BENEFIT/COST RATIOS FOR SNOW MANAGEMENT TECHNIQUES ON DRYLAND AGRICULTURAL LANDS

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ABSTRACT

At least a third of the land covered by winter-accumulated snow across western North America between the 40th and 60th latitudes includes agricultural fields and livestock ranges. Snow-covers on these lands constitute a valuable natural resource available for management to increase dryland crop growth and commodity production. Managing the deposition of snows complements most cropping systems very well. Snow-covers insulate, protect, and provide water for overwintering and spring-seeded crops against freezing temperatures, damaging winds, and drought. The basic objective in designing techniques for utilizing more of the snow available is to provide snow-retention capacity equal to the expected delivery of snow to the field or rangeland being managed.

The benefit/cost ratios associated with snow management vary with the technique. They depend on many factors: initial costs, amortization life, snow-cover accumulations and storage capacities, winter temperatures, melt water captures, historic annual soil recharges from snow, crop choices and yields, weather-related demands, annual commodity returns, producer tolerances of inconveniences, field implement availability, etc. For annual cropping of cereal grains on the Canadian Prairies, one study reported estimated benefit/cost ratios ranging from 0.70 for field fencing to 68.0 for crop stubble height increases with ample snow and from 0.01 to 6.40 with scant snow, respectively. The costs for many techniques are so low that snow management can be practiced for 3, 4, or so years in sequence before costs, including interest, start outweighing benefits from one good snow year. (KEYWORDS: benefit/cost ratio, snow management, dryland agriculture, grazing livestock, hay crop)

INTRODUCTION

Snow management to enrich soil water reserves requires two considerations: control over-snow cover formation and influence over melt water disposition. These involve forcing the deposition of snow in desired locations, ensuring the infiltration of the melted snow water into the soil, and retaining the enrichment within the rootzone until transpired by the crop. In general, sandy soils and clay soils that tend to crack at the surface upon drying receive snowmelt waters with little difficulty. Loam soils, especially those rich in sodium, may show poor infiltration during snowmelt. The weather during the melt period may also cause restrictions in infiltration. Melt-freeze-melt sequences, as well as rain-on-snow, can result in ice lenses which may restrict water movement into the soil, causing overland flow away from desired locations.

SNOW-COVER CONTROL AND MANAGEMENT COMPONENTS

Snow-Covers

Snow-covers start as snowflakes. Snowflakes falling through air under the pull of gravity, or dashed by the wind, start as crystals of ice configured in many different shapes and sizes. The ice crystals that most frequently fall or blow with the wind on the plains and prairies east of the Rocky Mountains take the form of stellates or spatial dendrites with outwardly radiating spires of ice 1-5 mm long. These spires provide the mechanical linkage for individual crystals to join becoming snowflakes. When linkages break, parts of crystals varying in size, comprise the icy particle mix.

Snow Transport and Deposition

Control over the deposition of snow on fields and pastures involves regulation of the wind. The forces which keep a particle of snow airborne result from the winds' 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 a transient force which buoys the particles of snow in a wind-stream, regardless of whether the transported snow comes from a snow-cover or from concurrent snowfall.

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The flow of snow-ladened wind continually passes over surface features which affect the snow carrying capacity of the wind. These features, termed roughness elements, determine air turbulence and the transfer of momentum from atmospheric wind to the earth. If the wind moving along a uniform surface suddenly encounters taller roughness elements, turbulence is altered with the result that less snow can be transported, and deposition occurs. These taller elements are often referred to as wind barriers or windbreaks.

Snow Cover Retention Capacities

Surface features or elements, which cause snow to deposit, each appear to possess some maximum capacity for accumulating and retaining specific volumes of snow for a given wind speed and direction. Once retention approaches this capacity, further deposition diminishes. All roughness elements impose a type of air-drag (force) on the wind which moves over them (Tabler and Schmidt 1986). If the elements are far enough apart, the surface between the elements also contributes to the overall drag and the snow retention capacity. Effects from the intervening surface decrease as the spacing between the roughness barriers closes, becoming insignificant when closely spaced, uniformly cut crop stubble is encountered. The ability of a particular snow management technique to effect control over the accumulation and configuration of field snow-covers relates to the extent and nature of the drag imposed by the roughness elements associated with the technique. This drag depends primarily on the height of the elements and the wind speed at that height. The shape of the elements and the percentage of airspace between them (porosity) also influence drag, and thus, snow deposition and retention capacity.

In management techniques where the roughness barriers are widely spaced, a depositional pattern results along which the snow depth varies with distance from the barrier. Drifting snow is deposited wherever the threshold wind velocity at the surface decreases along the mean flow direction after encountering the barrier, implying that the surface of a snow deposit at maximum capacity is in equilibrium with the particle-transporting flow when the time-averaged surface wind effect is uniform with distance. Three main mixing layers are thought to operate downstream of a barrier: a layer of uniform flow just above the surface boundary layer, which represents the remains of the retarded air flow immediately behind the barrier; a main mixing layer, which expands with downstream distance from the barrier; and a wake boundary, that is, a kind of outer mixing layer between the undisturbed upper flow and the main mixing layer.

BENEFIT AND COST COMPONENTS OF SNOW MANAGEMENT

An economic evaluation of any snow management practice involves the recognition of the production objectives, the derived benefits, and the associated costs. The benefits include: direct returns from the sale of any agricultural commodities produced as a result of the snow management practice; secondary benefits, such as having less snow on roads; reduced soil erosion by wind; moderations of freezing temperatures; and any indirect benefits realized as a consequence of the of the technique. In most agricultural enterprises, the major objective in managing the snow more effectively follows the existing commodity production goals set by the producer. The techniques selected to manage the snow should also fit within the strategies followed to yield the desired products. Across the western North American plains and prairies, crop plant production concentrates primarily on small grains and forages for livestock.

The most easily identifiable costs associated with snow management practices are those related to inputs for which funds must be paid. These include the fixed costs of equipment purchases and other capital outlays plus the variable costs necessary to operate the equipment or perform agronomic operations. On most family ranches or farms, the allocation of labor costs become difficult to distinguish from less explicit “inconvenience” costs. Labor costs may further merge with managerial costs. If a particular task pertaining to snow control cannot be completed or if its timing is less than optimal, the real cost may show in the form of a penalty in foregone crop yield. Indirect costs and benefits are those not solely incurred by the producer; they connotate social consequences both positive and negative. Snow management may improve the visibility for those driving on roads during snowstorms, an indirect benefit welcomed by all.

Agricultural costs and production returns are usually accumulated and compared for yearly periods, reflecting the seasonal nature of farming and ranching. Calculation of the ratio of benefits over costs on an annual basis permits the agricultural enterprise, or any component of it, to be readily expressed and compared as yearly rates-of-return (yield) on investments:

$$R = \frac{B}{C} = \frac{\text{Benefit}}{\text{Cost}} = \frac{\text{Yield}}{\text{Investment}} \qquad [1].$$

If a snow management technique costing $10 per ha ($4/acre) yields an additional 135 kg of wheat grain per ha (2 bushes/acre), the benefit/cost ratio at a price of $148/t ($4/bushel) equals $20/$10 ($8/$4) or 2.

Snow control for better utilization of the snow resource depends significantly on the weather. In some instances, a rain-on-snow event may limit the infiltration capacity of the soil causing excessive runoff and downstream flooding instead of enriching soil water reserves as desired. There are also years that snow fall accumulations are very scant, providing almost no benefits from the snow management investment in that particular year. Consequently, the calculation of benefit/cost ratios associated with most snow management techniques within any farming or ranching operation may extend over periods longer than a single year. The variabilities involved may necessitate a two or even a five-year span. Because of climate variation, it may take four or five years before any benefits are derived from the snow management. This requires defining a benefit/cost ratio, R, which accumulates yearly costs, C, plus the compound interest on costs incurred in previous years:

$$R = \frac{B_1 + B_2 + B_3 + \ldots + B_k}{C_1(1+i)^{k-1} + C_2(1+i)^{k-2} + C_3(1+i)^{k-3} + \ldots + C_k(1+i)^{k-k}} \quad [2],$$

where i = interest rate, and k = number of years. If no benefits result until the k'th year, and if yearly costs are constant and adjusted for inflation using a constant k'th-year dollar,

$$R = \frac{B_k}{C_k[(1+i)^{k-1} + (1+i)^{k-2} + (1+i)^{k-3} + \ldots + 1]} \quad [3],$$

which for r = B/C in the k'th year is

$$R = \frac{r}{(1+i)^{k-1} + (1+i)^{k-2} + (1+i)^{k-3} + \ldots + 1} \quad [4].$$

Assume that we wish to calculate the expected return on applying a particular snow management technique which we know costs $7.50 per hectare per year and has a design benefit/cost ratio of 4.0 (r = 4) in any payback year. By using Equation [2] or when assuming the cost is in constant dollars and by applying Equation [3], R = 1.21 in the third year and R = 0.87 in the fourth year. Thus, if precipitation records for the district indicate probabilities of receiving the design snowfall water equaling only 0.2 (one year out of five) or 0.25 (one year out of four), a lower cost snow management technique should be considered.

SNOW MANAGEMENTS TECHNIQUES

Any practice which induces snow to accumulate or blow away preferentially to advantage the production of field crops qualifies as an agricultural snow management technique. The crop may benefit from the snow directly as when being insulated from cold temperatures, or later during the growing season when the melt water is utilized in crop growth. Often the same wind barriers, which cause the snow to deposit, remain standing as the crop grows, providing additional benefits to the crop by reducing wind movement, desiccation, and negating drought. The snow management techniques available to producers on the Great Plains and Canadian Prairies include field fences, vegetative windbreaks, snowplowing, crop leave strips, and crop stubble manipulation. Almost all are suitable for most all types of crops and have been applied primarily in the production of cereal grains and hay.

Field Fences

Field fences usually provide sufficient storage capacity for retaining all the snow available. In a 1937-39 test to better utilize snow water for grain production, Matthews (1940) and co-workers reasoned that most of the wind-blown snow would accumulate behind field-sited barrier fences constructed of brush or wood-on-wire. However, 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, proving difficult to cultivate.

Shrub and Tree Windbreaks

The practice of growing various species of woody vegetation adjacent to and within cultivated fields to curtail erosion, trap snow, reduce evapotranspiration, and increase crop yields was widely promoted on the North American plains and prairies. Many districts, especially in the past, featured shelterbelts of live trees and shrubs arranged in variously spaced rows. Farmers recognized the snow-trapping ability of live woody barriers but stressed that the ideal windbreak should distribute the snow uniformly over the adjoining cultivated fields and pastures. Frank and George (1975) showed that greater spreading of accumulated snow could be achieved by keeping the windbreak well pruned and porous.

Annual Plant Bands

Rows of tall annual plants, such as mustard or sunflowers can be seeded in bands as companions to the main crop for the purpose of reducing evapotranspiration and retaining additional snow cover. Farmers grew such bands in the cropping of spring wheat in the Altai Region of the Russian Federated Republic. They found that sufficient snow water was retained to allow cropping for a second or third year without summerfallow. Initially, wheat was seeded so that a 1.8 m (6 feet) wide strip was left unseeded every 30.6 m (100 feet), or a narrower band was left at closer spacings. About a month after the wheat had emerged, the unseeded strips were cultivated and seeded to three rows of sunflowers.

Perennial Grass Windbreaks

One of the first tests to evaluate the effectiveness of perennial grass windbreaks for snow retention and crop yield gain was conducted in Colorado. Double rows of sudangrass were grown spaced 11.6 to 18.3 m (38 to 68 feet) apart across the field. Within these barriers, researchers found that: (1) snow-covers averaged 15.2 cm (6 inches) deeper, (2) over-winter soil water reserves gained 38 mm (1.5 inches) more water, and (3) wheat yield was 269 kg/ha (4 bushels/acre) greater than outside the barrier system. In Montana, Black and Siddoway (1976) evaluated tall wheatgrass as a snow control barrier and found that the average yearly gain in soil water resulting from its use for seven test years was 45 mm (1.7 inches) under continuous cropping. Grass windbreaks have proven to possess medium to large snow storage capacities.

Snowplowing

One method of inducing the deposition of snow involves plowing freshly fallen snow into parallel ridges to serve as barriers to trap snow from subsequent storms. These ridges protrude into the horizontal wind stream causing airborne snow to deposit in the furrows between the ridges. The most effective are relatively tall and oriented perpendicular to the dominant direction of the snow-ladened wind. 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 (8.2 feet) apart. Snow-covers were measured at the time and increased the natural accumulation by 100% behind the ridges and 30% between them. Gains in soil water, except in grass pastures, were not as dramatic and probably explained obtaining only modest improvements in crop yields. Matthews concluded that snowplowing would increase yields for some crops and generally reduce potential soil erosion by maintaining a wetter surface longer into the summer.

Unharvested Crop Leave Strips

The first known trial of leaving strips of unharvested grain for snow-retaining barriers was during the winter of 1975-76 with a durum wheat crop grown near Leader, Saskatchewan (Steppuhn 1980). During the previous harvest 30 cm (1 foot) wide strips of standing plants 60-80 cm (2-2.6 feet) tall were left unharvested as barriers spaced 1, 2, and 3 swather widths apart, with a 5.3 m (15.5 feet) swather, on fields scheduled to be seeded in the following spring. The barriers at their respective spacings increased snow volumes by averages of 88, 80, and 70% over that accumulated on the non-stripped stubble, which had accumulated an average of 21.1 cm (8.3 inches).

In a 1977-78 test with crop leave strips, a 22.2 ha (50 acre) field of spring wheat located 5 km (3 miles) east of Saskatoon, Saskatchewan was swathed in October 1977, 12.1 ha (30 acres) conventionally and 8.1 ha (20 acres) by leave-stripping. Leave strips measured 40 cm (16 inches) in width and were spaced on 12.9 m (42 feet) centers which amounted to an unharvested crop area equaling 3.1% of the total. The conventionally swathed portion of the field yielded 2216 kg/ha (33 bushels/acre) and left a standing stubble of 15 cm (6 inches) in height. The unharvested crop investment in leave strips was computed as the product of the unharvested area and the conventional yield, 3.1% x 2216 kg/ha, and equaled 68.5 kg/ha (1.02 bushels/acre). Snow-cover retention, surveyed in March 1978, showed that the leave-strips had trapped an average water equivalent of 89 mm (3.5 inches) more than had the conventional stubble. Soil water gains measured between fall and spring averaged 53 mm (2.1 inches) greater under the strip treatment compared to the conventional stubble.

Alternate Height Swathing

Some crops must be double swathed to obtain a single windrow of sufficient quantity to combine efficiently. Nicholaichuk et al. (1984) demonstrated that grain fields near Swift Current, SK swathed double but alternately tall and short retained significantly more snow-cover over a 12-year period than fields cut uniformly short. Average water equivalents equaled 54 mm (2.1 inches) for mid-winter snow-covers in alternating stubble swathed in widths of about 8 m (25 feet) compared to 42 mm (1.6 inches) for comparative single height stubble.

Stubble Leave Strips

Attachments to swathers have been devised which leave tall-standing stubble strips as barriers for snow retention. Two types of attachments have been developed: deflectors, which bend the standing crop to the side allowing the stems to be cut closer to the seed heads and clippers, with separate, narrow sickle-bars positioned above the main cutting sickle for a taller cut below the seed heads. Shape and height of the tall stubble strips vary with the attachment. Tall stubble strips formed by prototype swather attachments were initially tested during the winter of 1979-80 in Saskatchewan on heavy clay soil. Both deflector and clipper barriers increased snow-cover by two-fold or more over the conventional snow catch. Overwinter gains in soil water equaled 75.5, 112.5, and 55,0 mm for deflector, clipper, and conventionally swathed crop trials, respectively. These extra soil water gains contributed to 2073, 2515, and 1075 kg/ha grain yields from the following spring wheat crop for the same respective treatments.

Uniform Crop Stubble

If grain crop varieties are available such that they can mature within the growing seasons between early and late frosts in most years, direct cut headers on field combines can be used in straight cut combining rather than windrow swathing with later combine pick-up. Harvest operations, whether by direct combining or by windrow and thresh, typically result in standing crop stubbles of uniform height. However, windrowing the crop with a swather requires a relatively low cut 15-20 cm (6-8 inches) for placement of the windrowed grain and straw. This one-two pass technique, although extending the time for maturing the grain, tends to limit the height of the resulting stubble, regardless of crop height and restricts the capacity of the stubble to retain all the snow available. Single pass, direct (straight) combining presents opportunity for obtaining relatively large volumetric storage capacities, offering better snow-cover retention. Stubble height is limited only by the grain crop's height.

COMPARING SNOW MANAGEMENT TECHNIQUES BY BENEFIT/COST RATIOS

Inclusion of all possible alternatives in any benefit-cost analysis of a water resource project greatly assists in selecting the most cost-effective and efficient design. Snow management may rank as a relatively low-cost choice that dryland agricultural producers could consider. Benefit-cost analyses would identify various choices and associated economics for the possible incorporation of a snow management technique in their production systems. Considerations in selecting the best technique in this service include maximum snow water storage capacity, relative cost, and benefit/cost ratios by technique and snow availability (Table 1). The large ratios for straight combining, alternate height swathing, and leave stripping indicate possible techniques that, because of low costs, can be continually practiced for several years in anticipation of a season with a profitable snow capture. They are techniques which show the greatest adaptability to the highly variable climate characteristic of the mid-continental plains and prairie region.

The ratios listed in Table 1 under the heading, 'Ample,' were computed as if the maximum possible snow storage for each technique had been attained at least once over Winter or Spring. For some producers in some districts, this maximum would b achieved with reduced frequency because of limits in snow availability. If the relative cost of the snow management technique used remained below the return in benefits, i.e., benefits exceeded total costs, and the ratios ranged above a value of one, for the combined years applied, the practice has merit. Even when 'Scant' snow years appear and winter snows do not completely fill the available storage capacity, the extra snow still yields benefits, and promotes commodity production, A snow management practice can continue for several years with only scant snow additions according to Equation [2]. In fact, one or more snowstorms likely occur and contribute to the snow stored up to maximum capacity by applying one of the bottom four techniques listed in Table 1. In many districts within the northern plains and prairies, storage up to maximum capacity will be realized yearly. In the remaining districts, back-to-back ‘scant’ snow years are not expected more than 2, 3, or 4 years before an ample snow year emerges.

The concluding argument for implementing an active management strategy aimed at better utilization of the semiarid snow resources available focuses on cost. Techniques have been identified which require little cost to implement. Despite the rather unpredictable or fickle nature of snows on the prairies and plains, sufficient snow does fall to manage every year in many districts, but elsewhere may require additional years to reach full benefit. Raising the header while straight combining to leave extra tall stubble, leaving narrow strips of last-cut hay unharvested, attaching swather devices to leave tall-stubble strips, cutting alternate heights when double swathing, or even leaving narrow strips of low-yield grain crops unharvested are techniques of such low cost that one may apply them for two or three years in sequence before the costs start outweighing benefits.

Table 1. Comparative storage capacities, relative costs, and benefit/cost ratios for various snow management techniques designed to render agricultural benefits for dryland crops grown on the semiarid plains and prairies of interior North America.

Snow Management Technique	Relative Cost	Benefit/Cost Ratio	
		Scant or	Ample Snow
Snow fences	900.00	0.30	0.78
Woody windbreaks	300.00	0.28	0.70
Vegetative windbreaks:			
Sunflowers	35.50	0.01	1.41
Perennial grass	23.53	0.82	3.48
Snow plowing	20.00	0.05	3.30
Crop leave strips	7.50	0.95	8.28
Clipper	2.00	3.40	17.00
Deflector	1.50	3.20	18.68
Alternate height swathing:			
windrow & thresh	1.50	1.52	12.76
Tall uniform crop stubble:			
straight combining	0.50	6.40	68.00

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