Subsoiling to improve snowmelt infiltration and alfalfa yields within tall wheatgrass windbreaks

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Steppuhn, H., Waddington, J. and McConkey, B.G. 1995. **Subsoiling to improve snowmelt infiltration and alfalfa yields within tall wheatgrass windbreaks**. Can. Agric. Eng. 37:261-268. An Orthic Brown silt-loam Chernozemic soil near Swift Current, Saskatchewan, was subsoiled with a Paraplow to a depth of 350 mm prior to seeding alfalfa. Snowmelt infiltration through silty soils often improves following subsoiling, especially if the technique is coupled with practices to augment the snowcover. The subsoiling treatment followed a split-plot design superimposed on a randomized-block experiment with three alfalfa varieties (Rangelander, Beaver, and Angus) grown in an open field and within a grass windbreak system. Double rows of tall wheatgrass (*Thinopyrum ponticum*), averaging 1.2 m in height and spaced on 15.2-m centres, formed vegetative windbreaks designed to enhance snowcovers and moderate growing-season evapotranspiration. Snowcover water equivalents, spring soil water contents, and forage production from all the alfalfa varieties were greater in the windbreak shelter than in the open field. Hay-crop yields and soil water reserves were not significantly improved by subsoiling during any of the five production years following treatment either within or outside the wind shelter. Therefore, Paraplow subsoiling to improve infiltration is not recommended for dryland alfalfa grown on Orthic Brown Chernozemic soils of silt-loam texture in southern Saskatchewan.

Keywords: subsoiling, paraplow, snow management, windbreaks, alfalfa, shelterbelt

Un loam limoneux chernozémique orthique brun situe près de Swift Current en Saskatchewan a été travaillé avec une sous-soleuse de type Paraplow à une profondeur de 350 mm, avant d'être ensemencé en luzerne. L'infiltration de l'eau provenant de la fonte des neiges s'améliore souvent après le sous-solage, surtout si cette technique est jumelée à des méthodes qui favorisent la rétention de la neige. Le sous-solage a été pratiqué selon un dispositif en parcelles divisées, dans des champs ouverts ou protégés par des brise-vent herbacés, ensemencés de trois variétés de luzerne (Rangelander, Beaver et Argus) et répartis selon un dispositif aléatoire par blocs. Des rangées doubles d'agropyre (Thinopyrum ponticum), d'une hauteur moyenne de 1.2 m et espacées de 15.2 m formaient de brise-vent afin de favoriser la rétention de la neige et la réduction de l'évapotranspiration durant la saison végétative. Les équivalents en eau de la neige, la teneur en eau des sols au printemps et la production de fourrage de toutes les variétés de luzerne ont été supérieurs dans les champs protégés par les brise-vent que dans ceux qui étaient ouverts. Le sous-solage n'a pas amélioré de façon significative les rendements en fourrage et les réserves en eau du sol au cours des cinq années qui ont suivi le traitement, que ce soit pour les champs ouverts ou pour ceux protégés par les brise-vent. Le sous-solage avec un Paraplow pratique dans le but d'améliorer l'infiltration n'est donc pas recommandé sur un loam limoneux chernozémique orthique brun du sud de la Saskatchewan.

INTRODUCTION

Soils in semi-arid climates have often been mechanically cultivated to improve their transmission of water and to retard their desiccation. At the same time, trees and shrubs have been planted on the Canadian Prairies in windrows to retain deeper snowcovers and to abate desiccating winds. In 1971, Black and Siddoway (1971) described a windbreak system using tall wheatgrass (*Thinopyrum ponticum* (Podp.) Barkworth & D.R. Dewey, previously *Agropyron elongatum* (Host) Beauv.) seeded in double rows and spaced on 15.2 m centres across fields producing dryland crops. Besides controlling wind erosion, the system showed promise to conserve water, reduce the need for summerfallow, and increase grain crop production. The tall wheatgrass system has been researched in Montana by Aase and Siddoway (1974, 1976), Black and Siddoway (1976), Aase et al. (1976), Aase et al. (1985), Black and Aase (1986), and in Saskatchewan by Nicholaichuk (1981), Steppuhn and Nicholaichuk (1986), and McConkey et al. (1990b).

Black and Siddoway (1975) recognized that the tall wheatgrass system not only decreased transpiration demands on the wind-sheltered crop, but also increased snowcover and meltwater volumes. Willis and Frank (1975) also cautioned that managing snow to provide more soil water for crops involved infiltrating the meltwater as well as enhancing the snowcover. Monitoring the accumulation and infiltration of snow water behind grass windbreaks in Saskatchewan, Nicholaichuk et al. (1984) consistently measured less soil water enrichment and less wheat yield than expected based on the increased volume of snow retained by the system. Gray et al. (1986) indicated that a non-cracked, frozen soil cannot absorb all the water in an average Prairie snowcover, and suggested that subsoiling to alter soil structure and create fissures would improve snowmelt water infiltration.

Subsoiling in semi-arid climates without concomitant snowcover enhancement has produced mixed results. Deep tillage increased the conservation of winter precipitation in the northwestern U.S.A. (Massee and Siddoway 1966; Lindstrom et al. 1974; Zuzel and Pikul 1987), and in Saskatchewan (Granger and Gray 1986; Patterson et al. 1986; Grevers 1988, 1989). However, many earlier studies showed no water conservation benefit from deep tillage on the Great Plains (Duley 1957; Power et al. 1958; Black and Power 1965; Haas et al. 1966) or on the Canadian Prairies (Wenhardt 1950-55; Patterson and Lapp 1964).

The effects of snowcover management coupled with a one-time subsoiling of a Chernozemic silt-loam soil in Saskatchewan were assessed over a four-year period (McConkey et al. 1990a). Subsoiling in the autumn to a 350-mm depth substantially increased snowmelt infiltration for the first crop year following the treatments. Although the subsoiling did not significantly increase snowmelt infiltration in subsequent years, it did increase the depth to which meltwater had penetrated. The subsoiling treatment increased grain yields over the control treatment by an average of 20%, but only when the snowcover was enhanced two-fold or more. Marginal yield benefits persisted to the third year following subsoiling when annually-repeated management retained a measurable snowcover.

Snow management can also benefit forage production on the Great Plains and Canadian Prairies. Ries and Power (1981) increased soil water by 24 mm for each 10 mm increase in stubble height of perennial grasses left over winter. This increased dry-matter yield by 115 and 62 kg/ha for introduced and native forages, respectively. Wight et al. (1975) tested a rotary subsoiler in eastern Montana pastures that punched holes on a one-metre grid pattern so as to rupture the subsoil. The practice increased infiltration and soil water reserves by an average of 76 mm. Haas and Willis (1971) constructed 9-m wide level benches with dikes to retain water. Bromegrass (*Bromus inermis* Leyss.) seeded on the dikes trapped blowing snow, and the resulting water increased alfalfa (*Medicago sativa* L.) production by 100% or more.

The objective in the current study was to observe the results obtained from a one-time subsoiling of a Chernozemic silt-loam soil within a tall wheatgrass windbreak system subsequently seeded to alfalfa. The effects of such subsoiling on snowcover accumulation, soil water reserves, and forage yields from three alfalfa varieties were investigated.

STUDY SITE AND METHODS

Study site

The windbreak system selected for this study is located 3 km southeast of Swift Current, Saskatchewan and has been described by Steppuhn et al. (1987). The continental climate of the site is typically semi-arid. Mean annual precipitation is 359 mm, with up to one-third usually falling as snow. Mean growing season (May, June, July) precipitation and pan evaporation average 168 and 736 mm, respectively. Prevailing winds flow from the west (22% of the total). Air temperatures can range from - 40 to + 40 C. Forage growth is usually sufficient for one hay cut per year. The climate demands the use of very winter-hardy, drought-resistant alfalfa varieties.

The windbreak system at the study site consists of unharvested tall wheatgrass (cv. Orbit) which, by 1978, was established as double-row wind barriers averaging 1.2 m tall, 1.2 m wide, and spaced on 15.2 m centres 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 bounded by a grass windbreak on each side. An adjacent 3.3-ha area to the south remained without windbreaks and was designated as an open-field control for evaluating the grass shelterbelt. Both areas form part of an extensive plain which slopes approximately 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 (Canada Subcommittee on Soil Classification 1978). The topsoil developed from a loess veneer (approximately 0.6 m thick) overlying loam-textured till; the depth to the B horizon ranges between 0.08 and 0.2 m (Ayres et al. 1985). The topsoil contains about 2.7% organic matter and transmits water with hydraulic conductivities (lab-measured) from 70 to 800 mm/d; hydraulic conductivities through the B and C horizons reach maximums of 3000 and 200 mm/d, respectively.

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 grain production (McConkey et al. 1990b; Steppuhn and Nicholaichuk 1986).

Treatments

In autumn 1985, the two outer crop strips on the east and the west sides of the system were paired; each strip fronts an open area and would tend 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. The control area without windbreaks was similarly divided into pairs of 15.2 by 183 m strips. On October 21, 1985, one strip of each pair was randomly chosen and subsoiled lengthwise with a Paraplow (Howard Rotovator Co. 1983). The volumetric water content in the upper 0.4 m averaged 13% for both the open-field and the wind-sheltered plots.

The Paraplow has a 25.4 mm wide shank which is slanted 45° laterally 254 mm from the points. The stated purpose of the lateral bend is to increase lifting and fracturing of the soil. A coulter cuts the soil approximately 75 mm deep in front of each shank. The points at the ends of the shanks are 64 mm wide. An adjustable shatter plate is located behind the points. The shatter plate was set at its shallowest (i.e. to produce the least amount of soil lift) as recommended for dry soils (Howard Rotovator Co. 1983). The three shanks were spaced 0.5 m apart and the tillage depth was 0.35 m. The Paraplow is known for its ability to minimize surface soil disturbance (McConkey et al. 1990a).

After subsoiling, the areas were left undisturbed over winter. In May 1986, the strips in both areas were divided crosswise into three plots. The centre 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 other than normal to the windbreaks. In each strip, three alfalfa varieties were seeded, one per plot, at random, in north-south rows spaced 0.61 m apart: cv. Rangelander (creeping root pattern), Beaver (branched taproot), and Angus (taproot). The area without windbreaks was divided and seeded the same way at the same time. In both areas, the alfalfa was seeded into standing wheat stubble.

The three alfalfa varieties also possess inherently different regrowth potentials for a second cut: Angus = high; Beaver = medium; and, Rangelander = low. Besides having regrowth differences, these varieties vary in their capability to dry the soil and influence any effects from subsoiling.

Measurements

The merits of subsoiling were evaluated by observing the snowcover retention, soil water content (autumn and spring), and alfalfa forage yield associated with each treatment. Snowcover depths and specific gravities of vertical snow cores in each plot were surveyed at least once a year in 1986 through 1991 except in 1987 when snowcovers were not sufficient for measurement. After each survey, which was usually conducted after a major wind storm, mean snowcover values were calculated from the 10 to 30 snow depth observations and 3 to 5 gravity measurements taken per plot and used to calculate the mean snowcover water equivalent for each plot according to Steppuhn (1976).

Each year from 1987 through 1991, soil cores for water content calculations and plant samples for determination of forage yields from each plot were obtained within one-metre of each other. Samples of alfalfa from one-metre segments in 3 to 8 rows uniformly spaced across the width of each plot (at midpoint) were cut at a 50-mm stubble height, oven-dried at 50°C and weighed. Following this, the hay on each plot was mowed, field-dried, baled, and removed. Soil cores 25 mm in diameter were extracted in April (after the winter snowcover had melted) and in the autumn of each year to sample soil water contents within the 0-0.15, 0.15-0.3, 0.3-0.6, 0.6-0.9, and 0.9-1.2 m depth increments. Three cores were removed from each plot during sampling, except in the autumn and the spring of 1986-87, when six cores per plot were extracted. On October 5, 1987, the soil at the centre of each plot was very carefully cored with a truck-mounted, 47 mm diameter, hydraulic sampler (Giddings Machine Co.) to a 0.6-m depth, and the bulk densities determined for the 0-0.1, 0.1-0.2, 0.2-0.3, 0.3-0.45 and 0.45-0.6 m increments. These and previous bulk density determinations in the plots were subsequently used to calculate the volumetric water contents of all the other gravimetric soil water samplings according to Gardner (1965).

A computerized procedure for applying Duncan's new multiple range test within an analysis of variance by the SAS Institute (1990) was used to assess statistical significance of the treatments. Snowcover water equivalent, soil water content, soil bulk density, and forage yield as affected by alfalfa variety and subsoil treatment were evaluated with respect to plot location (wind-sheltered or open-field). Significance was interpreted at the 5% probability level.

RESULTS AND DISCUSSION

Autumn soil water

The mean soil water content determined from samples taken within each plot every autumn in anticipation of over-winter recharge did not differ significantly between the paired plots for plowed and non-plowed treatments in 36 out of 36 comparisons during the six years following subsoiling (Table I). Results were the same at all depth layers and for the layers combined over the 1.2-m profiles. Neither the three alfalfa varieties nor the plot position within or outside the grass wind-shelter strongly affected autumn soil water reserves. Alfalfa is capable of transpiring large volumes of water

Table I: Mean* volumetric soil water content (%) measured within 1.2 m of the surface in the autumn before the onset of snowfall; data were averaged from three or more cores per plot and arranged by Paraplow and non-plow treatments; each plot was seeded in May 1986 to one of three varieties of alfalfa (cv. Rangelander, Beaver, Angus)

Year	Rangelander		Beaver		Angus		SE†
	Plowed	Not plowed	Plowed	Not plowed	Plowed	Not plowed	
	% by volume						
	Open, no wind shelter						
1986	20.5a	21.0a	19.9a	21.2a	19.7a	20.3a	3.0
1987	12.3a	11.7a	12.0a	12.0a	12.1a	12.2a	1.2
1988	11.9a	12.0a	12.1a	12.0a	11.9a	12.4a	1.1
1989	12.5a	12.8a	12.8a	13.2a	13.0a	12.9a	1.0
1990	10.5a	10.9a	10.8a	11.1a	10.7a	10.8a	1.0
1991	10.5a	10.8a	10.9a	10.7a	10.6a	10.7a	1.4
	Sheltered by grass windbreak						
1986	20.3a	20.8a	20.7a	20.1a	20.6a	20.7a	2.1
1987	12.8a	12.4a	12.3a	12.2a	12.3a	12.5a	1.1
1988	11.7a	11.5a	11.5a	11.8a	11.9a	11.6a	1.6
1989	14.0a	14.3a	13.7a	13.9a	14.0a	14.0a	1.2
1990	11.0a	11.0a	10.7a	11.2a	10.6a	10.4a	1.4
1991	11.0a	11.6a	11.6a	10.9a	11.5a	11.4a	1.2

* Averages followed by the same letter within a row are not significantly different at the 5% level according to Duncan's New Multiple Range Test.

† SE = Standard error of the mean based on 15 soil cores per treatment except in 1986 when 30 cores per treatment were taken

Table II: Mean* snow water equivalent covering plots on date of snow survey, averaged according to alfalfa variety (Rangelander, Beaver, or Angus) and subsoiling treatment (Plowed = subsoiled with Paraplow, Not plowed = no subsoiling); the snowcover over each plot was measured at 10 to 30 locations for depth and 3 to 5 locations for specific gravity

Date†	Rangelander		Beaver		Angus		SE‡
	Plowed	Not plowed	Plowed	Not plowed	Plowed	Not plowed	
	mm						
	Open, no wind shelter						
14 Jan 1986	49a	51a	48a	53a	47a	52a	9.4
11 Feb 1988	16a	18a	20a	20a	17a	19a	4.1
19 Jan 1989	42b	45ab	45ab	47ab	44ab	52a	6.5
14 Mar 1990	21a	23a	22a	23a	22a	23a	2.4
30 Apr 1990§	28	28	28	28	28	28	-
1 Feb 1991	27a	27a	31a	32a	33a	30a	4.2
	Sheltered by grass windbreak						
14 Jan 1986	83a	63a	82a	66a	84a	70a	19.7
11 Feb 1988	52a	41a	50a	41a	50a	41a	10.8
19 Jan 1989	69a	61a	71a	67a	70a	64a	15.7
14 Mar 1990	22a	24a	22a	23a	22a	24a	1.5
30 Apr 1990	38a	34a	40a	28a	40a	34a	15.7
1 Feb 1991	41a	41a	51a	45a	47a	44a	14.2

* Means followed by the same letter within a row are not significantly different at the 5% level according to Duncan's New Multiple Range Test.
† Snowcover was insufficient for any measurement during 1987.
‡ SE = Standard error of the mean obtained from 50 to 150 depth and 15 to 25 specific gravity observations per treatment
§ Warm temperatures forced measurements to be bulked for all plots in the open field.

(Halvorson and Reule 1980) and, in most years, tended to withdraw nearly all the water available in each plot regardless of treatment. Thus, after the alfalfa became established, all plots could be expected to approach winter with uniformly low soil water reserves. The three varieties of alfalfa removed less water from the soil during 1986, the year of seedling establishment, than in subsequent years. This fact plus abundant rainfall during September and October resulted in the relatively large reserves of water measured in the autumn of 1986.

Snowcover water equivalent

The mean areal water equivalent of the snow covering the plots did not differ significantly between the plowed and non-plowed pairs in all 33 comparisons resulting from the snow surveys (Table II). Snowcovers were highly variable as indicted by the large standard errors, but with a tendency for the strips on the west half of the windbreak system to retain more snow than the east strips (Fig. 1). Two snow surveys were conducted in 1990. The April survey reflected snowcover magnitudes retained from one storm which deposited more snow than that which had accumulated during the entire winter (March 1990). The snow survey data showed that while grass wind shelters retained more snow than the open field, paraplowing, as might be expected, exerted limited influence on snowcover accumulation.

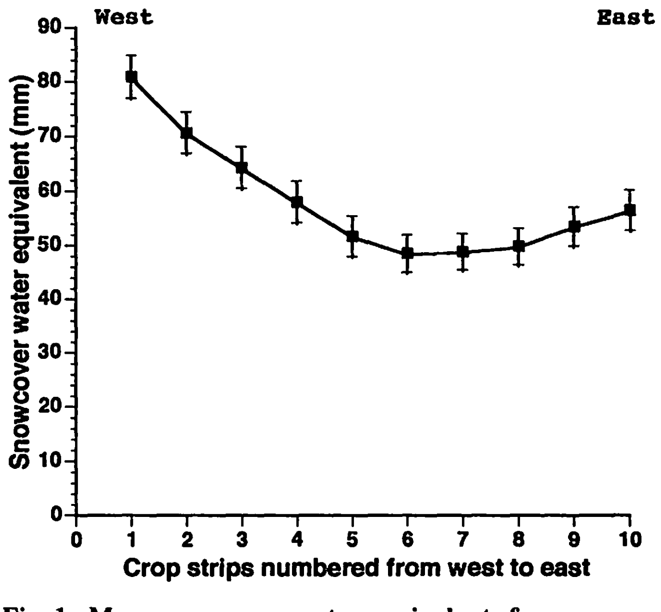

Fig. 1. Mean snowcover water equivalents for crop productions strips (14.0 m wide) numbered from west to east within the tall wheatgrass shelter averaged from yearly snow surveys, 1986-1991. Bars reflect the standard errors associated with each point. (Snowcover was insufficient for any measurement during 1987.)

Table III: Mean* volumetric soil water content (%) measured within 1.2 m of the surface in April after snowmelt; data were averaged from three or more cores per plot and arranged by Paraplow and non-plow treatments; each plot was seeded in May 1986 to one of three varieties of alfalfa (cv. Rangelander, Beaver, Angus).

Year	Rangelander		Beaver		Angus		SE†
	Plowed	Not plowed	Plowed	Not plowed	Plowed	Not plowed	
	% by volume						
	Open, no wind shelter						
1987	20.5a	19.9ab	19.3b	19.6ab	20.2ab	20.3a	1.8
1988	12.9a	12.6ab	13.1a	11.9b	12.4ab	12.1b	0.9
1989	15.0b	15.6ab	15.5ab	15.5ab	15.9ab	16.6a	2.2
1990	15.0a	14.6a	14.7a	14.9a	15.1a	14.7a	1.5
1991	15.7a	15.5a	14.5a	14.4a	14.2a	15.6a	2.2
	Sheltered by grass windbreak						
1987	22.9a	22.0a	22.2a	21.6a	22.0a	22.0a	2.4
1988	14.8a	13.8a	14.6a	13.5a	14.1a	13.4a	1.8
1989	20.7a	19.8a	20.1a	21.0a	19.6a	19.9a	4.3
1990	18.1a	16.9a	18.6a	17.4a	17.7a	17.6a	2.8
1991	15.5a	16.2a	16.7a	16.2a	16.1a	16.3a	2.6

* Means followed by the same letter within a row are not significantly different at the 5% level according to Duncan's New Multiple Range Test.

† SE = Standard error of the mean based on 15 soil cores per treatment except in 1987 when 30 cores per treatment were taken.

Spring soil water and over-winter recharge

Soil sampling for water content in April and the previous autumn of each year (1987-1991) allowed comparisons of the over-winter recharge in each plot. The mean soil water reserves (for each depth increment and in combination to 1.2 m) and the over-winter recharge did not differ significantly between the plowed and non-plowed treatment pairs in 29 out of 30 comparisons during the five years following subsoiling and alfalfa establishment (Table III, Fig. 2). Neither alfalfa variety nor position of the plot within or outside the windbreak system statistically affected differences in spring soil water content and recharge between plow treatments. In every year, over-winter recharge and spring water volumes tended to be greater within the wind shelter than in the open (Fig. 2). Sheltered plots contained more soil water than plots in the open-field at the start of each growing season.

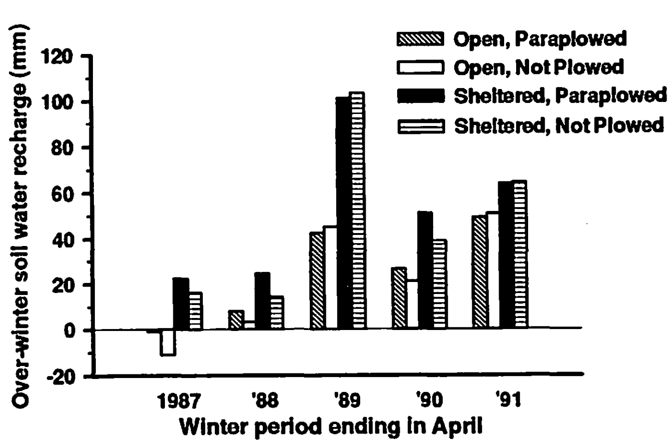

Fig. 2. Mean over-winter water recharge (mm) within 0-1.2 m of soil in open-field and grass-sheltered alfalfa plots averaged by Paraplow and non-plowed treatments.

Forage yields

Mean annual forage yields for the three varieties combined did not differ significantly between the plowed and non-plowed treatments whether compared within or outside the windbreak shelter (Fig. 3). Comparisons within individual alfalfa varieties showed similar results (data not shown). As with the snowcover and soil water, notable differences in forage yield (ignoring the 8% windbreak area) were measured between wind-sheltered and open-field alfalfa. In ten comparisons between sheltered and open alfalfa during 1987-1991 for plowed and non-plowed plot pairs, the lowest difference in yield equalled 228 kg/ha (9%) with all ten comparisons favoring the wind shelter system (maximum yield difference = 1284 kg/ha).

In our trials with alfalfa, the Paraplow treatment did not improve hay crop yields even where snow management with grass windbreaks increased snowcover and spring soil water. These results did not follow the findings obtained from subsoiling tests with annually-seeded crops (Gray et al. 1986; McConkey et al. 1990a) where subsoiling proved advantageous when included with snow management. The soil bulk density measurements taken two years after subsoiling showed a distinct trend toward lower densities in the top 0.3

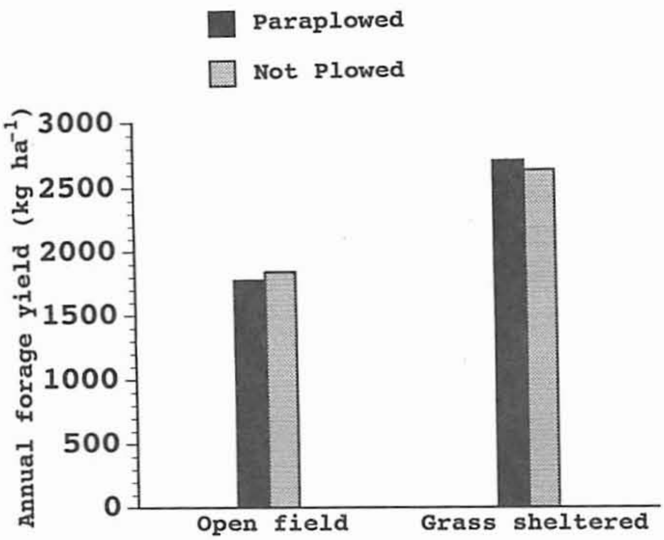

Fig. 3. Mean annual alfalfa forage yields in open-field and grass-sheltered plots for 1987-91 (No adjustment for the 8% area occupied by the windbreaks).

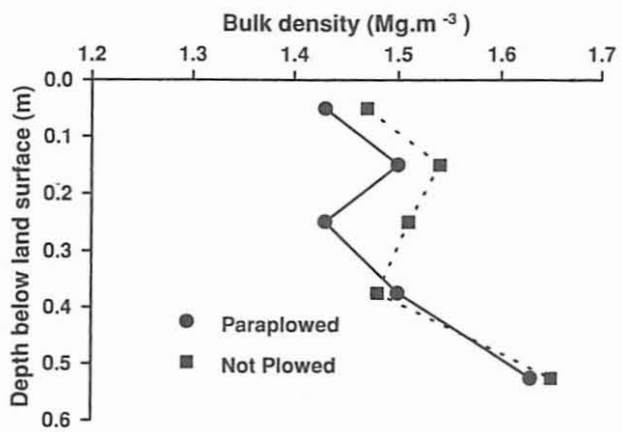

Fig. 4. Mean bulk densities from soil core sections to 0.6 m taken two years after treatments, averaged (N = 30 per point) for Paraplow and no subsoiling. (The only difference in bulk densities statistically significant at $p < 0.05$ was the 0.2-0.3 m depth layer.)

m of the plowed plots (Fig. 4). The differences, however, were only significant in the 0.2-0.3 m depth increment and were not significant when the data were separated by the three alfalfa varieties. Despite this trend toward lower bulk densities following subsoiling, which parallels those found by others (Muktar et al. 1985; Grevers 1988, 1989; McConkey et al. 1990a), Paraplowing did not improve water intake nor forage yield. Many possible reasons could be presented to explain these results: differences in subsoilers, depth of subsoiling, evapotranspiration effects, frozen waters at the soil surface, etc. However, the most likely reason is that when soils are covered by perennial vegetation, such as alfalfa, they commonly acquire an ability to infiltrate most if not all the available surface water; the subsoiling appeared not to have improved upon this capability (Holtan and Kirkpatrick 1950). In our study, the magnitude of the over-winter soil water recharge correlated with the accumulated over-winter precipitation (November to April) caught in the standard gauge. Catches of 113, 80, 72, 66, and 41 mm (for 1989, 1991, 1990, 1987, and 1988) resulted in the same sequence of years reflecting the amount of soil water recharge (Fig. 2) from high to low. This implies that all the plots sown to alfalfa consistently infiltrated the bulk of the over-winter water available each year.

CONCLUSIONS

Snow management to increase soil water includes efforts to maximize the infiltration of the meltwater from enhanced snowcovers. Subsoiling with a Paraplow in autumn 1985 prior to seeding alfalfa the following spring within and outside a tall wheatgrass windbreak system proved ineffective in promoting soil water infiltration and increasing forage yields. These results applied to both the open-field and wind-sheltered plots, although snowcovers, soil water, and forage yields were consistently enhanced by the shelter for five production years (1987-1991) following treatments. Therefore, subsoiling with a Paraplow is not recommended for dryland alfalfa on Chernozemic silt-loam soils in the semiarid zones of southern Saskatchewan.

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