SNOW MANAGEMENT FOR CROP PRODUCTION ON THE CANADIAN PRAIRIES [1]

668-80

by

H. Steppuhn [2]

Introduction

Snow management is the art and science of utilizing or manipulating the snow resource for human benefits. On the Canadian Prairies, as indeed over the entire northern Great Plains, efforts to control snow are directed primarily toward (1) keeping snowdrifts from obstructing roads, highways and raillines, (2) preventing damage from floods caused by melting snow, (3) accumulating clean snow in winter recreational areas, (4) trapping drifting snow in shelterbelts surrounding farm buildings, livestock, equipment, and homes, (5) collecting snow to provide sweet water for gardens, livestock, waterfowl and domestic uses, and (6) retaining an augmented layer of snow over dryland field crops for winter protection and soil water enrichment. This paper pertains to the latter objective and relates snow management to soil water requirements and overwinter survival of crops in a cold, semiarid environment.

The Canadian Prairies include a loosely defined area approaching 700,000 km^2 (275,000 sq. miles). The region forms part of the North American Great Plains which originally supported vegetation associations ranging from short grass prairie to aspen-midgrass parkland (Figure 1). Over 60% of the area has been cleared or "broken" and converted to the production of cereals, oilseeds, and forages.

The climate is distinctly seasonal consisting of cold winters and warm summers. Mean annual precipitation increases from 300-350 mm in the central southwest near Lethbridge and Bad Lake (Figure 1) to over 500 mm at the region's eastern, northern and northwestern extremities. Approximately half of the yearly precipitation occurs during the growing season (Table 1). Unfortunately, a large fraction of this water falls in showers measuring 6.4 mm (0.25 inch) or less; 75% of the summer rain falling at Swift Current, Saskatchewan occurs in such limited showers (Pelton, 1967). These waters generally fail to reach the soil root zone before being evaporated. Estimated potential evapotranspiration over the Canadian Prairies ranges from 500 to 900 mm annually and gives the region its semiarid character.

Average accumulated snowfall over the region varies generally from 1/5 to 1/3 of the annual precipitation. At any location, however, a wide yearly spread exists; the range of 14 to 40% tabulated in Table 1 for Bad Lake, Saskatchewan, is indicative. Collectively, the snow resources of the Prairies are significant. The eleven-year (1968-78) mean annual snowfall water equivalent of 101 mm measured at Bad Lake represents a conservative estimate of the Prairie average. Yet, when multiplied by the total area included in the region, the snow water would occupy a volume measuring 70 billion m^3, an amount equalling 1/4 to 1/2 of the total annual flow entering the St. Lawrence River from the Great Lakes (Water Survey of Canada, 1974).

Snowcover permanency over the Prairies was described by McKay (1964) and is depicted in Figure 1. Snowcovers over the central southwestern zone frequently disappear and reform in response to varying weather and chinook winds. East, north and northwestward of this zone snowcovers disappear less frequently until at the region's extremities they tend to persist throughout the winter.

Snow, a Water Source for Dryland Crops

Greb (1975) listed eight studies in which the recharge of soil water by melted snow

---

[1] Presented at the 48th Annual Meeting, Western Snow Conference, Laramie, Wyoming, 15-17 April 1980.

[2] Division of Hydrology & Agricultural Engineering Department, University of Saskatchewan, Saskatoon, Saskatchewan S7N OWO.

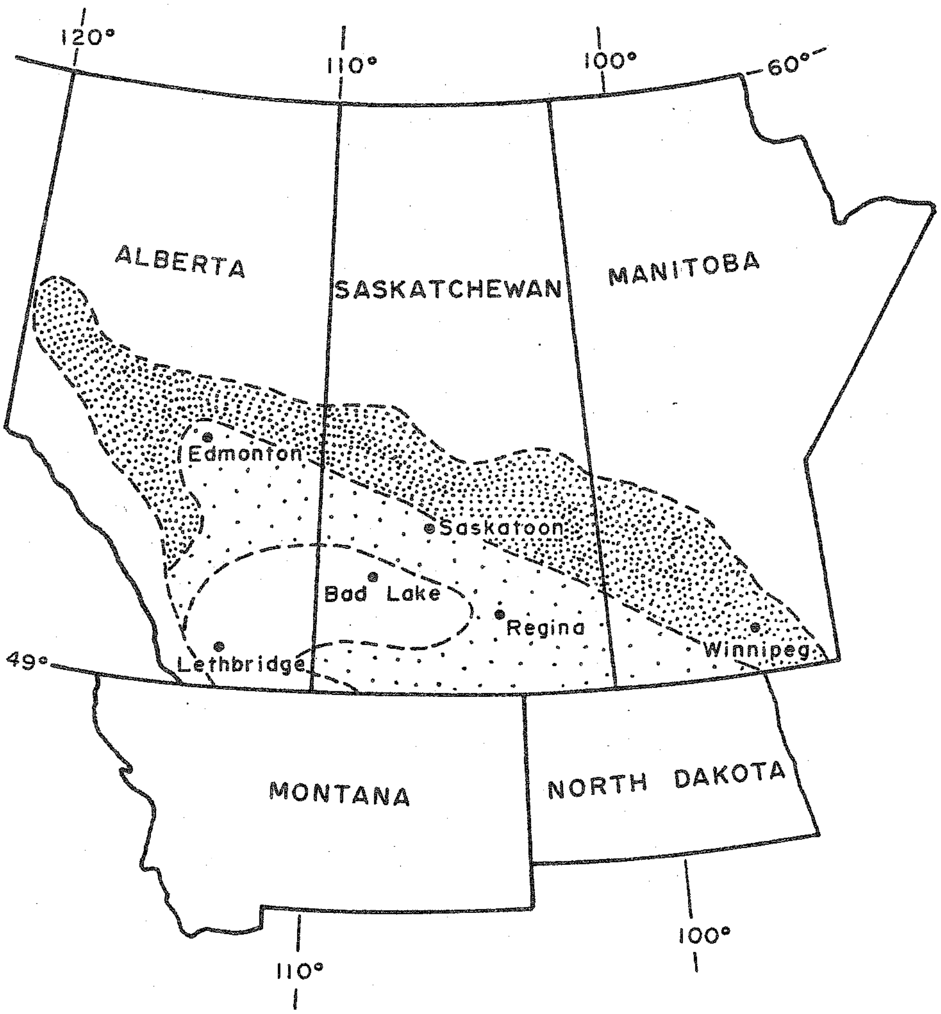

Figure 1. The Canadian Prairie Region; degree of shading indicates snowcover permanency during winter, ranging from a zone where frequently lost (white) to a zone where covers remain throughout the winter (dark).

was considered highly significant to the water economy of dryland crops. Staple and Lehane (1952, 1954) presented 12 years of field data relating available water with spring-seeded wheat yields on seven farms in southwestern Saskatchewan. Bare survival of the plants required 125-150 mm of water either from growing-season rainfall (measured by rain gauge) or from stored soil water (mass differences between soil cores obtained at harvest and seeding times). With the availability of additional waters up to a total of 262 mm, grain yield increased slowly to 942 kg/ha (1 bushel wheat/acre = 67.3 kg/ha), while each subsequent mm increment of water (until some maximum near (412mm) yielded from 9.2 to 16 kg of additional grain per hectare. Comparison of these water requirements with the average growing season rainfall of 149 mm typical of this district quickly reveals the need for ample soil water to realize an economic spring wheat crop. Recognizing that spring-seeded crops dominate on the Prairies, the Saskatchewan Advisory Council on Soils and Agronomy (1978) recommended a root-zone water reserve of 100 to 125 mm at seeding time to achieve satisfactory yields from spring-sown cereals.

One of the aims of dryland agronomy is to effect maximum crop yield at the lowest possible per unit cost by optimizing productional inputs of land use, soil management, pest control, machinery utilization, market assessment, etc. The manipulation of snowcovers to direct and accumulate water in desired field locations offers agronomy a direct water management opportunity, short of irrigation. The widespread practice of summerfallowing as part of dryland cropping rotations attests to its economic success but requires sizable inputs of land, machinery, fuel and labor to effect water conservation. Measurements taken in the spring have shown that some 45 mm more water are available in fallowed southwestern Saskatchewan soils compared to soils in cropped fields (1971-77 data summarized by the Agrometeorology Research and Service Section, Agriculture Canada, Ottawa). If snow management can increase over-winter soil water enrichments in an amount approaching 45 mm (approximately 15 cm of snow), the need for summerfallowing diminishes and more land becomes available for production. An increase in the soil water status also allows (1) the growth of more water-demanding crops, (2) an increase in the grazing capacity of pastures and rangelands, (3) a more effective utilization of applied fertilizers, (4) the inclusion of legume or green-manure crops in yearly rotations to reduce costly fertilizer needs, and (5) the harvesting of grain and oil-seed straw for paper or alcohol production which otherwise must be left to protect fallowed soils against wind erosion.

Snow management to augment soil water involves the dual objectives of trapping the snow where it is needed and holding the melted snow water until the soil thaws sufficiently to permit infiltration (Willis, 1979). In general, the first objective becomes more important and the second less critical in dryer climates, and vice versa.

Management to trap snow over cultivated fields and pastures basically involves regulation of the wind. The forces which keep a particle of snow air-borne result from the wind's turbulent character. Within any horizontal wind stream, turbulence causes individual elements of air to move in all directions, even upward against gravity. This upward motion imparts the transient force which bouys the particles of snow in a wind stream. Any increase in net horizontal speed strengthens the upward vector and multiplies the capacity for snow transport. Any obstacle or barrier protruding into the wind stream develops a local, near-motionless region of air incapable of supporting the heavier-than-air particles of snow causing deposition. Thus, a carefully-designed system of regularly-spaced wind-break barriers can cause and direct the deposition and accumulation of snow over fields and pastures crossed by snow-laden winds. Such barriers also lessen any further wind-borne entrainment of the trapped snow.

An additional factor, described by Tabler and Schmidt (1972) concerns the mass sublimation from snow carried in a surface wind. Tabler (1973) estimated that under favorable conditions up to 52% of the annual snowfall in a wind-prone environment could sublimate before melting. Snow management practices which cause the deposition of wind-borne snow and act to minimize entrainment of the snowcover in the air stream automatically reduce sublimation, thereby conserving additional water for crop growth. Steppuhn and Gray (unpublished report, 1977) applied a theoretical sublimation model based on the work of Schmidt (1972) to hourly meteorological observations during the 1974-75 winter at six stations on the Canadian Great Plains. Total winter snowfall at these stations averaged 105.8 mm, while estimates of the maximum seasonal quantities of snow which the measured wind could have transported and caused to sublimate while in transport averaged 10.2 tonnes per metre width and 235 mm per unit area (Table 2). Potential sublimation at four of the six stations exceeded the measured snowfall; the actual quantities sublimated were, of

Table 1. Precipitation Summary, 1968-78, Bad Lake Climatological Station near Bickleigh, Saskatchewan, operated by Atmospheric Environment Service of Canada and the Division of Hydrology, University of Sasaktchewan

Year	Rainfall 16 August through 15 May	Snowfall Water Equivalent October-April	Rainfall 16 May through 15 August[1/]	Total Precipitation 16 August-15 August	Snow/Total Ratio
	mm	mm	mm	mm	%
1967-68	75	75	105	255	29
1968-69	139	108	130	377	29
1969-70	98	148	195	441	33
1970-71	33	108	151	292	37
1971-72	31	91	132	254	36
1972-73	48	83	72	203	40
1973-74	66	167	260	494	34
1974-75	59	101	145	305	33
1975-76	29	84	194	307	27
1976-77	98	39	146	283	14
1977-78	62	104	108	274	38
Mean					
1968-78	67.1	100.6	148.9	316.7	32
Standard Deviation	±33.9	±34.5	±51.7	±86.5	±5

[1/] Summer growing season.

Table 2. Accumulated snowfalls, hourly averaged 10 m wind speeds, numbers of storms with wind speeds above threshold for drifting (7 m/s), total storm hours, estimated snow transport and potential sublimation at six Canadian climatological stations during Winter 1974-75

Station	Accumulated snowfall water equivalent	Average hourly wind speed	No. of storms	Storm hours	Estimate of maximum possible snow transport	Potential sublimation
	mm	m/s			tonnes/m width	mm
Winnipeg Manitoba	129.3	9.08	41	900	9.18	109
Regina Saskatchewan	82.0	9.35	48	1115	13.01	185
Saskatoon Saskatchewan	78.0	8.80	40	686	5.88	122
Bad Lake Saskatchewan	101.2	9.38	33	763	8.95	162
Edmonton Alberta	108.0	8.73	27	329	2.62	64
Lethbridge Alberta	136.6	10.5	39	1087	21.74	765

course, less because these potentials assumed an unlimited supply of snow moving in an ever-saturated wind stream.

Management to augment soil water reserves also concerns the fate of the melt waters derived from enhanced snowcovers obtained by barrier techniques. The rate of melt water infiltration might be sufficiently hindered, especially under sub-zero temperatures, to force overland flows away from desired locations, or the capacity of the soil to hold water for the time required in coarse-textured media could be exceeded, allowing drainage below the root zone, or the soil water might be removed by evaporation from soil surfaces and by transpiration through early weeds.

Some potential for controlling or directing snowmelt infiltration for agricultural advantage appears possible. Erickson et al (1978) monitored snowmelt runoff rates in fields which had been summer cropped and fallowed. Rates in the latter average three times greater than those in the cropped fields. Willis et al (1969) showed that a taller crop stubble caused the snowcover to melt earlier and at a slightly faster rate than a shorter stubble. In general, the more rapid the exposure of soil surfaces through the snow, the greater the capacity of the surface medium to absorb melt water under frozen conditions.

Snowcover and Winter Crop Survival

The protection afforded plants by snow buried under it is well recognized. If a shrub has only been partially submerged by snow, severe damage has often been observed just above the snow surface (Van Wijk and Derksen, 1963). The snow provides an environment which prevents desiccation caused by winter transpiration and which reduces ambient heat loss during periods of low air temperatures.

The usual winter flow of heat through a snowcover originates from the ground and moves upwardly to the atmosphere which acts as a thermal sink. The moderation of ambient temperatures surrounding winter crops protected by snow relates to the low thermal conductivity of snow ($Wm^{-1}\ K^{-1}$): 0.046 for fresh, light snow, 0.33 for old, dense snow, 2.2 for ice (0^oC), 0.57 for liquid water (10^oC), and 0.025 for air (10^oC). The relatively low conductivities of snow below 0^oC stem from the medium's large air content and the low conductivity of this air.

Thus, the snowcover thickness influences the depth to which the water in a soil will freeze. Frost depths in a three-year Finnish study by Ylimäki (1962) ranged from 55 to 65 cm on plots kept snow-free, 12 to 22 cm where snowcovers were normal, and 9 to 17 cm under plots covered by an above-normal complement of snow. The same researcher compared the overwinter survival of various legumes, cereals and grasses in snow-free and snow-covered environments. His results, shown in Table 3, demonstrate the effectiveness of a snowcover in fostering the winter survival of nine crop species.

Table 3. Overwintering of Cereals, Grasses and Legumes in Snowcover Trials 1952-53 Tikkurila, Finnland (Taken from Ylimaki, 1962)

Species and Strain	Winter Survival (100-0)*	
	Snowcovered	Free of Snow
Winter rye, Toivo	90	67
Winter wheat, varma	66	13
Timothy, Ta 01	53	47
Meadow fescue, No. 601/50	85	20
Perennial ryegrass, No. 664/50	31	1
Italian ryegrass, No. 408/50	3	0
Red clover, Tammisto	72	4
Alsike clover, Tetra Weibull	80	0
Alfalfa, Flamande	60	0

$$^{*}\text{Winter Survival} = 100 \times \frac{\text{plant density in spring}}{\text{plant density in autumn}}$$

Snow Management Practices

Any effort, which induces snow to accumulate preferentially or to melt in such a manner as to infiltrate and remain stored in the soil until utilized by a crop, qualifies as a snow management practice. Broadly classified, these practices on the Canadian Prairies involve field fences, snowplowing, vegetative barriers, stubble management, and surface modifications.

Field Fences

One of the earliest tests to harvest snow for soil water enrichment was initiated in 1937 at Scott, Saskatchewan. According to Matthews (1940), the investigators reasoned that wind-blown snow would accumulate behind field-sited barrier fences constructed of brush or wood-on-wire. Not only did the barriers prove costly, but they collected snow in a non-uniform areal pattern, resulting in alternate strips of wet and dry soil, which proved difficult to cultivate. Consequently, this technique is not followed in western Canada.

Snowplowing

One method of inducing the deposition of snow involves plowing freshly-fallen snow into parallel ridges which serve as barriers to trap snow from subsequent storms. These ridges protrude into the horizontal wind stream causing air-borne snow to drop from suspension and deposit in the furrows between the ridges. The most effective ridges are tall and oriented perpendicular to the dominant direction of snow-laden winds.

On the Canadian Prairies, snow ridging, as an agronomic practice to augment soil water for crops has received periodic attention. Matthews (1940) reported on ridging tests conducted at Scott, Saskatchewan during 1937-39 using a pull-type snowplow. Ridges were spaced 2.5 m apart. Snowcovers were measured at the time of maximum accumulation and are summarized in Table 4.

Table 4. Snowcover comparisons for snowplowed ridges at Scott, Saskatchewan, March 1939 (Taken from Matthews, 1940).

Location	Average snow depth	Average bulk density	Average water equivalent
	cm	kg/m^3	mm
In Ridges	61.0	308	188
Between Ridges	49.0	300	122
Natural Snowdrifts	31.5	300	94

Snowplowing increased the natural accumulation of snow by 100% in the ridges and 30% between them. However, gains in soil water, except in grass pastures, were not as dramatic and probably explain obtaining only modest improvements in crop yields. Matthews concluded that snowplowing would definitely increase yields for some crops and generally reduce potential soil erosion by maintaining a wetter surface longer into the summer.

In 1962, Keys (1963-72) revived snowplow tests at Scott and initiated tests at Loverna near the Alberta-Saskatchewan border. Keys encountered difficulty in establishing ridges in some years, owing to a lack of snow, and recorded a wide yearly variation in results. Nevertheless, ridging was thought responsible for average increases in spring wheat yields of 2% at Scott and 10% at Loverna.

Recent snowplowing trials on stubble fields in southwestern Saskatchewan (Dyck et al, 1979) gave varying results. In 1972-73, an exceptionally strong wind levelled the ridges, sweeping the snow from the fields. In 1975-76, a mid-winter thaw melted many of the ridges, severely reducing their effectiveness. In 1976-77, the initial snowcover available for manipulation proved insufficient to form adequate ridges. However, in 1973-74, one of the effective years, snowplow treatments accumulated 43% more snow water and stored 70% more soil water than when no treatment was applied (Table 5). Also, the additional water derived from the ridged snow penetrated deeper into the soil. Water in-

Table 5. Water Summary, 1973-74 Snow Ridging in a Stubble Field 8 km Northeast of Bickleigh, Saskatchewan

Treatment	Snow Water	Soil Water (0-72 cm profile)		
	28 March 1974	27 Sept. 1973	7 May 1974	Difference
	mm	mm	mm	mm
Non-ridged				
Block III	115	162	250	88
Block IV	97	125	181	56
Average	106	143	215	72
Ridged				
Block I	164	161	296	136
Block II	140	120	230	110
Average	152	140	263	123
Average difference	46	3	48	51

crements due to ridging at depths of 15,30.5 and 61 cm were 15, 39 and 226% of those for the non-ridged. The authors concluded that the successful ridger must be prepared (1) to plow fields immediately following snowfall, (2) to assume the risk of failure with each plowing, and (3) to appreciate that the practice during some years will not bring added benefits.

Vegetative Barriers

The practice of growing tall, woody windbreaks adjacent and within cultivated fields to curtail wind erosion, trap snow, reduce evaporation, and increase crop yields has been strongly promoted in the USSR, USA and Canada. Extensive regions exist where field after field is sheltered by live trees and shrubs arranged in variously-spaced rows. Many field observers have recognized the snow-trapping ability of live, woody barriers, but stressed that the ideal windbreak should distribute the snow uniformly over the intervening cultivated and pasture areas. Frank and George (1975) agreed and demonstrated that pruned windbreaks effect the desired distribution better than vegetative barriers which are less pervious to the wind.

Staple and Lehane (1955) summarized a five-year study in Saskatchewan to evaluate the influence of windbreak shelters on crop yields. Each shelterbelt consisted of contiquous rows of caragana (2.5 m in height), ash (7 m) and maple (7 m), each extending the length of the field; belts were spaced 137 m apart across the field. Soil water and wheat yields sampled at various distances perpendicular to the barriers diminished outwardly from the barriers(Figure 2). Taking into account the area occupied by the barriers, the net increase in spring wheat yield within sheltered fields averaged for the test period was 47 kg/ha per year.

Permanent grass barriers seeded in rows spaced 15 m apart across fields to trap snow are new to the Canadian Plains. Orbit tall wheatgrass and Altai wildryegrass have been seeded under barrier-test at the Swift Current Agricultural Research Station. The greatest potential for these barrier systems related to the expansion of areas seeded to winter wheat.

Field-sited vegetative barriers need not be permanent to be effective. Recognizing the value of snow retention, extension specialists in Saskatchewan suggested leaving ample late-season hay growth, even if the final mowing left only narrow, uncut strips spaced the width of the mower throughout the field (personal communication). Erickson and Steppuhn (unpublished report, 1976) extended the idea of such leave strips to a 1975 crop of spring-seeded durum wheat. During fall harvest, test strips 30 cm wide of standing wheat 60-80 cm tall were left unharvested to function as snow-trap barriers spaced 1, 2 and 3 swather widths (5.3, 10.7 and 16.0 m) apart on fields scheduled to be sown in the following spring. Snow depths at the time of maximum accumulation, measured on the non-

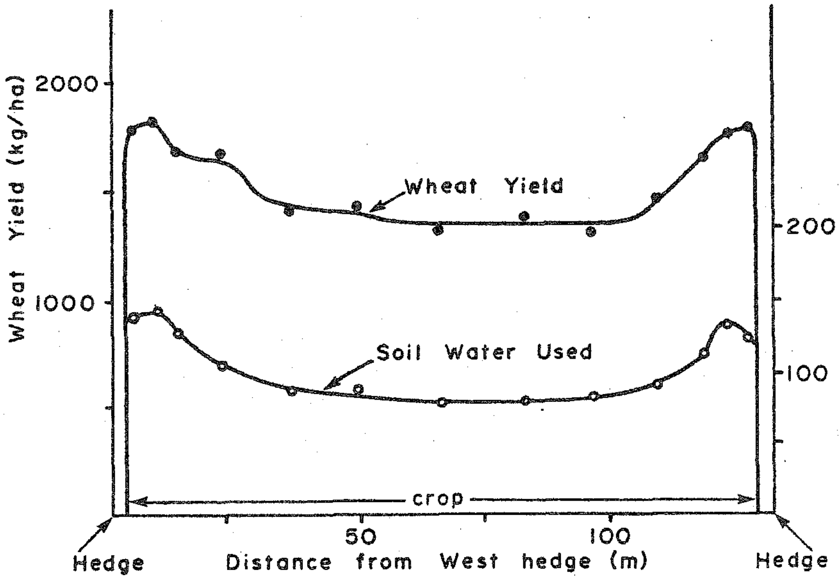

Figure 2. Wheat yield and soil water used between shelterbelts, Aneroid, Saskatchewan (Staple and Lehane, 1955).

stripped portion of two test fields, averaged 21.2 ± 2 cm. The barriers in these fields increased snow volumes by averages of 88, 82 and 70 percent for the respective spacings. (Table 6)

Table 6. Average March Snow Depths Measured on One Acre Test Blocks in Three Fields near Leader, Saskatchewan, 1975 Durum Wheat Stubble and 30 cm Wide Crop Leave Strips Spaced every 1, 2 and 3 Swather Widths, Winter 1975-76

Treatment (September 1975)	Spacing		Crop Investment of: Total	35 bu Crop	Snow Depth (March 1976)	
	ft	m	%	bu/acre	cm	% of Non-stripped
Non-stripped			0	0	21.2	100
Stripped:						
1 Swather Width	17.5	5.3	5.36	1.88	39.8	188
2 Swather Widths	35.0	10.7	2.73	0.96	38.6	182
3 Swather Widths	52.5	16.0	1.84	0.66	36.0	170

Snow harvesting with crop leave strips has economic viability. For example, a 50 acre (20.2 ha) field of spring wheat located 5 km east of Saskatoon, Saskatchewan, was harvested in October 1977, 30 acres (12.1 ha) conventionally and 20 acres (8.1 ha) by leave-stripping. [The entire field was surrounded by summerfallow.] Leave strips measured 0.4 m in width and were spaced on 12.9 m centers which amounted to an unharvested crop area equalling 3.1% of the total. The conventionally windrowed and combined portion of the field yielded 2216 kg/ha (33 bushels/acre) and left a standing stubble of 15 cm in height. The unharvested crop investment was computed as the product of unharvested area and conventional yield, 3.1% x 2216 kg/ha = 68.5 kg/ha (1.02 bu/ac).

Snowcover retention was surveyed on 10 March 1978 and showed that the leave-strip barriers had trapped an average extra water equivalent of 89 mm more than had the conventional stubble (Table 7). Gravimetric soil water measurements obtained in the autumn and spring indicated an average additional gain of 53 mm in the 5-80 cm profile under the strip treatment compared to the stubble. Each additional mm of water has been associated by Staple and Lehane (1952,54) with an increase in spring wheat yield of 9 to 16 kg/ha. If the conservative figure of 8 kg/ha/mm were assumed, the return from the leave-strip treatment accounted for an extra yield of 53 mm times 8 kg/ha/mm or 424 kg/ha (6.3 bu/ac) and the ratio of return for investment reached 424/68.5 or 619%.

Table 7. Water Summary for Stubble Field (Spring Wheat) 5 km East of Saskatoon, Saskatchewan; 40% of Field Snow-Managed during Winter 1977-78 using Leave Strips from 1977 Spring Wheat Crop, 60% of Field Left as Normal Non-stripped Overwinter Stubble.

	Snowcover on 10 March 1978		
Field	Depth	Bulk Density	Water Equivalent
	cm	kg/m^3	mm
Stripped (20 acres)	36.8	330	122
Non-stripped (30 acres)	12.8	255	33
Difference	24.0	75	89

	Soil Water (5-80 cm profile)		
	Autumn 1977	17-21 April 1978	Difference
	mm	mm	mm
Stripped	230±25	335±63	105
Non-stripped	191±31	243±44	52
Difference	39	92	53

Stubble Management

The merits of leaving standing crop stubble to trap wind-blown snow is well known and documented (Staple and Lehane 1952; Willis et al, 1969). As expected, stubble from tall crops, such as sunflowers, grain corn and sorghum retain more snow than shorter stubble as obtained from wheat, barley, flax, etc. In March of 1976 Erickson and Steppuhn (unpublished data) measured snowcover depths averaging 9.5 cm in spring wheat stubble and 21.8 cm in sunflower stubble grown in southwestern Saskatchewan. At another location in central Saskatchewan, average depths for the two stubbles were 15 and 32 cm, respectively.

Various methods of cutting the crop during harvest have been tried with the purpose of leaving an effective stubble barrier for trapping wind-transported snow. Willis (1979) presented a set of snowcover measurements taken under test conditions at Mandan, North Dakota, which compared uniformly cut stubble to a stubble cut at the same height but in strips 1.5 m wide and separated by intervening 3-m strips cut at the ground surface. Although snowcover depths did not differ appreciably between the uniformly and alternately cut stubble, the snow trapped in the low cuts was considerably denser than that found in the taller stubble. Consequently, snow water equivalents in the alternate height stubble averaged 108.6 mm compared to 62.9 mm in the uniformly cut stubble.

Efficient combine threshing of light crops often causes farmers to place the cut swaths from two windrowed widths together for subsequent combining. This operation allows the two swaths to be cut at alternate heights, one low at 20 m or less above the ground and one high at 40 cm or more. Three years of water equivalent comparisons between alternately and uniformly-cut fields by Nicholaichuk and Norum (1975) always favored the former by differences of 7.1, 16.2 and 5.3 mm during 1973, 1974 and 1975, respectively.

Surface Modifications

Surface tillage or treatments to effect snow management is not commonly practiced on the Canadian Plains. Early tests on cultivated fields were initiated principally to control soil erosion, but with the secondary objective of holding snow and promoting infiltration of melt waters. Fall plowing with damming listers on summerfallow was tested in 1938 and 1939 at ten sites in southwestern Saskatchewan and reported briefly by Staple et al (1960). No significant over-winter enrichments of soil water were detected, giving little promise for the practice. The merits of diked, narrow terraces were also tested in the same dryland region of Canada, in 1931-34. From this experiment Barnes (1938) reported spring wheat yields for diked and non-diked plots averaging 1770 and 1410 kg/ha on fallow, and 700 and 470 kg/ha on stubble.

Summary

Manipulation of the snowcover offers the greatest potential for increasing the water available to grow dryland crops on the Canadian Prairies. The characteristics of snow which make it suitable for management are (1) its availability for manipulation during its precipitation or while stored above ground, (2) its susceptibility to redistribution by wind, (3) its tendency to sublimate while wind-transported, and (4) its compatibility with existing cropping practices. The elements which combine to form effective snow management on the Prairies are snow, wind, barriers and melt-water infiltration. Successful management depends both on the weather and the placement of wind barriers at advantageous times and locations. Thus, the merits of any snow control program depend on the probabilistic nature of weather conditions and sequences. Although some management efforts will probably fail, the overall number of successes will dominate, thereby, assuring a long-term net benefit.

The snowcover enhancement techniques which have been tried on the Prairies include placement of field fences, snowplowing, planting arborescent field barriers, cutting of tall stubbles, modification of soil surfaces, and leaving unharvested crop strips. Each technique features advantages which serve specific conditions and operations. In the case of leave-stripping its advantages include ease of establishment, formation of a tall barrier, flexibility in choice of spacing and strip width and field location, no overwinter maintenance, compatibility with field operations and machinery, and low cost. Two possible disadvantages are the extra seed source left with the strips and the danger of lodging, reducing trapping efficiency.

The methods of snow harvesting described above are capable of increasing overwinter soil water recharge by 50 mm. Such a gain is of the same magnitude as realized during the summerfallow summer and winter. Therefore, snow management could reduce the need for summerfallow to conserve moisture. A parallel advantage has been indicated for snowcover enhancement as a practice to aid survival protection for winter crops.

Literature Cited

Barnes, S. 1938. Soil moisture and crop production under dryland conditions in western Canada. Canada Dept. of Agric. Publ. 595, 43p.

Dyck, G. E., D. Erickson and H. Steppuhn. 1979. Snow ridging to increase soil water. Proc. Soils & Crops Publ. 403, U. of Sask., 1-12p.

Erickson, D., W. Lin and H. Steppuhn. 1978. Indicies for prairie runoff from snowmelt. Proc. 7th Symp. Water Studies Inst. Applied Hydro, Saskatoon.

Frank, A. B. and E. J. George. 1975. Windbreaks for snow management in North Dakota. Proc. Snow Management on the Great Plains, Great Plains Agric. Council Publ. 73: 144-153pp.

Greb, B. W. 1975. Snowfall characteristics and snowmelt storage at Akron, Colorado. Proc. Snow Management on the Great Plains, GPAC Publ. 73: 45-64pp.

Keys, C. H. (1963-72). Unpublished data. Moisture conservation & utilization of winter precipitation. Can. Dept. Agric., Saskatoon Res. Station.

Matthews, G. D. 1940. Snow utilization in Prairie Agriculture. Can. Dept. Agric., Res. Branch, Publ. 696, 21p.

McKay, G. A. 1964. Relationships between snow survey and climatological measurement for the Canadian Great Plains. Proc. Western Snow Conf. 32: 9-18pp.

Nicholaichuk, W. and D. I. Norum. 1975. Snow management on the Canadian Prairies Proc. Snow Management on the Great Plains, GPAC Publ. 73: 118-127pp.

Pelton, W. L. 1967. Wheat and climate. Proc. Can. Centennial Wheat Symp., Western Co-operative Fertilizer Ltd. Modern Press, 207-224pp.

Saskatchewan Advisory Council on Soils and Agronomy. 1978. Saskatchewan fertilizer and cropping practices 1978-79. Ext. Div., U. of Sask., 13p.

Schmidt, R. A., Jr. 1972. Sublimation of wind transported snow - a model. USDA For Serv. Res. Paper RM-90, 24p.

Staple, W. J. and J. J. Lehane. 1952. The conservation of soil moisture in southern Saskatchewan. Scientific Agric. 32: 36-47pp.

Staple, W. J. and J. J. Lehane. 1954. Wheat yield and use of moisture on substations in southern Saskatchewan. Can. J. Agric. Sci. 34: 460-468pp.

Staple, W. J. and J. J. Lehane. 1955. The influence of field shelterbelts on wind velocity, evaporation, soil moisture and crop yield. Am. J. Agric. Sci. 35: 440-453pp.

Staple, W. J., J. J. Lehane and A. Wenhardt. 1960. Conservation of soil moisture from fall and winter precipitation. Can. J. Soil. Sci. 40: 80-88pp.

Tabler, R. D. and R. A. Schmidt. 1972. Weather conditions that determine snow transport distances at a site in Wyoming. Proc. Int. Symp. on the Role of Snow and Ice in Hydrology, 118-127pp.

Tabler, R. D. 1973. Evaporation losses of wind blown snow, and the potential for recovery. Proc. Western Snow Conf. 41: 75-79pp.

Van Wijk, W. R. and W. J. Derksen. 1963. Sinusoidal temperature variation in a layered soil. Chap. 6, 171-209pp. In Physics of Plant Environment. North-Holland Pub. Co., Amsterdam.

Water Survey of Canada. 1974. Historical streamflow - Ontario Summary. Inland Waters Directorate, Water Resource Branch, Environment Canada.

Willis, W. O., H. J. Haas and C. W. Carlson. 1969. Snowpack runoff as affected by stubble height. Soil Sci. 107(4): 256-259pp.

Willis, W. O. 1979. Snow on the Great Plains. Proc. Modeling of Snow Cover Runoff, CRREL, Am. Geophy. U. and Am. Meteor. Soc., 56-62pp.

Ylimäki, Aarre. 1962. The effect of snow cover on temperature conditions in the soil and overwintering of field crops. Annales Agric. Finniae 1: 192-216pp.