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"BEST PAPER"

AT THE WESTERN SNOW CONFERENCE

CAN LIVESTOCK PRODUCERS MANAGE SNOW TO GROW MORE ALFALFA IN DRYLAND WATERSHEDS?

by

H. Steppuhn and K.G. Wall[1]

ABSTRACT

Double rows of tall wheatgrass (Thinopyrum ponticum), spaced on 15.2-m centers, have been recommended as vegetative windbreaks designed to enhance snowcovers and moderate growing-season evapotranspiration on the northern Great Plains and the Canadian Prairies. Such a windbreak system along with an adjacent open area on non-irrigated land near Swift Current, Saskatchewan, was seeded to three alfalfa varieties (Rangelander, Beaver and Angus) in 1986. Snowcover water equivalents, spring soil water contents, alfalfa water consumption, and forage production in all three varieties, observed over seven years, were significantly greater in the windbreak shelter than in the open field. The over-winter recharge of water in the upper 120 cm of soil averaged 22 mm (78%) greater behind the windbreaks than in the open. This extra water contributed to a 40% increase in mean annual forage yield from 1610 to 2250 kg ha^{-1}.

INTRODUCTION

Trees and shrubs, in single or multiple rows, commonly shelter agricultural crops in wind-swept watersheds on the northern Great Plains and the Canadian Prairies. Land managers use these shelterbelts to direct snowcover accumulation and to control a measure of their hydrologic resources. Black and Siddoway (1971) suggested that rows of tall wheatgrass (Thinopyrum ponticum (Podp.) Barkworth & D.R. Dewey, previously Agropyron elongatum (Host) Beauv.) offered an alternative to tree and shrub windbreaks.

Tall wheatgrass, a perennial bunchgrass, typically develops seed culms averaging a meter or more in height when placed in double-row wind-barriers spaced on 15.2 m centers across fields producing dryland crops. Research has shown that this grass shelterbelt system reduces ground windspeeds (Aase and Siddoway 1974), controls soil erosion (Aase et al. 1976), deepens snowcovers (Black and Siddoway 1975; Nicholaichuk 1981), extends the geographic range of overwintering crops (Steppuhn and Nicholaichuk 1986), conserves water (Aase and Siddoway 1976), increases or stabilizes grain production (Black and Siddoway 1976; McConkey et al. 1990), and minimizes the need for summerfallow (Black and Aase 1986).

The soil water enrichments resulting from windbreaks are attributed to greater snow catch in the shelter than in the open field and to reductions in evapotranspiration of the wind-sheltered crop (Siddoway 1970). Although windbreaks accumulate more snow, the proportion of their snowmelt water which enriches soil water reserves is less than in the open field because a larger fraction of water is lost to sublimation, evaporation, runoff, and deep percolation (Black and Siddoway 1971; Nicholaichuk et al. 1984).

The merits of windbreaks have typically been evaluated for increased production of dryland grain crops (Pelton 1967; Black and Siddoway 1976). Windbreaks can also benefit

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[1] Research Scientist and Plant Ecologist, Semiarid Prairie Agricultural Research Centre, Agriculture & Agri-Food Canada, P.O. Box 1030, Swift Current, Saskatchewan S9H 3X2. Voice: (306)778-7243, Fax: (306)773-9123, EMail: steppuhn@em.agr.ca

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forage production. Ries and Power (1981) report increases in soil water of 2.4 mm for each cm increase in stubble height of perennial grasses left over winter. Each 10 mm addition to the soil water increased dry-matter yield by 115 and 62 kg ha^{-1} for introduced and native forages, respectively. Haas and Willis (1971) constructed 9-m wide level benches and seeded the dikes with bromegrass (Bromus inermis Leyss.) to trap snow and retain meltwater. This increased alfalfa (Medicago sativa L.) production by 100% or more compared to that obtained outside the system without irrigation.

Alfalfa, a preferred feed for dairy cows and other livestock, can extract large volumes of water from deep root zones (Brun and Worcester 1975; Halvorson and Reule 1980). Alfalfa typically withdraws water from soil layers down to 3 m or deeper, and offers growers an option for drying the soil and controlling salinity while producing an economically viable crop (Wentz 1992).

The objective of this paper is to compare snowcover accumulation, water conservation, and alfalfa hay production between a tall wheatgrass windbreak system and an open field. Dairy producers are especially dependant on high-quality alfalfa hay for good milk production. Irrigated alfalfa has become the preferred roughage to feed milk cows and other livestock in western North America. Unfortunately, water for irrigation is not always available, resulting in regional shortages of hay. Can snow management with tall wheatgrass windbreaks enhance dryland alfalfa hay production?

STUDY-WINDBREAK SYSTEM

A windbreak shelter located 3 km southeast of Swift Current, Saskatchewan, was selected for this study, and has been described by Steppuhn et al. (1987). The continental climate of the site is typically semiarid. Annual precipitation averages 359 mm, with up to one-third falling as snow. The mean growing season (May, June, July, August) precipitation and Class A pan evaporation equal 210 and 883 mm, respectively. Prevailing winds blow from the west (22% of the time). Air temperatures can range from-40 to +40 C.

The study system consists of unharvested, double-row, tall wheatgrass (var. Orbit), seeded into rows 61 cm apart during 1975. By 1984, they formed double-row wind barriers averaging 1.2 m tall, 1.2 m wide, and spaced on 15.2 m centers across a 3.3 ha square area. Eleven windbreaks, oriented north-south, divide the area into ten crop production strips each 14.0 m wide and 183 m long. An adjacent 3.3-ha area starting 20 m to the south remained without windbreaks and was designated as an open-field control for comparisons. Both areas form part of an extensive plain which slopes an average 0.6% to the south. The soil of the plain is mapped as a Swinton silt loam (Ayres et al. 1985) and is classified an Orthic Brown Chernozem, an Aridic Haploboroll by the U.S. system (Canada Subcommittee on Soil Classification 1978). The topsoil developed from a loess veneer (approximately 55 cm thick) overlying mainly loam-textured glacial till (Ayres et al. 1985). Bulk densities measured across the site ranged from 1.35 to 1.5 Mg m^{-3} in the A horizon (8 to 20 cm thick), 1.5 to 1.6 in the B, and increased with depth from 1.6 to 2.0 in the C. Generally, equal wind fetch and the same aerodynamic roughnesses characterize the two areas. From 1979 through 1985, both areas were part of an experiment to measure the effects of tall wheatgrass windbreaks on wheat (Triticum aestivum L.) grain production (Steppuhn and Nicholaichuk 1986; McConkey et al. 1990).

STUDY METHODS

At the start of the experiment, the outer crop production strips on the east and the west sides of the system were paired; each strip is sheltered by a windbreak which fronts an open area on one side and tends to accumulate more blowing snow than the inner strips. Each of the eight remaining strips was also paired with an adjacent strip forming a total of five pairs (replications). The control area without windbreaks was similarly divided into production pairs of 15.2 by 183 m strips.

In May 1986, the strips in both areas were divided crosswise into three plots each. The center plot was 45.7 m long; the outer two were 68.6 m long, to allow for potential edge effects caused by winds from directions trending parallel to the windbreaks. In each strip, three alfalfa varieties were seeded, one per plot, at random, in north-south rows spaced 61 cm apart (23 rows/strip): var. Rangelander (creeping root pattern), Beaver (branched taproot), and Angus (taproot). The area without windbreaks was divided and seeded the same way on the same day adding extra rows of alfalfa to occupy the spaces equivalent to the wheatgrass in the sheltered area.

Snowcover and soil water measurements began in 1986, the establishment year, and the first hay was harvested in 1987. In July 1991, parts of the windbreaks were badly trampled while collecting and baling the hay after a severe windstorm scattered it. To recover their uniformity, the windbreaks were cut at ground level in October 1991 and allowed to regrow.

The quantity of snow retained on each plot was surveyed at least once a year except in 1987 when snowcovers were never sufficient to measure. Each survey included from 10 to 30 observations of snowcover depth and 3 to 5 measurements of the specific gravity from vertical snow cores taken in each plot. After each survey, we used the observations to calculate the mean snowcover water equivalent for each plot according to the method described by Steppuhn (1976) where sample size and spacing are dictated by estimates of variability.

Each year from 1987 through 1993, alfalfa forage in one-meter lengths sampled from each of the third rows from the west and east sides and from the center row of each plot were cut at a 5-cm stubble height, oven-dried at 50 C, and weighed. Once sampled, all the hay on each plot was harvested with a mower-conditioner, field-dried, and baled. In 1989, the total hay-cut provided the basis for estimating forage yields in the open-field plots.

We extracted a soil core 25 mm in diameter at each forage sampling point in April after over-winter recharge, in July after the main hay cut, in September of 1987, 1991 and 1993 after a second hay cut, and in the fall of each year. Soil water contents were determined from each core for the 0-15, 15-30, 30-60, 60-90 and 90-120 cm depth layers. We removed a minimum of 3 cores per plot (except for single cores in April 1986) from each plot during sampling. On October 5, 1987, the soil at the center of each plot was cored with a truck-mounted, 47 mm diameter, hydraulic sampler (Giddings Machine Co.) to a 61-cm depth, and weighed to determine bulk density with depth. These and previous density determinations in the plots were subsequently used to calculate the volumetric water contents of all the gravimetric soil water samples.

In 1988, neutron access tubes were installed at the center of each plot to a depth of 3 m. Thereafter, we measured additional soil water volumes at 10-cm increments to 2.75 m by neutron backscatter at about the same time as the gravimetric samples were obtained. A climate station, operated by the Canadian government, was located within 600 m of all plots. Precipitation caught in standard Canadian gages was measured twice daily, and summed to determine periodic totals during the experiment.

The data were subjected to analysis of variance (SAS Institute 1990) using a model with 3 alfalfa variety plots within each of 5 replicates located in the open field and in the grass windbreak system (3 replicates for the second hay cut in 1993. Significance was interpreted at the 0.05 probability.

RESULTS

Snowcover Water Equivalent

The snowcover water equivalents that accumulated on the plots proved to be highly variable (Figure 1). Although mean error was high (up to 1/3 of the treatment mean), statistically, the wind-sheltered plots retained more snow than the open-field plots in all surveys except in March 1990, January 1992 and March 1993. The 1992 and 1993 exceptions likely relate to the Fall 1991 mowing of the grass windbreaks. In 1990, two snow surveys were conducted. The April survey reflected the snowcover retained from one storm which deposited more snow than all that had accumulated up to the March measurement. Alfalfa variety had no significant impact on snowcover retention at the times measured.

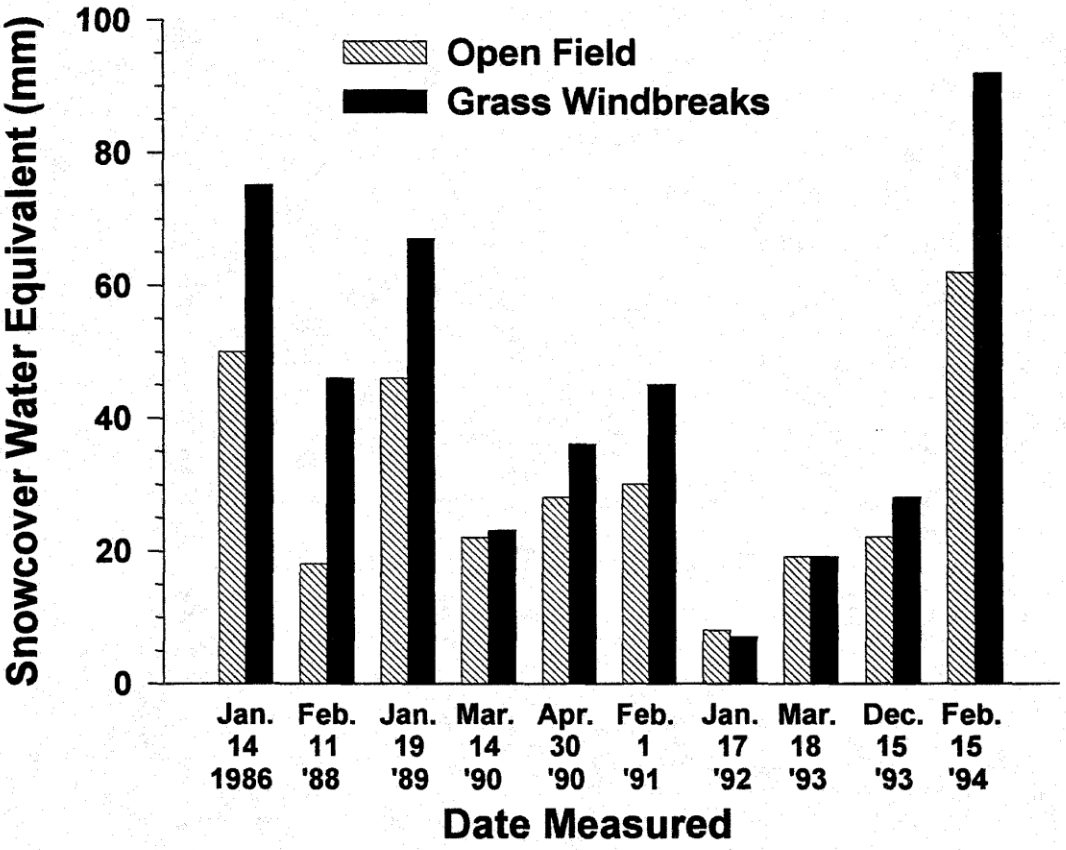

Figure 1. Mean snowcover water equivalents in open-field and grass-windbreak plots on the date surveyed; snowcover was insufficient for any measurement during 1987.

Soil Water

The mean soil water content from the surface to the 1.2-m depth during the course of the experiment ranged within 125-270 mm and tended to cycle yearly (Figure 2). Water reserves in the windbreak plots varied more than those in the open field, gaining over winter and losing during the growing season. The windbreak plots also contained significantly more soil water than the open-field plots every year in April but only in 2 years out of 7 in July and 3 years out of 8 in the fall (Table 1). Significant

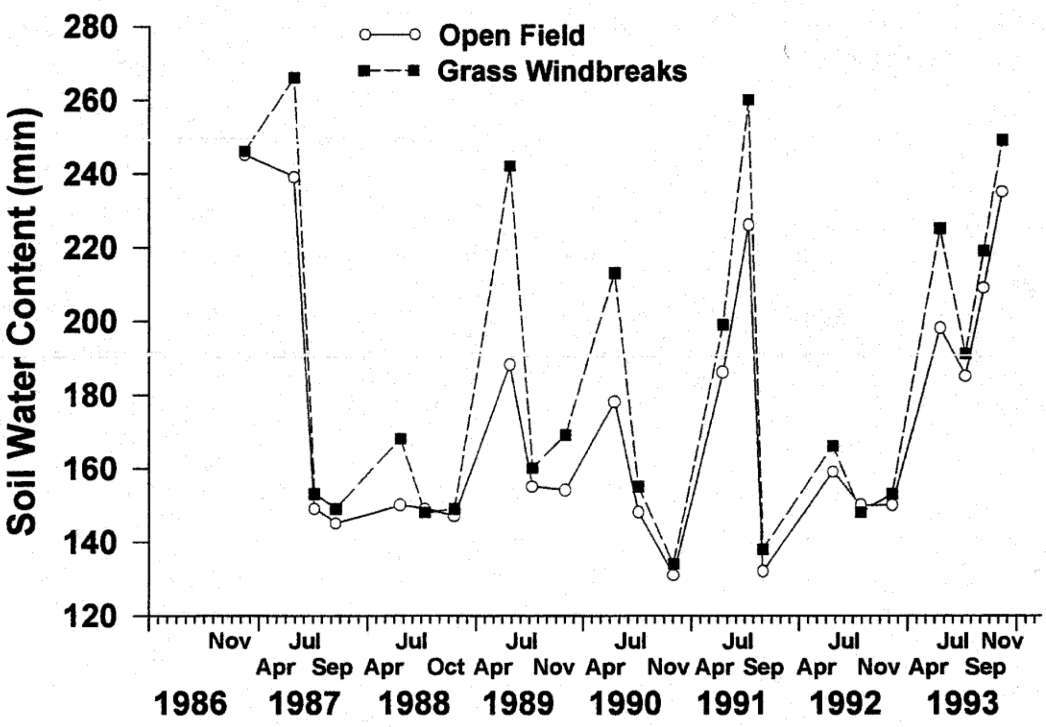

Figure 2. Mean water content in the top 1.2 m of soil sampled gravimetrically in April, July and the fall during 1986-1993 in open-field and grass-windbreak plots.

Table 1. Significance of changes in mean water content (Figure 2) in the top 1.2 m of soil sampled gravimetrically for alfalfa varieties in open-field and grass-windbreak locations. (ns = not significant)

Year	Month	Treatment significance*		Year	Month	Treatment significance*	
		Location	Variety			Location	Variety
1986	April	0.012	ns	1990	April	0.001	ns
	November	ns	ns		July	0.038	ns
					November	ns	ns
1987	April	0.001	0.009				
	July	ns	ns	1991	April	0.014	ns
	September	ns	ns		July	0.001	ns
					September	0.047	ns
1988	April	0.001	ns				
	July	ns	0.024	1992	April	0.021	ns
	October	ns	ns		July	ns	ns
					November	ns	ns
1989	April	0.001	ns				
	July	ns	ns	1993	April	0.003	ns
	November	0.001	ns		July	ns	ns
					September	0.046	ns
					November	0.025	ns

* Statistical probability for significant differences from
Location: open field or within grass windbreak system
Alfalfa variety: Angus, Beaver or Rangelander

differences in July and the fall occurred only after considerable growing-season rain fell, as in 1989. The alfalfa varieties significantly influenced upper water content in only 2 measurements out of 24.

The typical seasonal fluctuations in soil water content between November and the following July are exemplified by the 0-2.7 m depth profiles obtained from the 1989-90 neutron backscatter data (Figure 3). Although soil water reserves were enriched over-winter in the open-field plots as well as in the windbreak system, accumulations in the wind-sheltered plots were greater within the upper 1.7 m and, perhaps in lesser amounts, in the 2.1-2.7 m depth layers. During the April-July growing season, these soil water enrichments were reduced to levels near those of the previous November. This 1989-90 pattern of over-winter soil water recharge and growing-season withdrawal also occurred in the neutron data of 1988-89 and 1992-93, and in all upper soil water data except in 1991-92 just after the tall wheatgrass had been mowed.

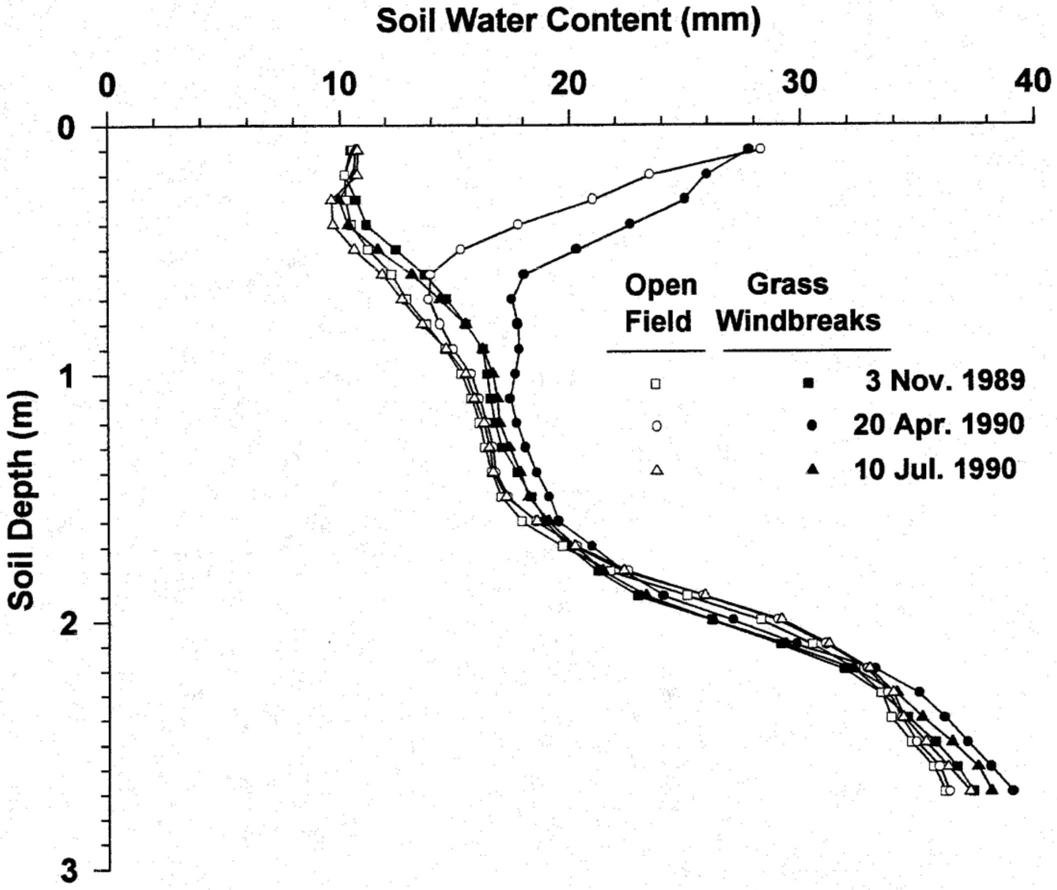

Figure 3. Mean water content by soil depth determined from neutron backscatter for open-field and grass-windbreak plots in November 1989, April 1990 and July 1990.

Precipitation during the 1987-1993 growing seasons also contributed to soil water volumes (Figure 4). The November-to-November precipitation in 1989, 1991 and 1993 exceeded that falling in any of the other years by more than 100 mm. The growing season precipitation (April-November) for 1986, the alfalfa establishment period, equalled 337 mm. In 1991, that fraction of the April-July rainfall which infiltrated the upper soil zone exceeded withdrawals resulting in a net gain in upper soil water reserves during that period in all plots (Figure 2). In 1993, the bulk of the rain occurred between July and September so that net increases in soil water shifted to this later period within the growing season. Whenever soil water content increased between July and the fall, a trend emerged for the upper soil zone to gain more water in the windbreak plots than in the open-field plots.

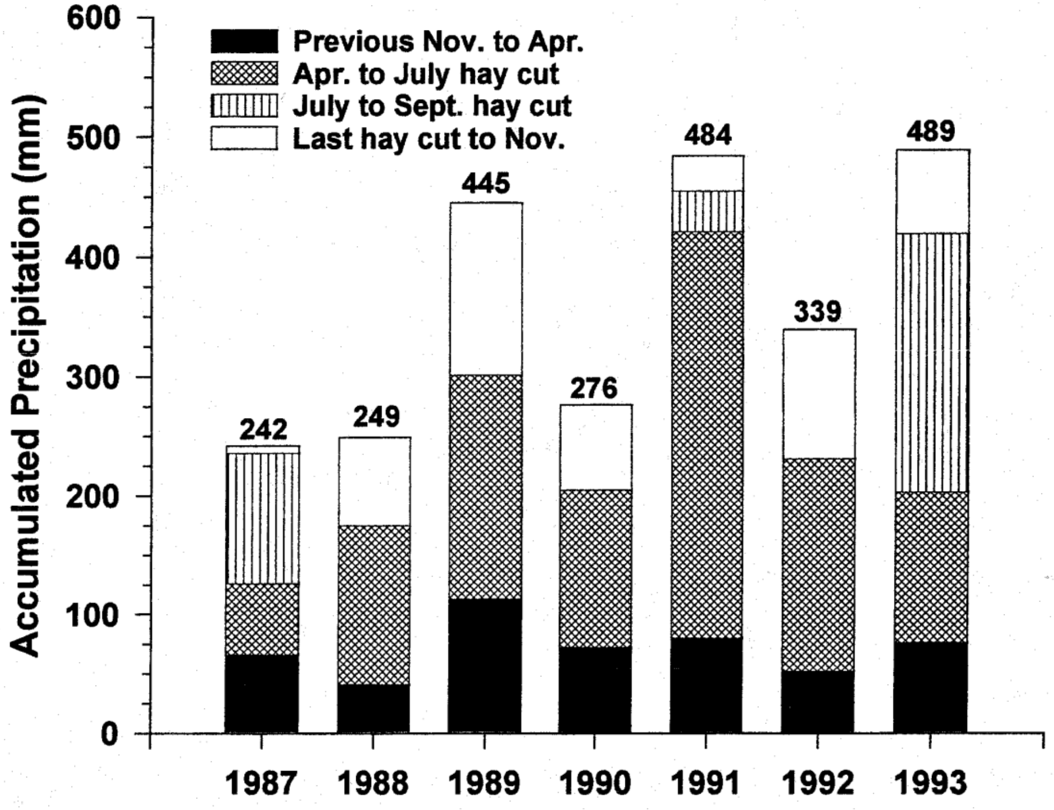

Figure 4. Precipitation recorded at the Canadian Atmospheric Environment Service Climate Station (within 600 m of the plots) and accumulated for periods defined by the soil water sampling dates.

The soil water status resulting from the increased rainfall during the latter years of the experiment shows in the fall neutron data for 1991-93 (Figure 5). The shape of the 1991 fall profiles had not changed from those determined by the fall measurements in 1988, 1989 and 1990, except for a slightly wetter trend above 2 m and a drying trend below. The 1992 profiles below 0.5 m contained the same or less water at all depths than those in Fall 1991, reflecting the drier year and the mowed windbreaks. The differences in the 1992 soil water content between the open field and windbreak plots were not significant at any depth except those below 2.2 m. In 1993, the growing season rainfall reversed the drying trend and resulted in wetter profiles than in 1992. The bulk of this enrichment occurred in the upper meter of soil where the windbreak plots contained significantly more soil water than those in the open field (Table 1). Between 1.5 and 2.4 m, enrichment favored the open field.

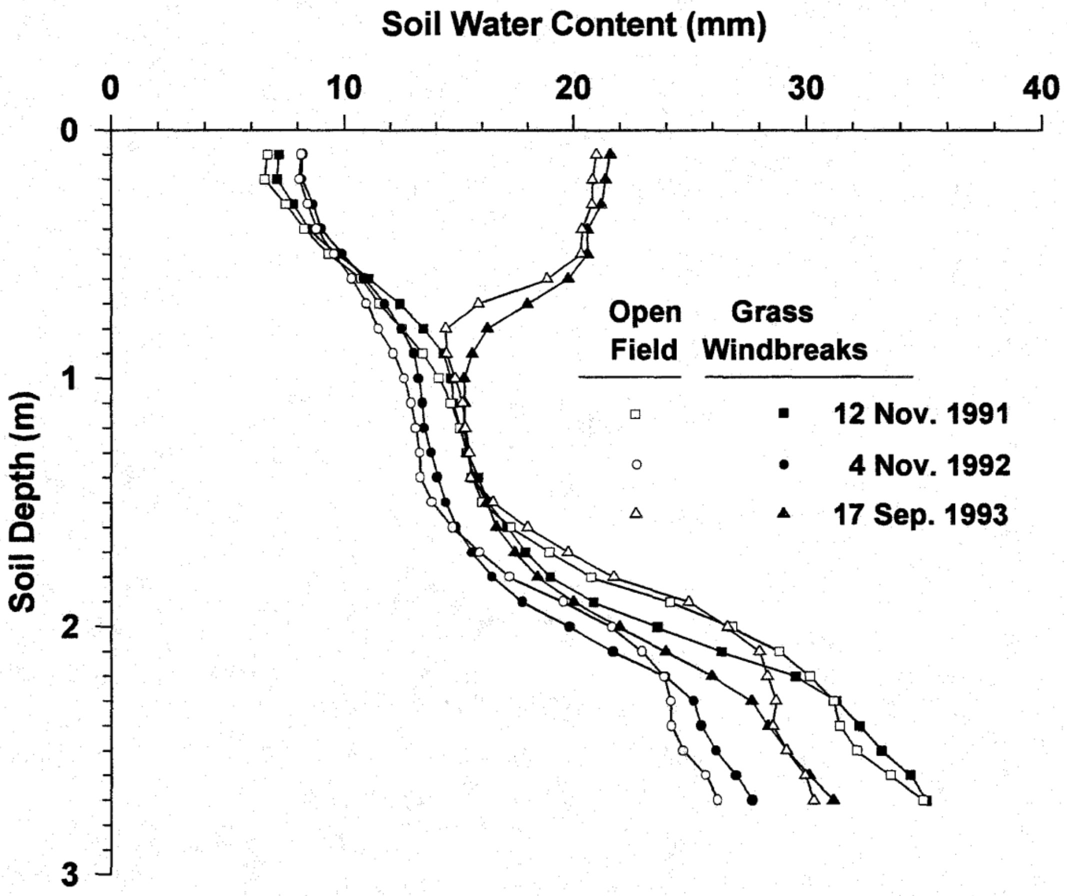

Figure 5. Mean water content by soil depth determined from neutron backscatter for open-field and grass-windbreak plots in November 1991, November 1992 and September 1993.

Forage Yields

The alfalfa produced sufficient forage in all plots for a July hay cut every year and a second cut in September of 1987, 1991 and 1993 (Figure 6). Total forage production summed over 7 years within the windbreaks (not adjusted for the 8% area occupied by the wheatgrass) was 10% greater from Beaver (16,515 kg ha^{-1}) than from Angus (14,967 kg ha^{-1}). Rangelander produced a total of 15,905 kg ha^{-1}; the windbreak shelter generated significantly greater yields than those obtained in the open field in every cut except in July 1992 and September 1993, which resulted in an average yearly increase of 40%, from 1610 to 2250 kg ha^{-1}, over the 7 production years. This average included 1992 and 1993 data following mowing of the windbreaks, and reduced to 32% when the area occupied by the windbreaks was subtracted.

Table 2. Average net water differences in the upper 1.2 m of the soil, the grass windbreak values minus those of the open field during specific periods of the year.

Year	Over-winter Prev.Nov-Apr	Spring Apr-Jul	Summer & Fall Jul-Nov	Water Year Prev.Nov-Oct
	- - - - - - - - - - - - -	- - - mm	- - - - - - - - - -	- - - - - - -
1987	25	-23	0	2
1988	14	-14	-2	-2
1989	52	-48	9	13
1990	20	-28	-3	-11
1991	9	21	-28	2
1992	3	-10	5	-2
1993	25	-22	5	8
sum	148	-124	-14	10

Alfalfa is capable of transpiring large volumes of water (Halvorson and Reule 1980) and, in most years, tended to withdraw all the readily available upper water in each plot regardless of treatment. Thus, after the alfalfa became established, all plots tended to approach winter with similar upper soil water reserves. The water in the lower root zone (below 1.2 m) served as a reserve supply for the plants, and tended to be utilized during the "dry" years and replenished during "wet" years.

The benefits of windbreaks have usually been considered to include reductions in evapotranspiration resulting from wind abatement. Support for this thesis from this study is the observation that recharge of the upper soil water from summer rainfall tended to be greater within the windbreak system. Maybe the windbreaks retarded soil drying as suggested by Aase and Siddoway (1976).

The grass windbreak system in our study is limited in size (3.3 ha). If our system, because of its size and upwind fetch, allowed extra measures of snow to accumulate in it, a larger windbreak system may not be as beneficial. Another caution associated with extrapolating our results pertains to the width of the grass rows. The current recommendation for establishing tall wheatgrass windbreaks is to seed double rows 15 cm apart, reducing the tall wheatgrass area to 3%. If this spacing causes windbreak porosity to become too sparse, new windbreaks may prove less effective than those with the 61-cm spacing of the system reported here.

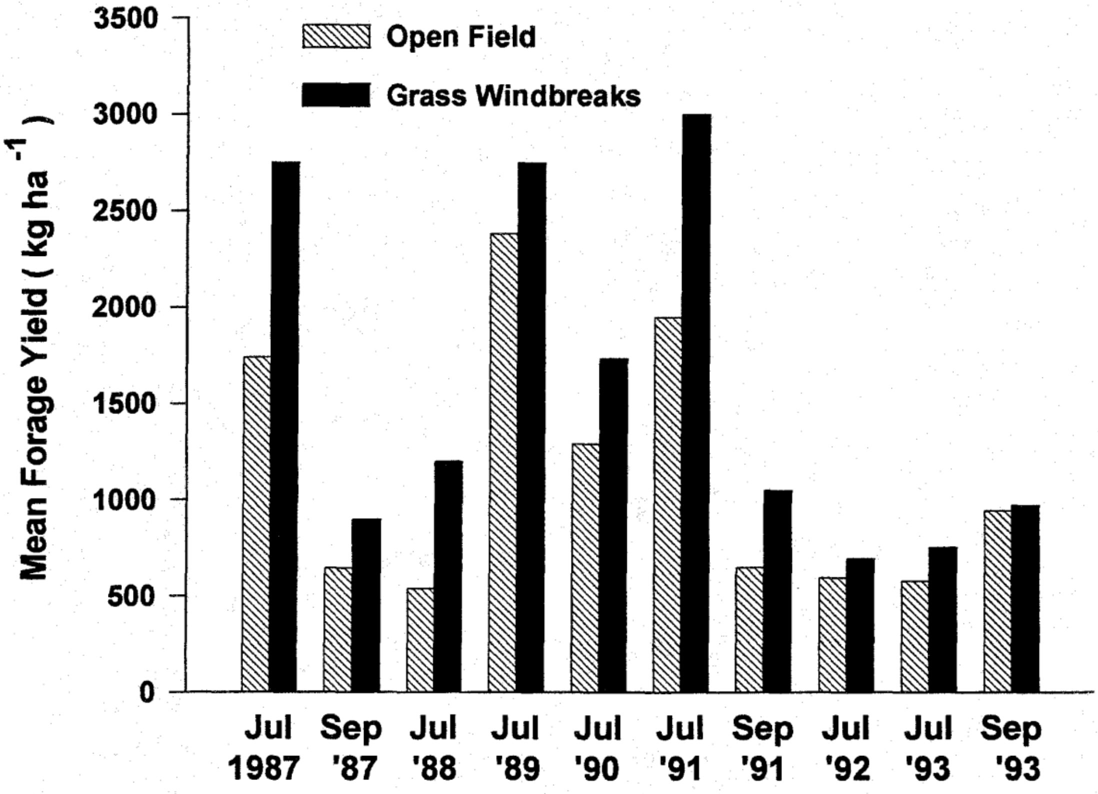

Figure 6. Mean alfalfa forage yields in open-field and grass-windbreak plots during 1987-1993; values were not adjusted for the area occupied by the windbreaks.

DISCUSSIONS

The soil in areas protected by the tall wheatgrass windbreaks received and retained more over-winter water recharge, and released more of this water during the growing season than the soil in the open areas. The result, on average, was 78% (22 mm per year) more water in the upper 1.2 m of soil within the windbreaks than in the open field at the start of each growing season. These differences contributed to the 40% greater forage yields produced behind the windbreaks than in the open (32% if windbreak area is subtracted). The wetter rooting environment allowed the alfalfa plants within the windbreak system to withdraw more soil water than the amounts withdrawn by the open-field plants.

The data presented in Figure 2 show that the top 1.2 m of soil contained, on average, approximately the same volume of water at the end of 7 years (November 1993) as at the beginning (November 1986). This implies that soil water reserves in the upper 1.2 m within alfalfa fields in semiarid climates will at sometime be recharged whether the field is or is not sheltered by grass windbreaks. The concept of an upper (0-1.2 m) soil water balance can be extended to the seasonal periods throughout the year (Table 2). The net change in water retained in the upper 1.2 m of the soil behind the windbreaks relative to those in the open field (windbreak minus open) during winter, spring, summer and fall of any water year (Nov.-to-Nov.) averaged 13 mm or less. This indicates that the extra soil water conserved by the windbreak system was consistently utilized by the alfalfa. The net gain over 7 years was only +10 mm.

CONCLUSIONS

- Tall wheatgrass windbreaks conserved 78% more water in the upper 1.2 m of soil than in the open field.
- The bulk of this water accumulated over winter and early spring (November to April), i.e., the yearly recharge.
- Alfalfa drew from this extra water every growing season to produce a more reliable hay supply averaging one-third more within the windbreaks than in the open field.
- In time, the soil water below 1.2 m was used by the alfalfa in dry years and partially replenished during wet years.

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