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Grazing effects on soil water in Alberta foothills fescue grasslands

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Abstract

Grazing can have a profound impact on soil water through its influence on infiltration via treading and on evapotranspiration through defoliation. Hydrologic changes in rangelands are most often associated with heavy grazing intensities although these changes do not increase linearly with grazing intensity. The objectives of this study were to quantify the impacts of grazing on the soil water regimes of sloped areas of the foothills fescue grasslands of Alberta. The study site was located at the Agriculture Canada Research Station at Stavely, Alberta. The effects of 2 grazing intensities (heavy = 2.4 AUM ha^{-1} and very heavy = 4.8 AUM ha^{-1}) for 2 grazing treatments (short duration = 1 week in mid-June and continuous grazing = May through October) were compared to an ungrazed control. The study was initiated in June 1988 and ended in April 1991. Surface soil water and soil water with depth were measured throughout each growing season using a neutron probe.

Surface soil water (0 to 7.5 cm) across slope positions was lowest in the control and highest in the continuous very heavy treatments, but the trend in profile soil water (to 50 cm) was the opposite. Total profile soil water in the short duration very heavy treatment was greater than that in the continuous very heavy treatment, while soil water in the short duration heavy treatment was similar to that in the continuous heavy treatment.

Vegetation at the study site was regularly water-stressed, as evidenced by soil water that was often below permanent wilting point, generally by mid-summer each year. Soil was near or below permanent wilting point in the autumn, regardless of its status throughout the growing season. Profile soil water was similar across treatments in autumn, indicating vegetation is using all available soil water. In contrast, soil water was generally near or above field capacity every spring, indicating the importance of snowmelt infiltration in these ecosystems.

Only major (greater than 75 mm) summer rainstorms recharged soil water to field capacity. Thus it is concluded that maintenance of a vegetative cover that will trap snow for potential snowmelt infiltration is critical to soil water recharge of these ecosystems. Any grazing management regime that enhances litter accumulation and carryover should facilitate such snowmelt soil water recharge.

Key Words: soil water, grazing effects, hydrology, fescue grasslands, evapotranspiration

Grazing, through its potential effects on near-surface soil physical properties can alter infiltration rates, and thus soil water. Liacos (1962), comparing ungrazed, lightly grazed, and heavily grazed treatments in California, found that soil water was always low under heavy grazing due to low infiltration and percolation rates. Calculated net rain interception loss was 10 mm greater in ungrazed than heavily grazed treatments and 7.5 mm greater than if lightly grazed. Infiltration rates in New Mexico were significantly higher in ungrazed than grazed treatments, but no differences were found between heavily and moderately stocked treatments (Gamougoun et al. 1984). Reduced infiltration rates as stocking density increased were also found by Warren et al. (1986b) in Texas.

In mixed prairie of the Northern Great Plains of South Dakota, the spring to fall change in soil water decreased with decreasing range condition (over a 122-cm soil profile: 101 mm, 84 mm, and 65 mm under high, medium, and low range condition, respectively) which the authors attributed to standing vegetation and mulch (Hanson and Lewis 1978). Water use by native grassland in southwest Saskatchewan over a 4-year period ranged from 21.5 to 35.5 cm, averaging 29.4 cm and accounted for approximately 90% of the annual precipitation (32.6 cm) (de Jong and MacDonald 1975). Little change occurred in soil water over time at depth intervals of 75 to 105 and 105 to 135 cm. Soil water was always higher in ungrazed exclosures compared to short duration grazed treatments near Fort Macleod, Alberta (Dormaar et al. 1989). At Stavely, Alberta on flat, grazed areas, soil water below 15 cm was highest during dry periods in the control and lowest under very heavy grazing; soil water in moderate and heavy treatments were similar. During a wet period, highest soil water was highest in the light and moderate treatments and lowest in heavy and very heavy treatments (Naeth et al. 1991a). Lowest surface soil water (0 to 7.5 cm) was often in the control which was more similar to heavy and very heavy grazing than to light and moderate grazing; water in very heavily grazed treatments was evaporated more readily (more bare ground) and that in the control was held in the heavy litter layer (Naeth et al. 1991b) or used by the dense vegetation. Infiltration rates were also reduced by heavy grazing (Naeth et al. 1990).

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Intensive rotational grazing systems have been proposed as alternatives to season-long grazing to mitigate the deleterious effects of grazing on soil properties. Abdel-Magid et al. (1987), in evaluating continuous, rotationally deferred, and short duration rotational grazing systems, found that grazing systems did not consistently influence infiltration, and short duration rotational grazing had no clear advantage for improving infiltration by surface crust destruction. Gamougoun et al. (1984) found infiltration rates under rotational treatments were lower than those in exclosures or continuous grazing treatments. Infiltration rates declined following short-term intense grazing: the detrimental effect was significant during periods of drought or winter dormancy, but not during periods of active plant growth (Warren et al. 1986a).

Rangelands are considered to be water-limited ecosystems. Soil water may be low due to poor infiltration and/or high evapotranspiration. These 2 processes are affected by grazing. Few studies have compared continuous season-long grazing with short duration grazing and ungrazed controls. The objectives of this study were to compare the effects of season-long continuous grazing and short duration grazing at both heavy and very heavy grazing intensities on soil water status, recharge (infiltration), and evapotranspiration rates. It was hypothesized that soil water status would be highest under the ungrazed control, intermediate in the short duration grazing treatments, and lowest in the continuously grazed treatments.

Study Site Description

The study site is located at the Agriculture Canada Stavely Range Substation approximately 100 km northwest of Lethbridge, Alberta. Approximate latitude is 50° N and longitude is 114° W. Annual precipitation is approximately 550 mm with 40% occurring as snow. May to September precipitation is 230 to 370 mm (Strong and Leggat 1981). Evaporation is low and Chinook winds moderate the climate during the winter. Air temperature fluctuates widely with a mean annual temperature of 5° C; the January mean is -10° C and the July mean is 18° C. There are approximately 230 growing days and the average frost free period is 25 days.

The topography is generally hilly and slopes on the study site range from 18 to 37%. Average slope is 21, 25, and 32% for the upper-, mid-, and lower-slope positions, respectively. Soils are generally fertile and well drained. Black surface soil averages 8 to 10 cm in thickness with 5 cm on the uplands and 15 to 18 cm in gently rolling flats. Depth to the C horizon is approximately 60 cm. Soils are dominated by Orthic Black Chernozems (Typic Cryoboroll) (Walker et al. 1991). Soil texture to 30 cm is generally clay loam, and clay loam-loam below.

Festuca campestris Rydb. (rough fescue) dominates ungrazed and lightly grazed areas; *Danthonia parryi* Scribn. (Parry's oatgrass) dominates heavily grazed areas and exposed sites with thin soils. There are a variety of subdominant grasses, forbs, and shrubs. Johnston et al. (1971) found lightly and heavily grazed fields were dominated by *Festuca campestris* and *Danthonia parryi*, respectively. Under very heavy grazing, *Festuca campestris* and litter were virtually eliminated. *Populus tremuloides* Michx. (trembling aspen) encroached upon lightly and moderately grazed grassland.

The area had been moderately stocked with cattle for summer grazing from 1884 to 1908, with horses from 1908 to 1920, then again with cattle from 1920 to 1944 (Johnston 1961). It was heavily grazed during the drought years of the thirties then lightly used as winter range from 1944 to 1949 at which time the continuous grazing treatments were established. The area where the short duration treatments were established in 1984 had been ungrazed or lightly grazed since 1949.

Research Design and Methods

Site Establishment

In 1988, research sites were established with treatments contrasting between the historical grazing regime (continuous throughout the growing season) and short duration, high intensity grazing. Continuous treatments were grazed from May through October; short duration treatments were grazed for 1 week in mid-June. Heavy and very heavy stocking densities at 2.4 and 4.8 AUM ha^{-1}, respectively, represent common grazing intensities for the area.

The short duration treatments consisted of two 30 by 120 m grazed strips and a 10 by 120 m ungrazed control each replicated 3 times, running down slope in a randomized split block design. The continuous treatments were located approximately 0.5 km from the short duration sites and designed in a similar manner minus the control. The control treatment for the short duration treatments and exclosures in the continuous treatments were not significantly different (soils, vegetation, etc.) thereby obviating a second control series for this study. All treatments faced east.

Meteorological Conditions

Daily air temperature and precipitation were measured at the study site, generally from mid-April to mid-November, depending upon the time of snowmelt and freeze-up. Daily values for these 2 parameters were obtained for 1988 to 1991, inclusive, and compared to the long-term normal parameters for the nearest monitoring station 50 km away (Claresholm).

Soil Water

Aluminum access tubes were installed in late May 1988 to depths of 60 to 90 cm: 3 access tubes were installed per grazing treatment in each of upper-slope, mid-slope, and lower-slope positions. Stones prevented all tubes from being installed to a uniform depth.

Soil water with depth was measured monthly throughout the growing season using a Campbell Pacific Nuclear 503 moisture depthprobe, starting at 15 cm and continued at 10-cm depth intervals. Surface soil water (0 to 7.5 cm) was measured adjacent to the access tubes on the same dates with a surface shielded neutron probe (Chanasyk and Naeth 1988). The first post-snowmelt soil water measurement date is hereafter referred to as 'spring' and the last measurement date of the season, usually in October, is hereafter referred to as 'autumn'.

Soil water calculated as a volume percent from field recorded counts was converted to soil water expressed as a depth and then summed to a common depth of 50 cm for treatment comparisons. Evapotranspiration (ET) was calculated as the difference between precipitation (measured on site) and change in soil water for a given period of time, assuming no runoff (runoff was measured and generally found negligible; Naeth and Chanasyk 1995), percolation below the root zone or lateral flow of water (due to generally low soil water and thus low hydraulic conductivities).

Statistical Analyses

For each parameter, significant differences of the means were detected using Analysis of Variance techniques with design following the convention outlined in the SPSS-X User Manual (SPSS 1988) for split blocks. Significant effects were further evaluated using Duncan's Multiple Range Test at the 10% level of significance (Steel and Torrie 1980).

Results and Discussion

Meteorological Conditions

Annual precipitation at Claresholm was 53% of the long-term normal in 1988 and close to it in 1989, 1990, and 1991. Overwinter precipitation (November 1 to March 31, inclusive) was 127, 105, and 170 mm for 1988 to 1989, 1989 to 1990, and 1990 to 1991, respectively. Study site precipitation was high in August 1988; May, July, and August 1990; May and June 1991; and low in May and July 1988, September 1990, July and September 1991 (Table 1). Total May to October precipitation was similar in 1988 and 1989 (1988 monthly extremes, 1989 more even distribution), highest in 1990 and intermediate in 1991. Monthly precipitation at Stavely and Claresholm was similar and often within 5 mm of each other.

Mean annual air temperature at Claresholm (data not shown) was near the long-term normal in 1989 and above it in 1988 (1.7° C), 1990 (0.6° C), and 1991 (1.2° C). Mean monthly air temperature was often above normal throughout the study period, especially during winter months (except February and March 1989 which were very cold). During the 1988 growing season, average air temperature was above normal each month with maximum air temperatures reaching 33° C in late June and July.

Table 1. Precipitation (mm) for Stavely Range Research Station.

Month	1988	1989	1990	1991
	(mm)			
May	17.0	28.7	85.9	73.4
June	58.4	45.7	46.2	124.0
July	15.2	36.6	99.1	4.1
August	108.5	54.9	90.4	24.6
September	20.6	40.1	7.9	16.0
October	10.2	26.9	15.2	44.7
May to October	229.9	232.9	344.7	286.8

Surface Soil Water

Across slope positions, surface soil water (0 to 7.5 cm) was consistently lowest in the ungrazed control, highest in the short duration very heavy, continuous heavy, and continuous very heavy and intermediate in short duration heavy treatments (Table 2). These results are likely due to large vegetation and litter biomasses in the control which intercepted precipitation; their absence under heavier grazing would increase surface soil water. Note that litter covered 65, 68, and 88% of the ground; standing litter height was 37, 49, and 60 cm; fallen litter was 0.2, 2.2, and 13.4 cm; each under very heavy, heavy, and control treatments, respectively (Naeth et al. 1991c); water holding capacity of litter was 103, 124, and >132% under very heavy, heavy, and control treatments, respectively (Naeth 1988). These surface soil water results differ from those of Dormaar et al. (1989), although these authors measured soil water only during the spring and autumn of 2 study years.

Table 2. Date-averaged and depth-averaged surface (0 to 7.5 cm) soil water ($cm^3/cm^3 \times 100$).

Slope Position	Control	Grazing Treatment: Short duration heavy	Short duration very heavy	Continuous heavy	Continuous very heavy
	($cm^3/cm^3 \times 100$)				
Upper	15.2 c	18.1 b	20.3 a	18.6 ab	20.6 a
Mid	16.6 b	17.6 b	20.1 a	18.1 ab	19.8 a
Lower	16.1 c	18.5 b	20.3 ab	21.2 a	21.5 a

Numbers in a row followed by similar lowercase letters are not significantly different ($P<0.1$).

Soil Water With Depth

Soil water to 50 cm generally decreased as grazing intensity increased, although differences were not always statistically significant (Tables 3, 4, 5, 6). Soil water to 50 cm was generally highest in the control and lowest in the continuous very heavy treatment. Over the 4-year study, soil water to 50 cm at upper-slope was higher in the control than under continuous very heavy grazing on all but 4 measurement dates (Fig. 1). Soil water was highest at mid-slope on 13 of 19 measurement dates.

Mid-summer was the time of greatest soil water stress (Tables 3, 4, 5); annual soil water was lowest in July 1988, August 1989, October 1990, and August 1991. It was especially low in July 1988 with an average value of 57 mm. Permanent wilting point (1.5 MPa) for the study site, determined from pressure plate apparatus (Naeth 1988) and measured bulk densities, was 95 mm for a 50-cm profile. Thus soil water to 50 cm was below permanent wilting point in approximately 50% of all date-treatment combinations for a given slope over the 4-year study (Tables 3, 4, 5). Note that in 1988, soil water was near or below permanent wilting point on all dates. Precipitation in August 1988 was high (108 mm) but of the 37 mm that occurred just prior to measure-

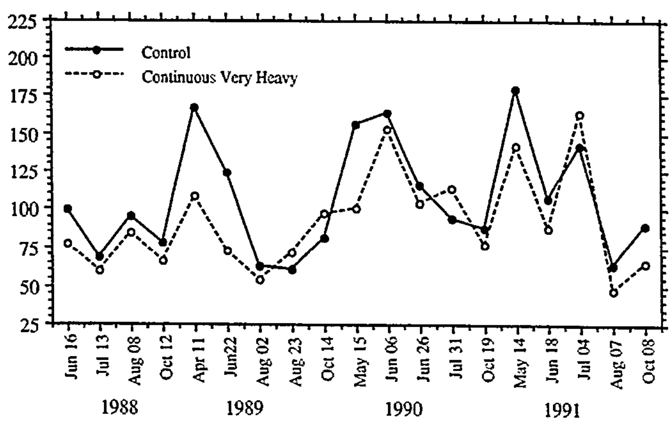

Fig. 1. Soil water content to a 50 cm depth in the control and continuous very heavy grazing

Table 3. Soil water (mm) to 50 cm in the upper-slope position.

Date	Precipitation	Control	Short duration heavy	Short duration very heavy	Continuous heavy	Continuous very heavy	SE	Probability
		Grazing treatment						
	(mm)	(mm)						
1988								
June 16	—	99 a	84a	82a	91a	77 a	5.4	0.180
July 13	27.9*	68 a	70 a	65 ab	54 b	59 b	2.8	0.020
Aug 08	57.2	95 ab	96 a	103 a	104 a	84 b	4.0	0.040
Oct 12	69.3	78 a	78 a	70 a	67 a	66 a	3.8	0.150
1989								
April 11	—	167 a	135 b	122 bc	135 b	108 c	7.2	0.002
June 21	66.8	124 a	107 b	88 c	95 c	72 d	3.4	0.000
Aug 02	52.8	63 a	60 a	59 a	57 a	54 a	2.5	0.210
Aug 23	27.4	60 b	68 b	64 b	86 a	71 ab	5.9	0.080
Oct 14	74.9	81 a	87 a	84 a	94 a	97 a	4.3	0.140
1990								
May 15	—	156 a	129 a	136 a	138 a	100 b	10.9	0.050
June 06	100.3	164 a	167 a	164 a	152 b	153 b	3.9	0.050
June 26	26.4	115 a	118 a	117 a	112 a	103 a	4.2	0.140
July 31	86.1	94 b	95 b	91 b	116 a	113 a	5.1	0.020
Oct 19	100.8	87 a	86 a	82 a	83 a	77 a	2.7	0.120
1991								
May 14	—	108 a	182 a	167 b	178 ab	142 c	4.9	0.001
June 18	41.4	107 a	107 a	97 b	93 bc	87 c	3.0	0.004
July 04	124.7	142 a	148 a	148 a	154 a	164 a	5.3	0.120
Aug 07	4.6	64 a	71 a	70 a	62 a	48 a	5.7	0.340
Oct 08	34.5	90 a	87 ab	82 bc	80 c	65 d	2.1	0.000

*Precipitation for the preceding period, in this case June 16 to July 13.
Numbers within a row followed by the same letters are not statistically significant ($p<0.1$).

ment on 18 August, 12 to 18 mm ran off the grazed treatments (Naeth and Chanasyk 1995).

Average field capacity (0.033 MPa) for these soils is 155 mm for a 50-cm profile (Naeth 1988). Soil water exceeded or was close to this value on only 5 measurement dates over the 4-year study: 11 April 1989 (only control upper-slope and continuous

Table 4. Soil water (mm) to 50 cm in the mid-slope position.

Date	Precipitation	Control	Short duration heavy	Short duration very heavy	Continuous heavy	Continuous very heavy	SE	Probability
		Grazing treatment						
	(mm)	(mm)						
1988								
June 16	—	89 a	79 a	78 a	75 a	78 a	5.1	0.520
July 13	27.9 *	60 a	57 a	62 a	54 a	56 a	5.0	0.850
Aug 08	57.2	98 a	79 a	93 a	96 a	85 a	5.5	0.190
Oct 12	69.3	69 a	53 c	61 b	67 ab	66 ab	2.7	0.010
1989								
April 11	—	S	S	S	193 a	152 a	7.4	0.040
June 21	66.8	125 a	117 a	125 a	117 a	91 b	4.2	0.001
Aug 02	52.8	69 ab	65 b	76 a	69 ab	56 c	2.7	0.005
Aug 23	27.4	81 b	68 c	94 a	80 b	66 c	4.5	0.008
Oct 14	74.9	99 a	82 a	88 a	91 a	95 a	4.2	0.180
1990								
May 15	—	162 a	162 a	158 a	163 a	107 b	4.1	0.000
June 06	100.3	160 a	161 a	161 a	158 a	154 a	3.1	0.530
June 26	26.4	127 a	128 a	125 a	135 a	99 b	4.6	0.003
July 31	86.1	126 b	140 a	144 a	123 b	104 c	3.7	0.000
Oct 19	100.8	98 a	92 ab	101 a	85 b	81 b	4.2	0.030
1991								
May 14	—	166 b	176 ab	181 a	191 a	148 c	5.5	0.003
June 18	41.4	114 a	114 a	115 a	99 b	89 c	2.1	0.000
July 04	124.7	154 a	158 a	158 a	159 a	155 a	4.0	0.860
Aug 07	4.6	79 b	73 b	93 a	82 b	61 c	4.2	0.004
Oct 08	34.5	91 a	84 a	90 a	82 a	78 a	3.5	0.120

* Precipitation for the preceding period, in this case June 16 to July 13.
Numbers within a row followed by the same letters are not statistically significant ($p<0.1$).
S = covered in snow.

Table 5. Soil water (mm) to 50 cm in the lower-slope position.

Date	Precipitation	Grazing treatment: Control	Short duration heavy	Short duration very heavy	Continuous heavy	Continuous very heavy	SE	Probability
	(mm)	(mm)						
1988								
June 16	—	82 a	82 a	71 b	72 b	71 b	2.5	0.010
July 13	27.9 *	52 a	55 a	50 a	44 b	51 a	2.2	0.050
Aug 08	57.2	81 a	95 a	93 a	78 a	81 a	6.5	0.310
Oct 12	69.3	59 ab	64 a	54 b	54 b	57 b	2.4	0.080
1989								
April 11	—	S	S	S	189 a	180 a	14.0	0.730
June 21	66.8	115 a	116 a	102 b	120 a	98 b	3.6	0.005
Aug 02	52.8	61 bc	65 ab	64 ab	69 a	57 c	1.8	0.001
Aug 23	27.4	62 a	67 a	70 a	66 a	61 a	6.6	0.850
Oct 14	74.9	88 a	94 a	93 a	92 a	91 a	3.7	0.860
1990								
May 15	—	157 ab	164 a	142 bc	142 bc	124 c	7.1	0.020
June 06	100.3	153 a	158 a	152 a	163 a	159 a	4.4	0.490
June 26	26.4	129 ab	130 ab	121 b	133 a	110 c	4.0	0.010
July 31	86.1	119 b	122 ab	114 bc	129 a	107 c	3.4	0.010
Oct 19	100.8	91 a	86 a	82 a	87 a	80 a	4.3	0.460
1991								
May 14	—	163 a	166 a	160 a	177 a	165 a	5.2	0.250
June 18	41.4	100 b	102 b	96 b	123 a	114 a	4.4	0.001
July 04	124.7	147 c	153 bc	144 c	158 ab	163 a	3.9	0.030
Aug 07	4.6	76 a	87 a	76 a	85 a	77 a	5.2	0.450
Oct 08	34.5	89 a	88 a	82 a	79 a	74 a	3.9	0.120

* Precipitation for the preceding period, in this case June 16 to July 13.
Numbers within a row followed by the same letters are not statistically significant ($p<0.1$).
S = Covered in snow.

heavy and continuous very heavy middle and lower-slope; note other treatments covered in snow), 15 May 1990 (control upper-slope, all except continuous very heavy middle-slope, control and short duration heavy lower-slope), 6 June 1990 (all treatments and slope positions), 14 May 1991 (not continuous very heavy upper- or middle-slope) and 4 July 1991 (all treatments and slope positions close or above) (Tables 3, 4, 5).

Snowmelt infiltration usually recharged soil water to field capacity, although lowest post-snowmelt soil water levels were always in the continuous very heavy treatment. Nineteen ninety snowmelt infiltration did not raise soil water to field capacity in the upper slope position (except in the control) but subsequent precipitation did (Tables 3, 4, 5). There were 99 mm of precipitation between 24 May and 6 June 1990, resulting in high soil water levels on this latter date. The high soil water on 14 May 1991 was largely due to snowmelt infiltration (only 37 mm of rain between 12 April and 14 May although 31 mm occurred 3 days prior to measurement). The high soil water on 4 July 1991 was due to high precipitation during the period 19 to 30 June (121 mm; 48 mm occurred on 21 June). Thus large amounts of precipitation are required to recharge the 50-cm soil profile to field capacity, with greater amounts required the later in the growing season the event occurs due to generally lower profile soil water.

Spring soil water (Tables 3, 4, 5, 6) was generally lowest in the continuous very heavy treatment, similar in short duration heavy, and continuous heavy treatments, but usually higher in the short duration very heavy than the continuous very heavy treatments. Trends across slope position were evident only for continuous very heavy grazing, for which soil water increased moving downslope.

Autumn soil water was less than 101 mm in a 50-cm profile in all treatments for all 4 study years; thus near or at permanent wilting point each year (Tables 3, 4, 5, 6). Autumn soil water for a given treatment was amazingly consistent across the 4 years for all slope positions, regardless of soil water status earlier in the growing season (contrast 1988 and 1990). Autumn was not generally the time of minimum soil water; that usually occurred in July or August (during the growing season).

Overwinter soil water recharge was most different between the control and the continuous very heavy treatment (Tables 3, 4, 5, 6), likely due to differences in the amount of standing and fallen litter. The critical importance of snowmelt infiltration to soil water recharge is evident from the data and clearly emphasizes the need for snow management strategies to enhance soil water on these rangelands. The higher the amount of standing and fallen litter, the higher the amount of snow trapped, and the higher the potential for recharge. For example, for the upper slope position on 14 October 1989 (Table 3), profile soil water was 16 mm higher for the continuous very heavy treatment than for the control but on 15 May 1990 soil water was much higher for the control (156 mm) than for continuous very heavy (100 mm). Precipitation from mid-April to mid-May was only 30.7 mm, but undoubtedly partially recharged soil water. The remaining water gained was due to higher snowmelt infiltration, a result of greater snow accumulation and infiltration on the control (Naeth and Chanasyk 1995).

In contrast to the large annual increases in soil water due to snowmelt infiltration (Table 6: overwinter increases averaged 77 mm across dates, treatments, and slope positions), on only 2 dates during the study was there a notable increase in soil water due to

Table 6. Date-averaged soil water (mm) to 50 cm.

Slope Position	Control	Short Duration Heavy	Short Duration Very Heavy	Continuous Heavy	Continuous Very Heavy
	Grazing Treatment				
	(mm)				
Average of all Dates					
Upper	115 (10) a	111 (9) a	103 (9) a	104 (8) a	87 (8) b
Mid	114 (9) a	110 (10) a	113 (9) a	110 (10) a	92 (8) a
Lower	107 (10) a	108 (9) a	99 (8) a	102 (10) a	96 (9) a
Autumn					
Upper	88 (5) a	87 (3) a	79 (5) a	79 (4) a	67 (13) a
Mid	91 (14) a	78 (17) a	84 (17) a	81 (8) a	77 (13) a
Lower	83 (16) a	84 (13) a	76 (17) a	75 (15) a	74 (15) a
Spring					
Upper	182 (10) a	167 (14) a	148 (13) b	150 (11) b	115 (10) c
Mid	177 (9) a	177 (10) a	176 (13) a	188 (12) a	132 (20) b
Lower	179 (10) a	171 (2) a	153 (11) a	163 (19) a	145 (19) a
Spring-Autumn					
Upper	92 (8) a	79 (14) a	67 (13) a	70 (13) a	44 (13) b
Mid	81 (5) a	89 (13) a	82 (16) a	105 (15) a	55 (20) b
Lower	87 (6) a	84 (1) a	74 (8) a	84 (20) a	67 (19) a

Numbers in brackets are standard errors
Numbers in a row followed by similar lowercase letters are not significantly different ($P < 0.1$).

rainfall (6 June 1990 and 4 July 1991). For example, the average recharge on 4 July 1991 was 50 mm across treatments and slope positions (Tables 3, 4, 5).

Welker et al. (1991) found summer showers of <12 mm on an a western wheatgrass dominated grassland were depleted after a maximum of 2.4 days while soil water inputs from larger precipitation events were lost at a lower rate (1.56 mm day^{-1}) than those from lighter showers. At Stavely, during the study period, only 13, 14, 23, and 23% of the days with measured precipitation had precipitation >12 mm for 1988, 1989, 1990, and 1991, respectively (data not shown). The actual number of such days was 3, 6, 7, and 8 for the 4 study years, respectively. Hence the majority of summer precipitation events at the study site do not recharge soil water. Only major precipitation events greater than 75 mm noticeably recharge soil water.

Soil water was highest over the 4-year study on 14 May 1991 and near its lowest on 7 August 1991 (Fig. 1). Soil water distribution with depth (excluding the near-surface 0 to 7.5 cm depth interval) was compared among upper-slope treatments on these 2 dates (Fig. 2). On 14 May, soil water distributions were similar for all treatments except continuous very heavy which was lowest (Fig. 2a). Treatment differences in profile soil water became less evident by 7 August (Fig. 2b), when soil water in all treatments except continuous very heavy (lowest) were similar at all depths to, and including, 45 cm. Note soil water in the continuous very heavy treatment at 55 cm remained constant between May and August (compare Figures 2a and 2b), indicating a lack of water withdrawal by roots, likely due to only shallow rooted plants in this treatment (Naeth 1988). This is in sharp contrast to the other treatments which showed soil water withdrawal to the greatest depth of measurement. Again the effects of high intensity grazing on soil water are evident.

Evapotranspiration

Evapotranspiration was calculated from the equation ET = precipitation—change in soil water, (assumption of negligible runoff most applicable for the control: Naeth and Chanasyk 1995) considering the first and last measurement dates in a given year. Upper-slope control evapotranspiration was 308, 383, and 295 mm, for 1989, 1990, and 1991, respectively (Table 3), corresponding to average evapotranspiration rates of 1.7, 2.5, and 2.0 mm day^{-1}. For example for 1989, total precipitation for the period 11 April to 14 October was 222 mm while the decrease in soil water for the period was 86 mm; therefore for this period ET = 222 mm + 86 mm = 308 mm. The period covered 187 days; therefore, the daily evapotranspiration rate was 308 mm/187 day. Values for 1988 were not calculated because of the late date of first measurement (project initiation). These evapotranspiration magnitudes are similar to those reported by de Jong and MacDonald (1975), but are likely liberal as some runoff, although small, did occur (Naeth and Chanasyk 1995). Slope position had relatively little effect on these average evapotranspiration values (data not shown).

Evapotranspiration over the growing season was lowest in the continuous very heavy treatment in 10 of 12 year-slope combinations (data not shown; calculated using the data in Tables 3, 4, 5). evapotranspiration was lower under short duration very heavy compared to short duration heavy, although treatment differences were small. A smaller change in soil water indicates reduced evapotranspiration, likely a result of lower soil water and/or less plant biomass evapotranspiring. In contrast, with only one exception, the change in soil water over the growing season was lower in continuous very heavy compared to continuous heavy, with the average difference between treatments being 22 mm (data not shown).

From Figure 1, three periods of major soil water decline are evident: 11 April to 2 August, 1989; 14 May to 18 June, 1991, and 4 July to 07 August, 1991. Daily evapotranspiration for the control in the upper-slope position (using data for these 3 periods from Table 3) averaged 2.0, 3.2, and 2.3 mm day^{-1} for each of these periods, respectively. Interestingly, even though soil water was near or above field capacity for all treatments on 4 July

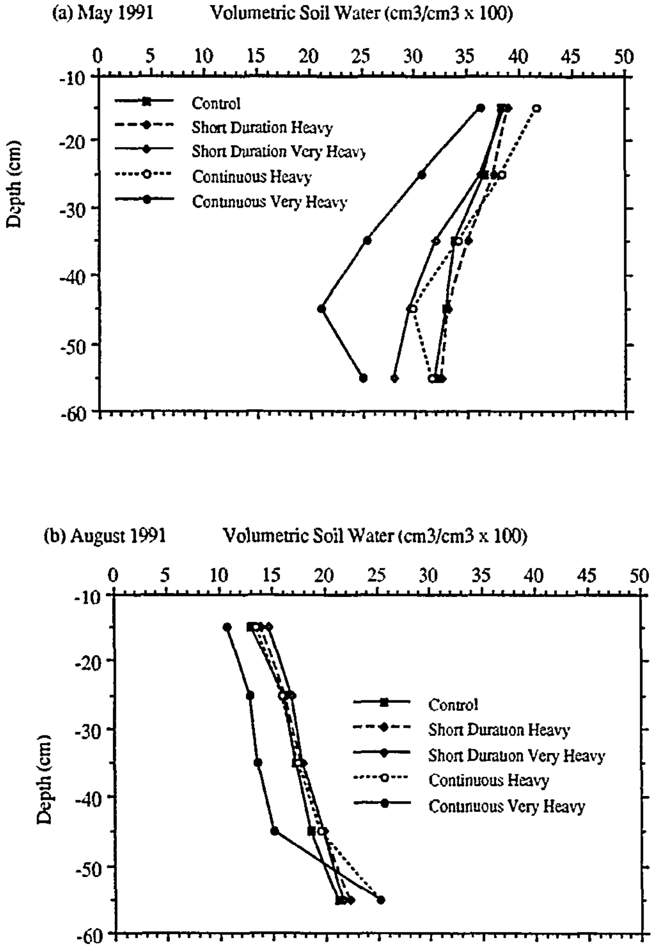

Fig. 2. Volumetric soil water with depth in (a) May 1991 and (b) August 1991.

1991, it was consistently below permanent wilting point by 7 August 1991, only 34 days later. The average evapotranspiration rate for this period for the upper slope position was 2.3 mm day^{-1} for the control, short duration heavy and short duration very heavy treatments; 2.7 mm day^{-1} for the continuous heavy treatment and 3.4 mm day^{-1} for the continuous very heavy treatment. Precipitation was only 4.6 mm during the period.

Summary and Conclusions

Surface soil water (0 to 7.5 cm) across slope positions was lowest in the control and highest in the continuous very heavy treatments, but the trend in profile soil water (to 50 cm) was the opposite. Total profile soil water in the short duration very heavy treatment was greater than that in the continuous very heavy treatment, while soil water in the short duration heavy treatment was similar to that in the continuous heavy treatment.

Vegetation at the study site was regularly water-stressed, as evidenced by soil water that was often below permanent wilting point, generally by mid-summer each year. Soil was near or below permanent wilting point in the autumn, regardless of its status throughout the growing season. Profile soil water was similar across treatments in autumn, indicating vegetation is using all available soil water. In contrast, soil water was generally near or above field capacity every spring, indicating the importance of snowmelt infiltration in these ecosystems.

Only major (greater than 75 mm) summer rainstorms recharged soil water to field capacity. Thus it is concluded that maintenance of a vegetative cover that will trap snow for potential snowmelt infiltration is critical to soil water recharge of these ecosystems. Any grazing management regime that enhances litter accumulation and carryover will likely facilitate such snowmelt soil water recharge.

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