of 10 years in Saskatchewan (excluding the extreme southwest) (Fowler, 1978)

	FSI
Bare summerfallow	>650
5 cm snowcover	540
10 cm snowcover	430
>15 cm snowcover	<320

EXTENDING THE AREAL RANGE OF WINTER WHEAT

Prior to 1976 winter wheat production on the Canadian Prairie was restricted to southern Alberta and the extreme southwest area of Saskatchewan (Figure 2). The conventional practice involved seeding on bare summerfallowed land with no provision for retaining a protective snowcover. Consequently the areal range for growing the crop was greatly restricted because of the killing winter temperatures common to the rest of the Prairies. Similarly, because of low temperatures, winter wheat production in North Dakota historically has been limited to the southwestern part of the state (Brun et al., 1986).

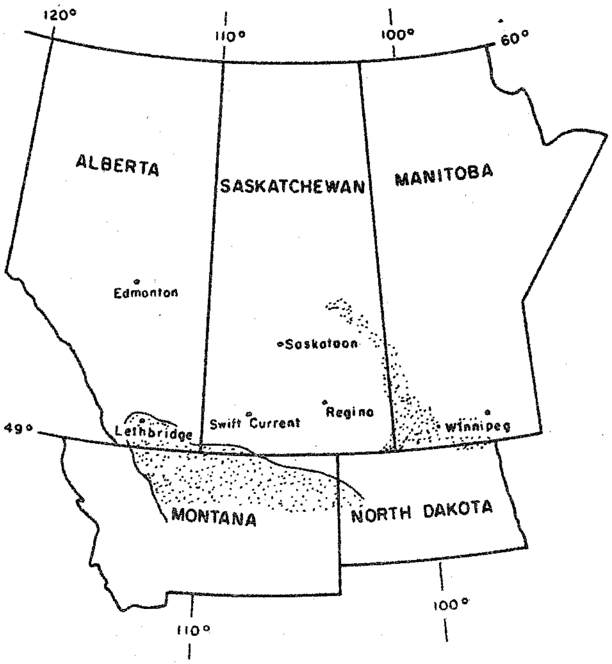

Figure 2. Canadian Prairie provinces and neighboring states showing the traditional winter wheat zone of southern Alberta and southwest Saskatchewan, and the new areas of limited production within the Black soils of Manitoba and eastern Saskatchewan.

Although a few wheat producers had long ago adapted snow management to grow winter varieties in the cold regions of the prairies, the crop did not become a recognized option until after 1975. The winter-hardy variety Norstar was first available in 1977, but equally important, the increased commodity price for wheat products gave greater production incentive. This permitted the producer to assume the greater cropping risk of annually seeding into a standing stubble. This practice forgoes the water enrichment and weed control benefits from summerfallowing, but it also provides a snow-trapping stubble 9-15 cm tall. This system has worked successfully in those regions of Western Canada and North Dakota where snowcovers tend to remain through the winter and where prairie winds are less apt to erode the protecting snowpack. The aspen parkland-prairie transitional zone of eastern Saskatchewan and southern Manitoba provide this environment (Figure 2).

Winter wheat production, especially on snow-bare summerfallow, still remains risky throughout most of the Canadian Prairie. If snowcover enhancement helped spread the crop's range into the transitional zone, perhaps other snow management techniques could advance the range even further. The difficulty rests with the need for summerfallow to control weeds, to reduce fertilizer costs, and to ensure maximum soil water reserves. In conventional practice, summerfallowing leaves no material which can stand as snow-trapping wind barriers. One option would be the seeding of a wind-breaking grass barrier system.

Tall Wheatgrass Barriers

The first North American test of a grass-barrier system to enhance grain prodution by snow management was conducted by Greb and Black (1971) at Akron, Colorado. They grew double rows of perennial sudangrass permanently spaced 11.6 to 18.3 m apart. Within this barrier system they found that: (1) snow averaged 15.2 cm deeper; (2) overwinter soil reserves gained 38 mm more water; and (3) wheat yield was 269 kg/ha greater than outside the system. In Montana, Black and Siddoway (1975) reported that a snow-control barrier system of tall wheatgrass provided similar benefits. Both locations are within traditional winter wheat production regions.

Chemical Summerfallow

Another option retains both the practice of summerfallowing and the stubble of the previous crop in a standing condition. Weed control is accomplished by the use of herbicides rather than by tillage. Consequently, winter wheat can be seeded into a standing snow-retaining stubble on land which has had the benefit of summerfallow.

Chemfallow presents the greatest advantage in those years when soil water reserves and growing season precipitation are insufficient to prevent crop water stress. Other positive factors include: greater soil surface residue to resist wind erosion; reduced water and soil lossed from runoff; reduced fuel consumption; reduced equipment costs; reduced labor costs. Negative aspects involve: chemical costs; soil salinization caused by excessive water from under utilization by crops; possible chemical hazards and negative perceptions.

WINTER WHEAT TRIALS AT SWIFT CURRENT

A tall wheatgrass barrier system was initiated in 1976 on an experimental farm near Swift Current, Saskatchewan. Centered in the semi-arid Brown Soil Zone of the Canadian Prairies, this location represents one of the more difficult regions for winter wheat survival and production (Figure 2). Grain farming is dominantely on summerfallowed land using spring-seeded cereal varieties, mostly hard red wheat. The first seeding of winter wheat within the barrier system was in the fall of 1980, and initiated the survival study reported in this paper.

Climate

The climate at Swift Current characterizes a cool continental type with wide extremes in temperature, precipitation and evaporation. Air temperatures between winter and summer typically range from -40 to 38°C. The 96-year mean annual precipitation equals 360 mm, one-third of which occurs as snowfall. The region's semi-arid character shows when the mean growing season precipitation of 158 mm is compared to the mean growing season pan evaporation of 734 mm.

Overwinter air temperatures during the winter-wheat survival trials at Swift Current always included minima well below Norstar tolerance minima. Table 5 indicates the number of days listed by month that air temperatures fell below lethal values. Winter wheat can successfully overwinter if the critical meristematic crown tissue survive. Wheat crowns are located between one and five cm below the soil surface; therefore, it is the soil temperature at this depth that determines survival. Differences between air and crown temperatures vary considerably, although at least 5°C can be expected (Shul'gin, 1957). Also, the Table 5 air temperature data also do not account for any moderation resulting from snowcovers, and serve only to indicate the typical occurence of values which can winter-kill Norstar winter wheat.

Table 5. Number of days for which the minimum daily air temperature at the Swift Current Experimental Farm was less than the minimum Norstar wheat survival temperature shown in Fig. 1.

Winter	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
1980-81	0	0	14	0	8	1
1981-82	0	0	5	28	20	11
1982-83	0	1	5	4	5	6
1983-84	1	0	17	10	1	9
1984-85	3	1	16	11	14	4

Field Trials

Winter wheat survival trials were conducted for four years during the period 1980-85. Norstar winter wheat was fall-seeded into replicate blocks (3 ha-area) within the tall wheatgrass barrier system and into replicate blocks outside the barriers. The barriers consisted of single-row, one-meter tall grass plants spaced on 15.25 m centers. The land sloped very gently and was essentially free of stones and tree-less in all directions. Winter winds were free to distribute snowcovers at will. The loess-derived soil is very uniform and is classed as an Orthic Brown Chernozemic Silty Loam of the Swinton Association (an Aridic Haploboroll by the USA classification).

Within the barriers the wheat was seeded with two different implements: by conventional hoe-drill following pretillage to prepare the seedbed, and by a no-till drill seeding directly into the standing stubble. Outside the barriers the crop was seeded either conventionally into a tilled seedbed or by drilling directly into standing stubble. The survival was compared (1) between conventional seeding within and outside the barriers, and (2) between the no-till barrier seeding and adjacent non-barrier chemical summerfallow blocks. Crops were seeded annually on all blocks except where chemically fallowed and the typical biennial cropping was followed. To control weeds all continuously-cropped blocks were summerfallowed by tillage during the 1983 growing season. Thus, four years of data are available for comparison.

Results

Previous measurements reported by Nicholaichuk et al. (1984) demonstrated conclusively that the Swift Current tall wheatgrass barrier systems resulted in deeper snowcovers than where they did not exist. Snowcover data obtained between 1981 and 1985 (Table 6) continue to support this conclusion. Snow volumes averaged approximately two-fold greater behind the barriers than outside the system in the four yearly surveys represented in Table 6. Under barrier management, average snow depths did not fall below the critical 10 cm value. However, without enhancement from the barriers, snow depths averaged below 10 cm as recorded during the 1984 and 1985 surveys. Consequently, wheat seedlings in these blocks were subjected to winter-kill. Table 6 also shows that snowcover augmented by the barriers increased overwinter soil water gains by an average 18 mm or 35%. Thus, the tall wheatgrass not only provided an extra measure of insulating snow but additional soil water as well.

Snow management to effect a greater winter wheat survival potential is demonstrated by the data in Table 7. Although survival counts were not in this study, the crop yield data led to the same conclusions. Winter wheat grain yields were about equal for the 1981 and 1982 crops. However, comparative yields in 1984 and 1985 favored the barrier wheat by 43% and 53%, respectively (Figure 3). Although the availability of more soil water within the barrier system contributed to the yield difference, visual field observations confirmed that overwinter survival was indeed greater under snow management.

Table 6. Average snow depth, snow water equivalent, and overwinter soil water change (OSWC) measured within and outside tall wheatgrass barrier systems seeded to winter wheat with hoe drill into prepared seedbed, Swift Current, Saskatchewan.

	Outside barriers			Inside barriers		
Date	snow depth (cm)	water equiv. (mm)	OSWC[+] (mm/120 cm)	snow depth (cm)	water equiv. (mm)	OSWC[+] (mm/120 cm)
Mar. 1981[‡]			27			16
Feb. 1982	24.6	74	29	42.0	116	34
Jan. 1983	11.9	21	91	15.5	28	70
Jan. 1984	9.3[#]	21[#]	32	15.6	33	-3
Feb. 1985	8.3[*]	25[*]	43	36.7	121	95

[+] Overwinter change in available soil water within the upper 120 cm

[‡] Insufficient snow for measurement

[#] From winter wheat blocks within 250 m

[*] From comparable spring wheat blocks within 20 m

Table 7. Average combined grain yields from annually-seeded winter wheat outside and within tall wheatgrass barrier systems, Swift Current, Saskatchewan.

	Grown[+] outside barriers		Grown[+] within barriers	
Year	kg/ha	(bu/ac)	kg/ha	(bu/ac)
1981	1632	(24)	1664	(25)
1982	2232	(33)	2306	(34)
1983	fallowed[‡]		fallowed[‡]	
1984	1366	(20)	1958	(29)
1985	985	(14)	1505	(22)

[+] Hoe drill seeded into prepared seedbed

[‡] Summerfallowed to control grassy weeds

Chemical summerfallow provided another snow management option to increase winter wheat survival. Although the average snowcover magnitudes as presented in Table 8 give a clear edge to the barrier systems, snow depths associated with the chem-fallow blocks still provided the low-temperature insulation required to successfully over-winter Norstar wheat. The overwinter soil water changes differed by only 5 mm between the two systems (excluding winter data following summerfallow).

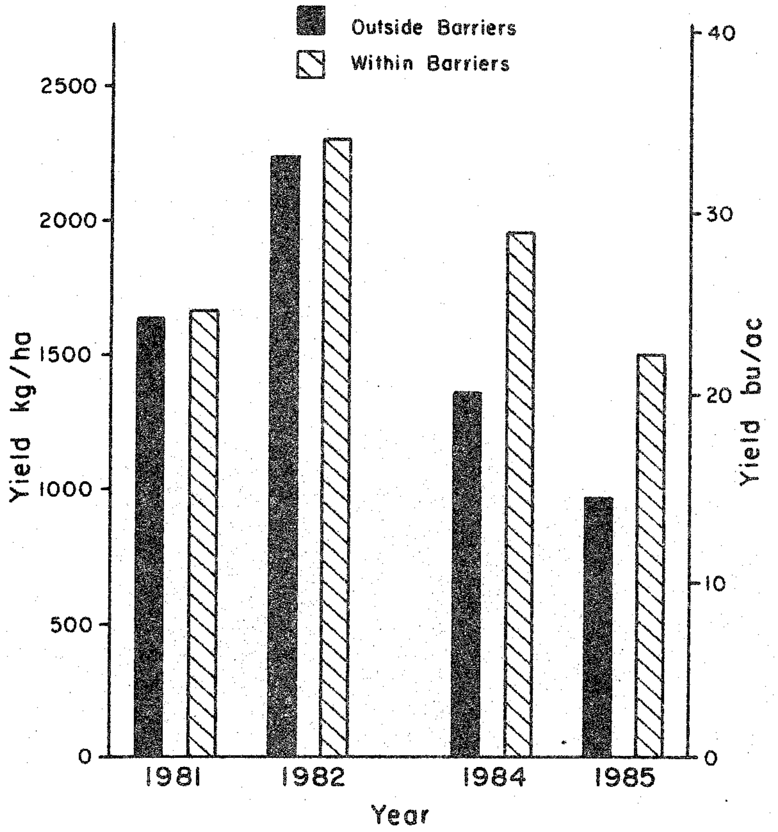

Figure 3. Average grain yields from winter wheat conventionally-seeded outside and within tall wheatgrass barrier systems, Swift Current, Saskatchewan.

Table 8. Average snow depth, snow water equivalent, and overwinter soil water change (OSWC) in winter wheat seedings, (1) within tall wheatgrass barriers, and (2) outside barriers on chemically-fallowed land, Swift Current, Sask.

	(1) No-till seeded within barriers			(2) No-till seeded into chem-fallow (1st winter)		
Date	snow depth (cm)	water equiv. (mm)	OSWC[+] (mm/120 cm)	snow[‡] depth (cm)	water[‡] equiv. (mm)	OSWC[+] (mm/120 cm)
Mar. 1981[#]			17			31
Feb. 1982	41.4	115	30	19.0	58	25
Jan. 1983	14.7	26	41	16.8	32	50
Jan. 1984	18.8	38	-8[*]	16.4	41	53
Feb. 1985	33.2	110	76	21.5	61	56

[‡] From comparable spring wheat blocks

[+] Overwinter change in available soil water within the upper 120 cm

[#] Insufficient snow for measurement

[*] First winter following a weed-controlling summerfallow

Winter wheat survival under chem-fallow proved equal to that obtained within the tall wheatgrass barrier system. Good survival is indicated in Table 9 and Figure 4 for both barrier no-till and chem-fallow. Grain yields for the latter were better in three of the four years reflecting the alternateyear cropping of the chemical summerfallow system.

Table 9. Average combined grain yields from winter wheat (1) seeded annually with a no-till drill within tall wheatgrass barriers, and (2) no-till seeded every other year outside of barriers into chemically-fallowed land, Swift Current, Saskatchewan.

Year	(1) No-till seeded within barriers		(2) No-till seeded into chemical fallow in alternating years	
	kg/ha	(bu/ac)	kg/ha	(bu/ac)
1981	1514	(22)	0	2974 (44)
1982	2484	(37)	2265 (34)	0
1983	fallowed+		0	2521 (37)
1984	1946	(29)	2352 (35)	0
1985	1210	(18)	0	1760 (26)

+ Summerfallowed to control grassy weeds.

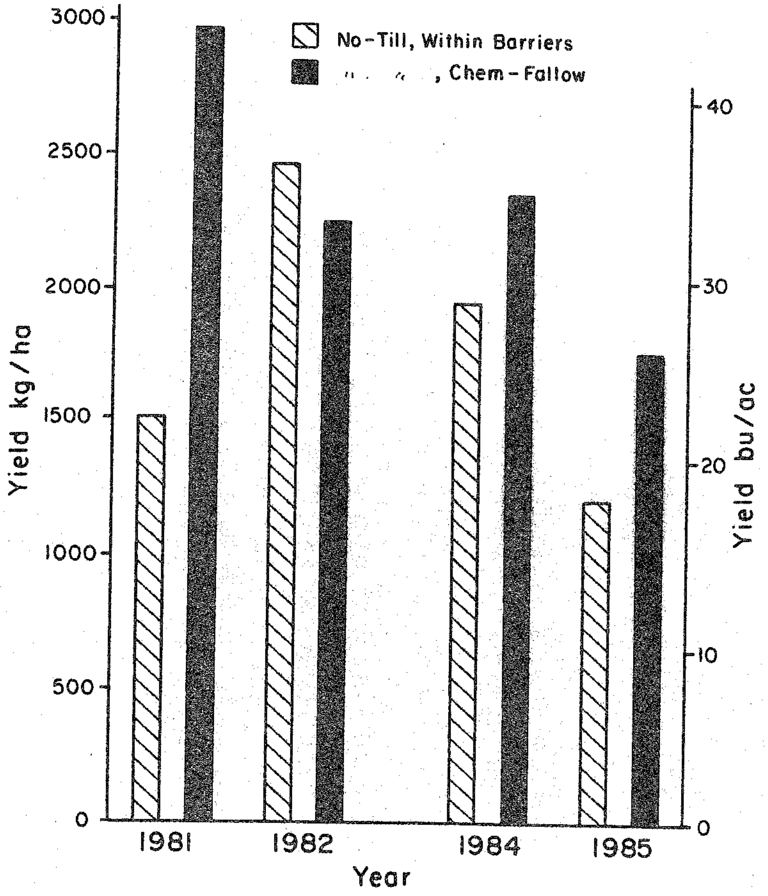

Figure 4. Average grain yields from winter wheat (1) no-till seeded annually within tall wheatgrass barrier systems, and (2) seeded every other year into chemical summerfallow , Swift Current, Saskatchewan.

CONCLUSIONS

Traditionally, winter wheat production has been difficult to sustain throughout most of the Canadian Prairies and the colder areas of North Dakota. Unfortunately, the warmer regions of the North American Plains, where wheat can successfully overwinter, are also the driest. Consequently, winter cereals have been fall-seeded on tilled summerfallowed land void of standing stubble. This has limited the areal range of winter wheat production, because these fields tend to lose protective snowcovers, restricting the crop to the warmer climates.

However, other options for extending the crop's range are being developed. Previous tests in western Canada and eastern North Dakota have demonstrated that seeding winter-hardy wheats into standing crop stubble 15 cm or more tall results in good economic winter survival, provided a continuous snowcover can be maintained. Even where snowcovers tend to appear and disappear throughout the winter, snow management for crop survival has good potential. The tests reported in this paper for Swift Current, near the center of this difficult area, indicate considerable advantage in managing snowcovers to effect better winter wheat survival.

Two snow management techniques were tested: tall wheatgrass snow-control barriers and chemical summerfallow. The snowcovers enhanced by wheatgrass barriers were sufficiently deep and persistent to ensure good wheat survival during every year of the five-year test. Grain yields indicated that chem-fallow performed equally well. However, grain yields from test blocks of annually-seeded winter wheat without extra snow management were depressed due to poor winter survival in half of the test years.

Based on this study, snow management appears to offer the opportunity of extending winter wheat production into regions previously considered too cold. The benefits resulting from such an extension include: an additional cash-crop option; the possibility of seeding less winter-hardy but more productive wheat varieties; possible reduction in summerfallow; a more even distribution of farm work during the year; increased protection against soil erosion; and the availability of another agronomic measure to control soil salinization.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the contributions to this paper by staff members of the Swift Current Agriculture Canada Research Station. Sincere appreciation is especially extended to Mr. C.D. Reimer for snow surveying and data handling and to Mr. P. Ludwig for data analysis, graphs, and manuscript typing, and to Mr. R.M. Bunnell for graph construction and Mr. T.G. Evjen for photography.

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