Soil water regimes of annual and perennial forages during drought years in the Aspen Parkland ecoregion of Alberta

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Bradshaw, D. L., Chanasyk, D. S., Baron, V. S. and Naeth, M. A. 2007. **Soil water regimes of annual and perennial forages during drought years in the Aspen Parkland ecoregion of Alberta**. Can. J. Soil Sci. **87**: 523–533. Periodic and prolonged drought can be devastating to pasture production, which increases the financial risk for grazing enterprises. A study was conducted during 2 drought years (2002 and 2003) in the aspen parkland at Lacombe, Alberta, Canada, to compare the soil water regime of meadow bromegrass (*Bromus riparius* Rhem.), alfalfa (*Medicago sativa* L.), and annual [oat (*Avena sativa* L.) and winter triticale (*X Triticosecale* Wittmack)] pastures with a naturalized, old grass pasture consisting of quackgrass (*Elytrigia repens* L.), smooth bromegrass (*Bromus inermis* Leyss.), and Kentucky bluegrass (*Poa partensis* L.). The pasture soil was an Orthic Black Chernozem of fine sandy loam to loam texture. Soil water measurements were conducted between May and October over 2 yr using a neutron scattering hydroprobe to a depth of 1.6 m. Annual and meadow bromegrass had similar and highest cumulative and volumetric water contents and old grass had the lowest. All pastures tended to use all water available by the end of the season, but annual pasture had higher soil water in spring and early summer due to delayed canopy development. Soil in the upper 40 cm of annual and meadow bromegrass pastures was at wilting point 5 to 10% of all measurement times compared with 65 to 71% of measurement times for alfalfa and old grass. Annual and meadow bromegrass pastures did not extract water below 1.2 m, while the other pastures did, and on the basis of soil water regimes, appear to be lower risk options than status quo old grass and alfalfa pastures during drought.

Key words: Soil water, forages, rotational grazing, drought, wilting point, field capacity

Bradshaw, D. L., Chanasyk, D. S., Baron, V. S. et Naeth, M. A. 2007. **Régime hydrique des annuelles et des vivaces fourragères lors des années de sécheresse dans l'écorégion des forêts-parcs à trembles de l'Alberta**. Can. J. Soil Sci. **87**: 523–533. Une sécheresse périodique ou prolongée peut s'avérer dévastatrice pour les pâturages et accroître les risques financiers des entreprises pratiquant la paissance. Lors de deux années de sécheresse (2002 et 2003), les auteurs ont effectué une étude dans la région des forêts-parcs à trembles de Lacombe, en Alberta, afin de comparer le régime hydrique du brome des prés (*Bromus riparius* Rhem.), de la luzerne (*Medicago sativa* L.) ainsi que des pâturages annuels [avoine (*Avena sativa* L.) et triticale d'hiver (*X Tritico secale* Wittmack)] avec celui d'une prairie redevenue sauvage, composée de chiendent (*Elytrigia repens* L.), de brome inerme (*Bromus inermis* Leyss.) et de pâturin des prés (*Poa partensis* L.). Les pâturages s'étaient établis sur un tchernoziom noir orthique dont la texture allait du loam au loam sablonneux fin. Les auteurs ont déterminé la concentration d'eau de mai à octobre grâce à une sonde à dispersion des neutrons jusqu'à une profondeur de 1,6 m, les deux années. Les pâturages annuels et ceux de brome présentent la même concentration cumulative et volumétrique d'eau, la plus élevée aussi, comparativement aux anciennes graminées, qui présentaient la teneur la plus faible. Les pâturages ont tous tendance à utiliser la totalité de l'eau disponible avant la fin de la période végétative, mais les pâturages annuels avaient plus d'eau au printemps et au début de l'été en raison du développement plus tardif du feuillage. Les 40 premiers centimètres de sol des pâturages annuels et de brome des prés se situaient à 5 à 10 % du point de flétrissement à tous les relevés, contre 65 à 71 % pour la luzerne et les anciennes graminées. Les pâturages annuels et ceux de brome des prés ne tirent pas l'eau du sol au-delà de 1,2 m contrairement aux autres types de pâturages. Compte tenu du régime hydrique du sol, ils semblent donc constituer une solution moins risquée que les graminées rendues à l'état sauvage ou les prés de luzerne lors d'une sécheresse.

Mots clés: Eau du sol, fourrages, pâturages tournants, sécheresse, point de flétrissement, capacité de charge

Soil water is the most limiting factor of grassland productivity in most parts of the world (e.g., Holechek et al. 1998). Plant growth and crop yield (Havlin et al. 1999) are primarily affected by soil water availability during the growing season, which depends heavily upon springmelt soil water recharge, summer precipitation, and the efficiency of soil water storage in the profile (De Jong and Bootsma 1988; Twerdoff et al. 1999).

Intensive grazing of perennial and annual forages is becoming increasingly popular. Perennial forage species are used as long-term pastures and in rotation with other crops in short-term sequences. Annual forage species, mostly cereals, are used as emergency pastures during drought, to extend the grazing season beyond that of perennial species, and to bridge gaps in beef production systems when perennials winterkill (Entz et al. 2002). Long-term dry conditions

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Abbreviations: **AICC**, Akaike's Information Criterion; **FC**, field capacity; **TSW**, total soil water; **WP**, wilting point that occur in semi-arid ecosystems do not occur in the parkland, but intermittent drought and dry years seriously limit pasture production, and increase financial risk for grazing enterprises.

Perennial forages generally begin using soil water much earlier in the growing season than annuals because they develop a transpiring canopy in mid to late April. This may be 6 wk earlier than annually seeded species. Early spring leaf production and a dense root system result in rapid water procurement, competitively favoring crested wheatgrass over other species in semi-arid regions (Frank et al. 1996). Annual forage pastures are seeded every spring (with the exception of fall-seeded winter cereals), have shallower root systems with lower biomass (Baron et al. 1999; Mapfumo et al. 2002), and therefore tend to use less water than perennial forages (Baron et al. 1999; Twerdoff et al. 1999).

Differences in water use occur among perennial forage species. Root depth, root density, and timing of canopy closure impact procurement and evaporative demand for soil moisture among species. Also, Thurow et al. (1986) concluded that infiltration rates were higher under bunchgrasses than sodgrasses. The growth habit of bunchgrasses (e.g., meadow bromegrass, orchardgrass) results in bare ground between plants [Alberta Agriculture Food and Rural Development (AAFRD) 1998]. By contrast rhizomatous species such as smooth bromegrass and Kentucky bluegrass form dense sods with little bare ground between plants (AAFRD 1998). Therefore, soil water may be lower under rhizomatous species than under bunchgrasses if difference in infiltration is the critical factor. However, soil water under all perennial forages will be depleted earlier in the season and to a greater extent than by annual forages (Twerdoff 1996) due to the earlier canopy development and resultant higher and earlier evaporative demand. Deep rooted species such as alfalfa (*Medicago sativa* L.) may procure water at soil depths below 1 m and are efficient in extracting soil water (Sheaffer et al. 1988) to the extent that the yield of subsequent crops in rotation may be compromised in semi arid (Campbell et al. 1990) and parkland ecosystems (Hoyt and Leitch 1983).

Previous research at the same location as this study compared annual and perennial pastures grazed at varying intensities (Baron et al. 1999; Twerdoff et al. 1999) and among pasture crop types in conjunction with modeling (Mapfumo et al. 2002). In all cases precipitation was above average during the growing season. The present study was conducted during two consecutive growing seasons with some of the lowest precipitation on record. Knowledge of differences in water use patterns among pasture crops under stressful circumstances should allow producers to make management decisions that assist in aversion of financial risk. The objective of this study was to quantify soil water regimes of annual and perennial forage treatments in dry years.

MATERIALS AND METHODS

Study Site

The study site was located at the Agriculture and Agri-Food Canada Research Station, Lacombe, Alberta, (52°27′N, 113°45′W). The soil is an Orthic Black Chernozem, ranging from a fine sandy loam on the northern edge of the site to a loam on the remaining area of the site (Bowser et al. 1951; Twerdoff 1996).

The 29-ha study area was established as perennial grassland prior to 1970. In 1995, 21.6 ha was broken and seeded to barley (*Hordeum vulgare* L.) for silage. This 21.6-ha area is hereafter referred to as Area 1, and was used for grazing research until the present study. In 1997, Area 1 was subdivided into 18, 1.2 ha paddocks (Fig. 1), which were seeded to alfalfa, meadow bromegrass (*Bromus riparius* Rehm.), alfalfa in a 50:50 mix, and Italian ryegrass (*Lolium multiflorum* Lam.) treatments, then rotationally grazed in 1998. The Italian ryegrass annual treatment was replaced by an oat (*Avena sativa* L.) and triticale (*X Triticosecale* Wittmack) mix in 1999. By 2002 meadow bromegrass-alfalfa treatments had lost all alfalfa due to grazing and winterkill, and are referred to as meadow bromegrass hereafter.

The land slopes west to east in Replicate 2, and north to south in Replicates 1 and 3 (Fig. 1). The unbroken 7.2 ha of the original study area (Area 2) was subdivided for the present study into six, 1.2-ha paddocks (Fig. 1). Its grass mixture contained smooth bromegrass (*Bromus inermis* Leyss.), Kentucky bluegrass (*Poa pratensis* L.), and quackgrass (*Elytrigia repens* L.), and is hereafter called old grass. The land is a series of slopes that alternate in direction, generally north to south. Beginning in 1999, half the paddocks in both areas were grazed rotationally from late May until mid September, while the other half were harvested as hay in mid July, allowed to regrow, and grazed from mid September until late October as stockpiled pasture.

The experimental design included four forage crop treatments assigned to two experimental areas. The randomization of the three annual forage crops was restricted to paddocks within three replicates in Area 1. Three forage treatments in Area 1 were Fleet meadow bromegrass, Speador II alfalfa, and an annual pasture mix of AC Mustang oat and Bobcat winter triticale (Table 1, Fig. 1). Two paddocks (replicates) in Area 2 were assigned as old grass treatments that consisted of approximately 70% quackgrass, 26% smooth bromegrass, and 4% Kentucky bluegrass on a dry weight basis and are representative of long-term perennial pastures in northern and central Alberta.

In 2002 and 2003, the four forage treatments received 30 kg ha^{-1} each of P_2O_5 and K_2O. The meadow bromegrass, annual, and old grass treatments also received 100 kg ha^{-1} N as NH_4NO_3. All fertilizer was broadcast in late April each year.

Paddocks were intensively, rotationally grazed (Barnhart et al. 1998; Barnes et al. 2003) with yearling beef heifers (cattle). Portable electric fencing was used to divide paddocks lengthwise into grazing strips averaging 0.16 ha. Available forage mass was harvested bi-weekly from six randomly selected ungrazed areas within 90 m ahead of the cattle. Samples were clipped 2.0 cm above ground by hand from six 0.25-m^2 areas. Forage from each replicate was bulked and weighed fresh and a 250-g sub-sample was taken

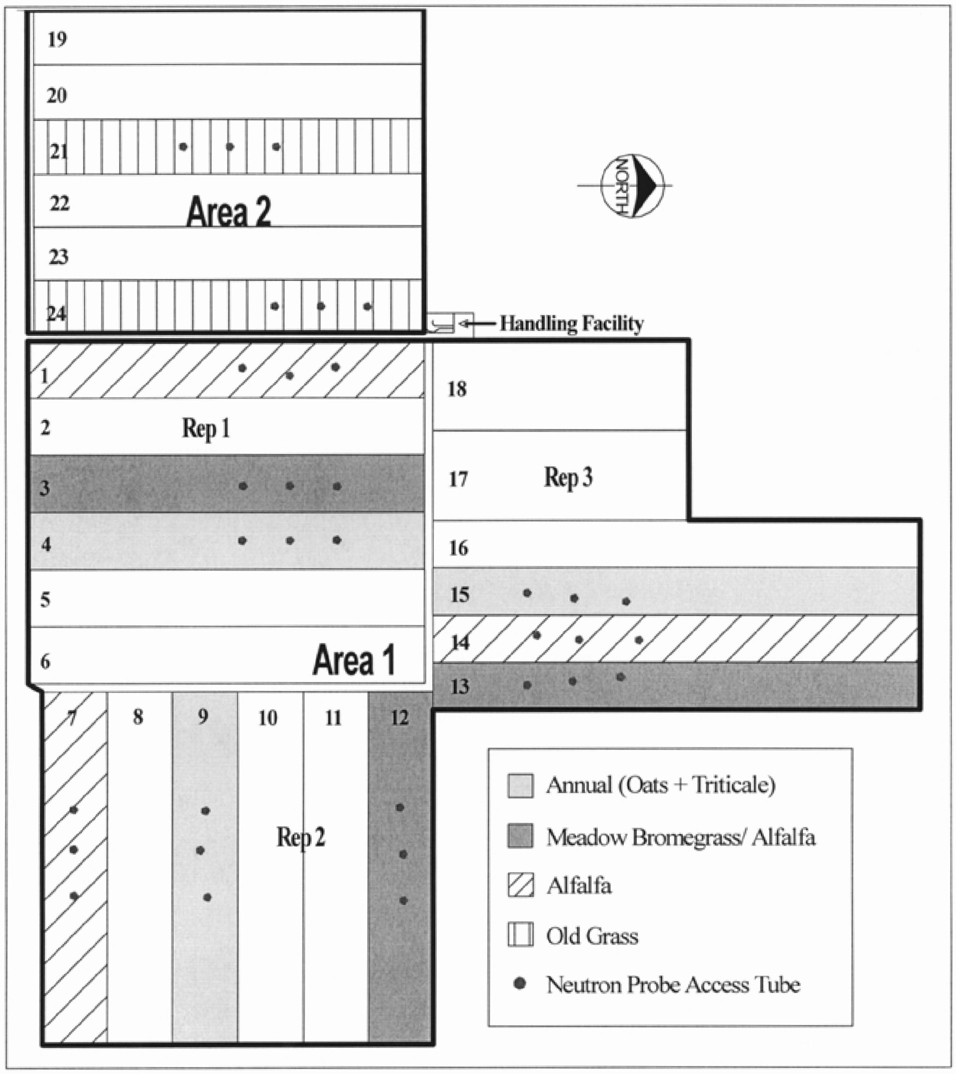

Fig. 1. Plot plan of Lacombe research study. Only shaded or patterned paddocks were monitored for this study. The remaining plots were stockpile grazed. Area 1 encompasses the short-term intensive system, comprised of Reps 1, 2, and 3. Area 2 encompasses the old grass system. Not drawn to scale.

and dried at 80°C for 48 h. Dried sub-samples were weighed to determine dry matter weight, which was consequently used to calculated forage yield. Yields were used to determine the stocking rate as the heifers were moved sequentially from strip to strip. Stocking rate was variable, based on a daily available forage allowance of 5% of animal weight and consumption levels of 50% over a 3- or 4-d grazing period.

Heifer numbers in each paddock were adjusted every 2 wk to reflect changes in available forage and cattle weights. Initiation of grazing, which usually occurs between May 21 and Jun. 01, was delayed due to dry weather and insufficient pasture growth. In 2002 it started Jun. 11 for old grass and meadow bromegrass, Jun. 17 for alfalfa and Jul. 16 for annuals; in 2003 it started Jun. 04 for old grass and meadow bromegrass, Jun. 16 for alfalfa and Jun. 20 for annual pastures.

Instrumentation and Data Collection

Meteorological data (monthly precipitation and mean monthly air temperatures) for the Lacombe CDA weather station located about 1 km south of the study site were obtained from Environment Canada for the most recent 30-yr period [Canadian Climate Normals (CCN); 1971–2000], the 2 study years, and the preceding year. The period April to October, inclusive, was used as the growing season for comparing the 2 study years and the CCN.

Aluminum access tubes for neutron probe soil water and density readings were installed in spring/summer 2002 within Area 1 (Paddocks 1, 3, 4, 7, 9, 12–15, inclusive) and Area 2 (Paddocks 21 and 24) to depths between 160 and 200 cm. In each paddock three tubes were installed about 30 m apart along a transect extending down the center of the paddock on similar landscape positions among paddocks (Fig. 1). Distances between tubes varied slightly on Paddocks 7, 9,

Table 1. Description of forage treatments at Lacombe, Alberta

Treatment name	Forage mix	Species seeding rate (kg ha^{-1})	Date seeded	Fertilizer (kg ha^{-1})	Paddock number[z]
Annual	Oat	78	Mid-May	100 N	4
	Winter triticale	101		30 P_2O_5	9
				30 K_2O	15
Meadow bromegrass	Meadow bromegrass	13	1997	100 N	3
	Alfalfa	5		30 P_2O_5	12
				30 K_2O	13
Alfalfa	Alfalfa	11	1997	30 P_2O_5	1
				30 K_2O	7
					14
Old grass	Quackgrass	Unknown	Prior to 1970	100 N	21
	Smooth bromegrass	Unknown		30 P_2O_5	24
	Kentucky bluegrass	Unknown		30 K_2O	

[z]Refer to Fig. 1.

and 14 due to difficult soil augering conditions at the time of installation.

Field bulk density measurements were taken with two Campbell Scientific 501DR Depth Moisture/Density Gauges once in 2002 in 10-cm increments, starting at 15 cm and continuing to the maximum allowable depth in each tube. Soil water was monitored with a Campbell Scientific 503DR neutron probe in the same depth increments. Measurements were made biweekly beginning Jun. 10 in 2002 and May 02 in 2003, and then every 3 wk from September to mid-October. Volumetric water content was calculated using locally derived calibration equations specific to the probe.

Soil water, expressed as total soil water (TSW) as a depth (mm), was calculated by multiplying volumetric water content at a given depth by the thickness of the relevant depth increment, then summing to a chosen depth. Each tube reached a depth of at least 160 cm. Four total soil water parameters used to quantify the soil water regime were TSW40, TSW80, TSW120 and TSW160; with the numbers corresponding to respective summation depths.

Soil water distribution with depth was examined for two measurement dates with extreme soil water conditions. Wettest measured soil conditions were represented by 2003 May 13 (hereafter referred to as the “wet day”) and driest measured conditions by 2003 Aug. 06 (hereafter referred to as the “dry day”).

Pressure plate analyses (Topp et al. 1993) were conducted to determine water retention characteristics at pressures of 0.01, 0.033, 0.1, 0.3, and 1.5 MPa, where 0.01 MPa represented field capacity for coarse-textured soils, 0.033 MPa represented field capacity for fine-textured soils, and 1.5 MPa represented wilting point, regardless of soil texture. Water retention was determined using soil samples collected 2003 Jul. 24 from paddocks 3, 14, 15, and 24 at 20-cm intervals to a depth of 2.0 m. These paddocks had representative soil profiles, as identified during access tube installation and soil physical property data collection in 2002. This provided a cross-section of soil textures across the study site. All samples were collected approximately 1 m east of each access tube. Samples were air dried, crushed, and ground by hand to pass through a 2-mm sieve.

Wilting point (WP), expressed as mm of soil water to a given depth, was calculated by multiplying laboratory-determined gravimetric water content at 1.5 MPa by depth increment thickness, then multiplying by average field measured bulk density for that depth increment, and summing to the given depth. Field capacity (FC) was similarly calculated and expressed as mm of soil water to a given depth, except soil texture was taken into account in choosing what pressure value to use. Regression-based empirical equations relating texture (% clay) to gravimetric water content, and data from the site were used to derive soil water retention parameters for depth intervals for which soil had not been analyzed in the laboratory.

Statistical Analyses

For statistical analyses an a priori assumption was made that treatment differences in the two experimental areas (Areas 1 and 2) were due to treatment effects rather than inherent differences in soil properties or microclimatic conditions between the areas.

Statistical analyses were conducted on TSW40, TSW80, TSW120, and TSW160. Data were subjected to an analysis of variance with the PROC MIXED procedure of SAS (Littell et al. 1996). The effect of replicate nested within experimental areas was considered random, and effects of treatment (Trt) and date, where applicable, were considered fixed for all analyses. Contrasts were used to determine date(s) for which the treatment effect was significant. A confidence level of 95% was chosen ($\alpha = 0.05$) to identify statistically significant effects.

A number of model configurations were explored for each response variable that accounted for the randomization restrictions in the two experimental areas, accounted for repeated measurements across dates within the growing season, and provided optimal model fit. One parameterization included/excluded variability among replicates by treatment combinations nested within experimental areas as a random effect. The model with this variance estimate included has two error terms; one each representing between block (replicate by paddock combination) variation and one for the between paddock variation. Furthermore, the parameterization with two error terms assumes between subjects (replicate by treatment combinations nested within experimental areas) and within subjects (subsampling and measurements across dates) variances are unique. When the variance for replicates by treatment combinations nested within experimental areas was excluded, models were tested that included/excluded a compound symmetry covariance structure implemented with the "repeated" statement of PROC MIXED. The preceding is a re-parameterization of the model including the replicates by treatment combinations nested within experimental areas variance estimate plus independent errors model that accounts for variability between and within experimental units (paddocks).

For each of the preceding model paramerizations, variance estimates were kept constant or allowed to vary across experimental areas. Accounting for unique variance estimates for the experimental Areas 1 and 2 would allow for the possibility of unique characteristics for each area.

The preceding model parameterizations were compared using the corrected Akaike's Information Criterion (AICC). Models with the smallest AICC estimate were considered to be best.

RESULTS AND DISCUSSION

Meteorological Trends

Leading up to the study, the August through October 2001 precipitation was 31.9 mm, or 24% of the CCN for that period, following July 2001, which had 136% of the CCN for that month. Over-winter (November through March) precipitation was close to the CCN for Lacombe for the 2 study years (Table 2). April precipitation in both study years, which included snow, was > twice the CCN for the month. The extra spring moisture in 2003 resulted in enhanced germination and canopy establishment for annual pastures compared with 2002. Both 2002 and 2003 growing seasons were very dry, with 56% of the CCN precipitation in June through October 2002, and 46% in 2003.

The probability for less than 175 mm (2002) is 0.06 or 6 yr in 100 and the probability of less than 165 mm (2003) is 0.05. The probability of these 2 low-rainfall years occurring consecutively is even much lower. The probability of an annual precipitation of 319 mm or less (2002) is 0.06 and 382 mm (2003) or less is 0.21; the Canadian climate normal over 98 yr is approximately 450 mm.

Mean April and May air temperatures were below CCN for both study years (Table 2). Mean air temperatures in 2002 were above CCN in June and especially July, while in 2003 they were above CCN for July and especially August. September air temperatures were near CCN in both study years.

Pasture Production

An extensive discussion of pasture performance is beyond the scope of this study. Because the grazing was managed, days of livestock on pasture was more indicative of differences among species than forage availability during grazing (Table 3). During 2002, the old grass, alfalfa, meadow bromegrass, and annual pastures were grazed for 73, 73, 83, and 42 d, respectively; in 2003 the same pastures were grazed for 58, 46, 58, and 49 d, respectively. This compares with 2000, a year of above-normal precipitation, when pastures were grazed for 105, 97, 105, and 86 d, respectively, and closer to target pasture days of 100. In 2000, rainfall was 69 mm above average over the April to September period, compared with the long term average.

Stocking rates did not differ as much among treatments within years or between treatments and years, but did vary from years of higher production not included in the study. The stocking rate (head ha^{-1}) for old grass, alfalfa, meadow bromegrass and annual pastures in 2002 when averaged over all grazing periods was 3.5, 5.2, 4.5, and 4.5, respectively; in 2003, 4.7, 4.9, 5.4, and 4.4, respectively; and in 2000, 4.7, 6.2, 7.4, and 5.2, respectively. In 2002, meadow bromegrass had significantly higher available forage yield than old grass in July, while alfalfa and meadow bromegrass had greater yields than the other pastures during August (Table 3). In 2003, pastures had similar yields during August, annual had the lowest yield during July and old grass and meadow bromegrass were unavailable for grazing in September.

Soil Water Trends

Soil Water Retention

Alfalfa and meadow bromegrass treatments had highest field capacities and wilting points; annual and old grass treatments had lowest (Tables 4–6). The old grass treatment had a dramatic decline in water retention below 100 cm; the annual less so below 140 cm (data not shown). These trends are likely due to the silt loam texture to 160 cm and loam to 200 cm under old grass (data not shown), but loam at 60 to 120 cm and clay loam to 180 cm for the annual. Meadow bromegrass and alfalfa treatments were underlain by clay at 80 and 100 cm, respectively.

Cumulative Soil Water

Annual and meadow bromegrass treatments had the highest TSW40 across both 2002 and 2003 (Table 4), albeit not necessarily statistically significantly different from alfalfa and old grass. In 2002 and 2003, the annual treatment had significantly greater TSW40 than all perennial treatments for June, likely because annual crops had not yet developed a full canopy so transpirational losses were lower than for perennial crops (Twerdoff et al. 1999). In 2002 the annual treatment was significantly different from old grass throughout the entire growing season. This was not the case in 2003; in addition to June, the annual treatment was only significantly different from old grass for the first reading in July. In 2002, annual treatments were initially wettest on average, followed by meadow bromegrass, alfalfa, and old grass treatments (Table 4). This trend continued for the remainder of the 2002 sampling dates. However, in 2003, the old grass treatment was wettest on the first monitoring date, followed by meadow bromegrass, annual, and alfalfa. This was simi-

Table 2. Precipitation and temperature data for Lacombe CDA station for 2002, 2003 and the CCN 1971 to 2000

Date	Precipitation (mm)			Mean Temperature (ºC)		
	CCN [z]	2002	2003	CCN	2002	2003
April	21.0	42.6	53.8	4.3	–0.9	3.6
May	55.6	37.7	46.3	10.1	7.6	8.5
June	75.7	12.2	45.2	13.9	15.1	13.7
July	89.4	35.8	16.1	15.4	17.4	16.8
August	70.8	66.0	19.8	14.7	13.7	16.8
September	47.3	39.7	33.6	9.8	9.1	9.7
October	16.6	13.7	23.3	4.5	0.6	5.8
November–March	69.6	71.8	64.2	–8.4	–8.8	–6.9
April–October	376.4	247.7	238.1	10.4	8.9	10.7
June–October	299.8	167.4	138.0	11.7	11.2	12.6

[z]Canadian Climate Normal; Environment Canada.

Table 3. Available forage yield for four forage treatments averaged monthly during 2002 and 2003 at Lacombe Alberta

Month	Annual	Meadow bromegrass	Alfalfa	Old grass
	(Mg ha^{-1})			
		2002		
July	NA[z]	3.4*a*	2.8*ab*	2.0*b*
August	1.0*b*	3.0*a*	3.1*a*	1.8*b*
September	3.4*a*	3.0*ab*	3.4*a*	2.2*b*
		2003		
July	1.3*b*	4.5*a*	4.3*a*	3.5*a*
August	2.3*a*	2.1*a*	3.1*a*	2.1*a*
September	2.0*a*	NA	3.2*a*	NA

[z]NA indicates that insufficient forage was available during the period to graze and/or measure.
a, *b* Means followed by the same letter within rows are similar according to LSD test at $P < 0.05$

Table 4. Total soil water to 40 cm (TSW40, mm) in the 2002 and 2003 growing seasons for four forage treatments

Date	Ppt [z] (mm)	Annual			Meadow bromegrass			Alfalfa			Old grass		
2002 Jun. 10	–	125[y]	(10)[x]	*a*	89	(10)	*b*	51	(10)	*b*	26	(4)	*c*
2002 Jun. 24	4	84	(10)	*a*	58	(10)	*b*	25	(10)	*bc*	11	(4)	*c*
2002 Jul. 10	7	46	(10)	*a*	49	(11)	*a*	19	(10)	*ab*	7	(4)	*b*
2002 Jul. 22	11	43	(9)	*a*	42	(9)	*a*	26	(9)	*ab*	11	(4)	*b*
2002 Aug. 07	34	104	(9)	*a*	101	(9)	*a*	85	(9)	*ab*	68	(4)	*b*
2002 Aug. 19	10	81	(9)	*a*	73	(9)	*ac*	52	(9)	*bc*	39	(4)	*b*
2002 Sep. 03	15	63	(9)	*a*	51	(9)	*ac*	31	(9)	*bc*	21	(4)	*b*
2002 Sep. 28	12	48	(9)	*a*	42	(9)	*a*	25	(10)	*ab*	12	(4)	*b*
2002 Oct. 21	21	55	(9)	*a*	50	(9)	*a*	37	(9)	*ab*	24	(4)	*b*
2003 May 02	–	92	(11)	*a*	105	(11)	*a*	82	(11)	*a*	106	(8)	*a*
2003 May 13	13	129	(11)	*a*	123	(11)	*a*	119	(11)	*a*	93	(8)	*a*
2003 May 28	17	122	(11)	*a*	88	(11)	*c*	96	(11)	*ac*	52	(8)	*b*
2003 Jun. 12	13	126	(11)	*a*	83	(12)	*b*	73	(11)	*b*	59	(8)	*b*
2003 Jun. 26	6	100	(11)	*a*	50	(11)	*b*	55	(11)	*b*	24	(8)	*b*
2003 Jul. 09	5	65	(11)	*a*	40	(11)	*ab*	39	(11)	*ab*	11	(8)	*b*
2003 Jul. 23	3	46	(11)	*a*	33	(11)	*a*	19	(11)	*a*	5	(8)	*a*
2003 Aug. 06	3	40	(11)	*a*	33	(11)	*a*	20	(11)	*a*	5	(8)	*a*
2003 Aug. 20	17	48	(11)	*a*	39	(11)	*a*	26	(11)	*a*	13	(8)	*a*
2003 Sep. 02	6	51	(11)	*a*	43	(11)	*a*	26	(11)	*a*	22	(8)	*a*
2003 Sep. 27	29	58	(11)	*a*	46	(11)	*a*	31	(11)	*a*	25	(8)	*a*
2003 Oct. 15	1	57	(11)	*a*	39	(11)	*a*	26	(11)	*a*	13	(8)	*a*
	FC_{40} (mm)	124			105			132			130		
	WP_{40} (mm)	42			39			43			34		

[z]Cumulative precipitation since previous measurement date.
[y]Means.
[x] Standard error.
a–c For a given date (row), treatments with the same letter are not significantly different ($P \leq 0.05$).

Table 5. Total soil water to 80 cm (TSW80, mm) in the 2002 and 2003 growing season for four forage treatments

Date	Ppt [z] (mm)	Annual			Meadow bromegrass			Alfalfa			Old grass		
2002 Jun. 10	–	202[y]	(24)[x]	*a*	159	(24)	*ac*	75	(24)	*bc*	45	(6)	*b*
2002 Jun. 24	4	152	(24)	*a*	119	(24)	*ac*	40	(24)	*bc*	24	(6)	*b*
2002 Jul. 10	7	91	(24)	*a*	99	(25)	*a*	30	(24)	*ab*	17	(6)	*b*
2002 Jul. 22	11	85	(22)	*a*	83	(22)	*a*	46	(22)	*ab*	22	(6)	*b*
2002 Aug. 07	34	149	(22)	*a*	151	(22)	*a*	110	(22)	*ab*	93	(6)	*b*
2002 Aug. 19	10	123	(22)	*a*	121	(22)	*a*	76	(22)	*ab*	60	(6)	*b*
2002 Sep. 03	15	105	(22)	*a*	94	(22)	*a*	51	(22)	*ab*	35	(6)	*b*
2002 Sep. 28	12	87	(22)	*a*	82	(22)	*a*	49	(23)	*ab*	23	(6)	*b*
2002 Sep. 21	21	96	(22)	*a*	92	(22)	*a*	55	(22)	*ab*	34	(6)	*b*
2003 May 02	–	129	(26)	*a*	174	(26)	*a*	135	(26)	*a*	157	(12)	*a*
2003 May 13	13	205	(26)	*ab*	209	(26)	*a*	209	(26)	*a*	146	(12)	*b*
2003 May 28	17	205	(26)	*a*	161	(26)	*a*	172	(26)	*a*	94	(12)	*b*
2003 Jun. 12	13	204	(26)	*a*	151	(28)	*ab*	129	(26)	*ab*	86	(12)	*b*
2003 Jun. 26	6	175	(26)	*a*	98	(26)	*ab*	101	(26)	*ab*	42	(12)	*b*
2003 Jul. 09	5	126	(26)	*a*	82	(26)	*ab*	75	(26)	*ab*	23	(12)	*b*
2003 Jul. 23	3	86	(26)	*a*	69	(26)	*a*	43	(26)	*a*	11	(12)	*a*
2003 Aug. 06	3	76	(26)	*a*	68	(26)	*a*	40	(26)	*a*	11	(12)	*a*
2003 Aug. 20	17	87	(26)	*a*	78	(26)	*a*	46	(26)	*a*	25	(12)	*a*
2003 Sep. 02	6	89	(26)	*a*	81	(26)	*a*	44	(26)	*a*	33	(12)	*a*
2003 Sep. 27	29	96	(26)	*a*	83	(26)	*a*	48	(26)	*a*	32	(12)	*a*
2003 Oct. 15	1	96	(26)	*a*	77	(26)	*a*	43	(26)	*a*	20	(12)	*a*
	FC_{80} (mm)	239			245			256			241		
	WP_{80} (mm)	82			95			79			59		

[z]Cumulative precipitation since previous measurement date.
[y]Means.
[x] Standard eror.
a–c For a given date (row), treatments with the same letter are not significantly different ($P \leq 0.05$).

Table 6. Total soil water to 160 cm (TSW160, mm) in the 2002 and 2003 growing season for four forage treatments

Date	Ppt [z] (mm)	Annual		Meadow bromegrass		Alfalfa		Old grass	
2002 Jun. 10	–	364[y]	(53)[x]	336	(53)	182	(53)	132	(59)
2002 Jun. 24	4	312	(53)	284	(53)	131	(53)	116	(59)
2002 Jul. 10	7	249	(53)	266	(54)	112	(53)	88	(59)
2002 Jul. 22	11	250	(50)	226	(50)	156	(50)	95	(59)
2002 Aug. 07	34	313	(50)	294	(50)	222	(50)	174	(59)
2002 Aug. 19	10	283	(50)	266	(50)	188	(50)	148	(59)
2002 Sep. 03	15	267	(50)	234	(50)	160	(50)	111	(59)
2002 Sep. 28	12	248	(50)	219	(50)	173	(52)	93	(59)
2002 Oct. 21	21	260	(50)	233	(50)	153	(50)	105	(59)
2003 May 02	–	254	(67)	323	(67)	258	(67)	277	(24)
2003 May 13	13	378	(67)	373	(67)	375	(67)	265	(24)
2003 May 28	17	368	(67)	329	(67)	335	(67)	211	(24)
2003 Jun. 12	13	370	(67)	340	(67)	283	(67)	187	(24)
2003 Jun. 26	6	345	(67)	263	(67)	249	(67)	151	(24)
2003 Jul. 09	5	292	(67)	234	(67)	213	(67)	115	(24)
2003 Jul. 23	3	241	(67)	207	(67)	160	(67)	88	(24)
2003 Aug. 06	3	231	(67)	208	(67)	160	(67)	82	(24)
2003 Aug. 20	17	238	(67)	221	(67)	148	(67)	90	(24)
2003 Sep. 02	6	240	(67)	221	(67)	155	(67)	103	(24)
2003 Sep. 27	29	261	(67)	226	(67)	173	(67)	97	(24)
2003 Oct. 15	1	257	(67)	220	(67)	146	(67)	90	(24)
	FC_{160} (mm)	506		575		581		444	
	WP_{160} (mm)	197		278		242		114	

[z]Cumulative precipitation since previous measurement date.
[y] Means.
[x] Standard error.
There were no significant treatment differences ($P < 0.05$).

lar to Burk et al.'s (2000) findings of higher spring TSW30 in treatments with standing dead vegetation and litter compared with fallow treatments. Since annual and alfalfa treatments had less vegetation (surface litter) remaining in the fall, less snow was likely trapped, with less snowmelt infiltration resulting in lower spring soil water. Dewatering by alfalfa was described by Entz et al. (2002).

By the second monitoring date in 2003, annual treatments were once again wettest, and continued to be wettest throughout the remainder of the year. For both years, annual and meadow bromegrass treatments had similar trends for TSW40, and alfalfa and old grass treatments had similar trends. Individual treatment TSW40s generally returned to similar levels in fall of each year (Table 4; e.g., 55 mm in October 2002 and 57 mm in October 2003 for the annual treatment; < 57 mm for all treatments). This suggests vegetation was using all available soil water, as evidenced by Naeth and Chanasyk (1995) who found profile soil water (TSW50) was similar across grazing treatments in fall, generally regardless of year, on rangelands dominated by rough fescue and Parry's oat grass. For TSW40 in 2002 and 2003, the interaction between sampling dates and forage treatments was significant, likely because phenology is an important factor in crop water use.

Trends for TSW80 (Table 5) were similar to those for TSW40, with few exceptions. The interaction between sampling date and forage treatment was significant, increasing the importance of timing versus crop water use. For most of 2002, and later 2003 sampling dates, the ranking of TSW80 by treatment was annual > meadow bromegrass > alfalfa > old grass. In 2002, the annual treatment was significantly different from old grass over the measurement period, but only significantly different from alfalfa in June. Alfalfa was not significantly different from old grass, and meadow bromegrass was intermediate, being not significantly different from either alfalfa or annual treatments. In 2003, the only significant treatment difference occurred from May 28 to Jul. 09 between annual and old grass.

Trends for TSW120 (data not shown) were similar to those for TSW80, except interactions between sampling date and forage treatment were not significant in 2002. These interactions were not significant for TSW160 in either year (Table 6). There was a significant difference in TSW120 among forage treatments in 2002; old grass was significantly lower than annual and meadow bromegrass. There were no significant treatment differences in TSW120 for 2003 or TSW160 for 2002 and 2003 (data not shown).

Total soil water to 40, 80, and 160 cm was predominantly < WP for alfalfa and old grass, but only once for annual (Table 7). Interestingly, meadow bromegrass had TSW80 and TSW160 predominantly < WP, but its regime for TSW40 was more like that of the annual treatment than perennial forages. These results support those from other range and pasture studies in Alberta, where soil water in both mid-summer and fall was generally at or near wilting point (Naeth and Chanasyk 1995; Twerdoff 1996; Mapfumo et al. 2003). This indicates that perennial forage species tend to use all of the soil water available to them by the end of the growing season.

Table 7. Frequency of soil water less than wilting point (days) during the growing season in 2002 and 2003

Depth increment	Annual	Meadow bromegrass	Alfalfa	Old grass
0–40 cm	1	2	13	15
0–80 cm	1	11	15	15
0–160 cm	0	14	16	11

Total number of measurement days = 21.

Soil water was higher for the annual compared with perennial treatments, likely due to its later canopy development and lower leaf areas, lowering evapotranspiration. Gill et al. (1998), also at Lacombe, found that bare ground was significantly greater under annuals than perennials (i.e., lower leaf area and low litter accumulation). However, Le Maitre et al. (1999) found litter on the ground surface tends to retain more water than bare soil, thus increasing infiltration. Therefore, annuals may experience lower infiltration than perennials, but water entering the soil is more likely to remain there for annuals because actual evapotranspiration from annuals is lower than that from perennial forages (Twerdoff 1996). In any event, the net effect was higher soil moisture under annuals compared with the old grass in particular.

Higher soil water under annual forages was similar to the results of two other studies conducted on cropland pastures in Alberta. In Lacombe, Mapfumo et al. (2003) found soil water was greatest in the annual forage treatment and lowest in the old grass treatment, which was the same old grass treatment used in this study. They concluded the general dryness of old grass was due to greater root biomass compared with alfalfa, meadow bromegrass/alfalfa, and annual forages. Baron et al. (2001) found live and dead root mass was 22.7, 12.7, 8.3, and 4.2 Mg ha^{-1} in the upper 80 cm of these old grass, alfalfa, meadow bromegrass, and annual pastures, respectively, averaged over 1999 and 2000; in the respective pastures 65, 60, 62, and 54% of the roots were in the upper 15 cm. Although Twerdoff (1996) also found higher TSW under annual than perennial forages in Lacombe, and by late August, TSW was lower under annual forages compared with meadow bromegrass and smooth bromegrass. However, 1994 and 1995 precipitation was above normal in Lacombe during Twerdoff's study, unlike during this study.

Soil Water with Depth

On the wet day, soil water profiles with depth were generally similar among annual, meadow bromegrass, and alfalfa treatments, with old grass having the lowest soil water at all depths (Fig. 2). On the dry day (Fig. 2), annual and meadow bromegrass treatments generally had similar water at all depths, and highest of all treatments. As on the wet day, soil water for the old grass treatment was lowest at all depths. Alfalfa had soil water midway between these to approximately 120 cm, after which its moisture profile matched those of the annual and meadow bromegrass. For both wet and dry days, soil water generally increased consistently with depth below 60 to 80 cm for all treatments.

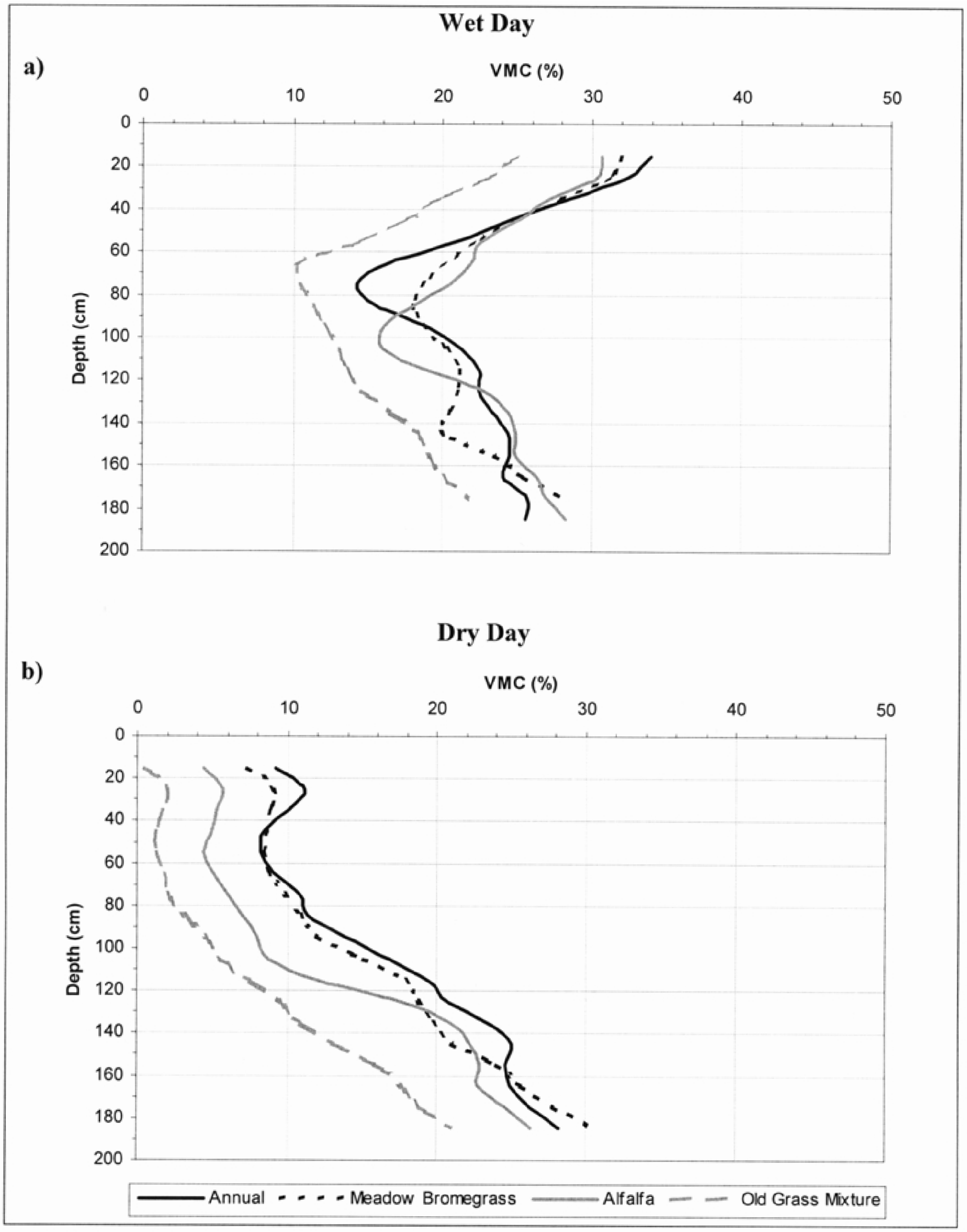

Fig. 2. Average volumetric water content (VMC) by forage treatment for (a) a wet day (2003 May 13) and (b) a dry day (2003 Aug. 06).

Comparing wet and dry days for a given treatment, annual and meadow bromegrass treatments had identical soil water below approximately 140 cm (data not shown), indicating no net water loss or gain in this zone, and perhaps suggesting no water uptake. In contrast, alfalfa and old grass treatments had higher soil water on the wet versus the dry day at all depths to 185 cm, indicating soil water recharge throughout the profile.

Twerdoff et al. (1999) also at Lacombe, examining soil profiles to 90 cm, found generally higher soil water in the uppermost 0 to 30 cm than deeper in the profile for both dry and wet days. The results of this study and the Twerdoff study are similar to 90 cm, an interesting result given that the latter occurred during wet years, in contrast to this study.

Soil Water with Time

The dual grouping of annual and meadow bromegrass, and alfalfa and old grass, is evident for soil water at depths of 55 and 105 cm over time in 2002 (data not shown). Meadow bromegrass and annual acted similarly, maintaining highest VMCs for both study years, whereas alfalfa and old grass maintained lowest VMCs, and followed similar trends. Soil water in alfalfa at 155 cm was more like that of annual and meadow bromegrass mid-season. These trends tended to be similar in 2003 (data not shown).

Volumetric water content generally increased with depth over time. Annual treatments were an exception during May to June when they had higher soil water at 55 cm than at 105 cm. Since the annuals had just been seeded, young seedlings were likely not able to evapotranspire the available soil water in the typical rooting zone (VMC at 55 cm). Therefore, extra soil water likely percolated, raising VMC at 105 cm in mid July.

IMPLICATIONS FOR STRATEGIC PASTURE MANAGEMENT

In years of normal precipitation, the 2000 ha of pastures comprising introduced forage species provide 66% of pasture production required for Alberta's beef herd (M. Bjorge, personal communication, Lacombe, AB). Most, perhaps 80%, of these pastures comprised naturalized species such as those found in the old grass treatment. This study indicates the use of these species places the industry at risk during years of below-normal rainfall. Cool-season species use water rapidly in spring, and those such as Kentucky bluegrass, quackgrass, and creeping red fescue, found in naturalized pastures, yielded 70% as much as smooth and meadow bromegrass species during years of below-normal precipitation (1998) in other studies at Lacombe (Baron et al. 2004). Species found in old grass pastures are used because re-establishing stands with improved species is expensive. This study indicates that seeding some annual and meadow bromegrass pastures, in place of, or in combination with, old grass pastures might be a strategy for low-rainfall conditions, rather than depending on an entire old grass pasture. Alfalfa is more heat tolerant than cool season grasses (Nelson and Moser 1994) and can procure soil water at depth (Sheaffer et al. 1988), but is noted for leaving soil in a dry condition so subsequent crops are difficult to establish in semi-arid regions (Entz et al. 2002). Thus, alfalfa may be more risky than meadow bromegrass pastures when multiple years of drought occur in the parkland ecoregion.

CONCLUSIONS

Soil water clearly varied with forage treatment. Annual and meadow bromegrass treatments had similar soil water trends over time, while alfalfa and old grass were similar. Annual and meadow bromegrass treatments had the highest cumulative and volumetric water, and old grass consistently had the lowest. This was likely due to a combination of a large root mass and high plant density in the old grass treatments, resulting in restricted infiltration and increased soil water uptake, both of which decrease soil water. Overall, soil water was highest in spring and declined throughout summer and fall, with the exception of considerable precipitation events, reaching lowest levels in late fall.

Once plant growth was initiated, both annual and perennial forages tended to use all available soil water. However, the delayed growth of annual forages in spring and shallower root systems in summer resulted in higher soil water in these pastures. Soil water regimes under meadow bromegrass seem to be unique, sometimes appearing like an annual forage and like a perennial at others.

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Alberta Agriculture, Food and Rural Development. 1998. Alberta forage manual. 10th ed. Alberta Agriculture, Food and Rural Development Publishing Branch. Agdex 120/20–4. 86 pp.

Barnes, R. F., Nelson, C. J., Collins, M. and Moore, K. J. 2003. Forages: v.1 An introduction to grassland agriculture. 6th ed. Iowa State Press, Ames, IA. 556 pp.

Barnhart, S., Morrical, D., Russell, J., Moore, K., Miller, P. and Brummer, C. 1998. Pasture management guide for livestock producers. Iowa State University, University Extension, Ames, IA. Pm-1713. 104 pp.

Baron, V. S., Mapfumo, E., Naeth, M. A. and Chanasyk, D. S. 1999. Sustainable grazing systems for perennial and annual forages on sloped lands. Canada-Alberta Environmentally Sustainable Agriculture Agreement (CAESA) Final Rep. RES-024-93. 160 pp.

Baron, V. S., Mapfumo, E. and Chanasyk, D. S. 2001. Top and root carbon and nitrogen pools of central Alberta pastures. *in* 2001 Abstracts ASA-CSSA-SSSA annual meetings. 2001 Oct. 21–25. Charlotte, NC [CD-ROM] ASA Inc., Madison, WI.

Baron, V. S., Dick, A. C., Bjorge, M. and Lastiwka, G. 2004. Stockpiling potential of perennial forage species adapted to the Canadian Western Prairie Parkland. Agron. J. **96**: 1545–1552.

Bowser, W. E., Peters, T. W. and Newton, J. D. 1951. Soil survey of the Red Deer Sheet. Report No. 16. Alberta Soil Survey. University of Alberta, Edmonton, AB. Bull. No. 51.

Burk, A. R., Chanasyk, D. S. and Mapfumo, E. 2000. Antecedent soil water for managed landscapes in central Alberta. Trans. ASAE **43**: 1467–1475.

Campbell, C. A., Janzen, H. H. and Bowren, K. E. 1990. Crop rotation studies on the Canadian Prairies. Research Branch, Agriculture Canada Government Publication Centre, Ottawa, ON. Publ. 1841/E. 133 pp.

De Jong, R. and Bootsma, A. 1988. Estimated long-term soil moisture variability on the Canadian prairies. Can. J. Soil Sci. **68**: 307–321.

Entz, M. H., Baron, V. S., Carr, P. M., Meyer, D. W., Smith, S. R., Jr. and McCaughey, W. P. 2002. Potential of forages to diversify cropping systems in the northern great plains. Agron. J. **94**: 240–250.

Frank, A. B., Bittman, S. and Johnson, D. A. 1996. Water relations of cool-season grasses. Pages 127–164 *in* L. E. Moser, D. R. Buxton, and M. D. Casler, eds. Cool-season forage grasses. Agronomy Monograph 34. ASA Inc., CSSA Inc., SSSA Inc., Madison, WI.

Gill, S. I., Naeth, M. A., Chanasyk, D. S. and Baron, V. S. 1998. Runoff and sediment yield from snowmelt and rainfall as influenced by forage type and grazing intensity. Can. J. Soil Sci. **78**: 699–706.

Havlin, J. L., Beaton, J. D., Tisdale, S. L. and Nelson, W. L. 1999. Soil fertility and fertilizers: an introduction to nutrient management. 6th ed. Prentice Hall Inc., Upper Saddle River, NJ. 499 pp.

Holechek, J. L, Pieper, R. D. and Herbel, C. H. 1998. Range management: principles and practices. 3rd ed. Prentice Hall Inc., Upper Saddle River, NJ. 542 pp.

Hoyt, P. B. and Leitch, R. H. 1983. Effects of forage legume species on soil moisture, nitrogen and yield of succeeding barley crops. Can. J. Soil Sci. **63**: 125–136.

Le Maitre, D. C., Scott, D. F. and Colvin, C. 1999. A review of information on interactions between vegetation and groundwater. Water S.A. **25**: 137–152.

Littell, R. C., Milliken, G. A., Stroup, W. W. and Wolfinger, R. D. 1996. SAS system for mixed models. SAS Institute, Inc., Cary, NC. 656 pp.

Mapfumo, E., Chanasyk, D. S. and Baron, V. S. 2003. Patterns and simulation of soil water under different grazing management systems in central Alberta. Can. J. Soil Sci. **83**: 601–614.

Mapfumo, E., Naeth, M. A., Baron, V. S., Dick, A. C. and Chanasyk, D. S. 2002. Grazing impacts on litter and roots: perennial versus annual grasses. J. Range Manage. **55**: 16–22.

Naeth, M. A. and Chanasyk, D. S. 1995. Grazing effects on soil water in Alberta foothills fescue grasslands. J. Range Manage. **48**: 528–534.

Nelson, C. J. and Moser, L. E. 1994. Plant factors affecting forage quality. Pages 115–154 *in* G. C. Fahey et al., eds. Forage quality, evaluation and utilization. ASA, Madison, WI.

Sheaffer, C. C., Tanner, C. B. and Kirkham, M. B. 1988. Alfalfa water relations and irrigation. Pages 373–409 *in* A. A. Hanson et al., eds. Alfalfa and alfalfa improvement. Agronomy Monograph, 29. ASA Inc., CSSA Inc., SSSA Inc., Madison, WI.

Thurow, T. L., Blackburn, W. H. and Taylor, C. A., Jr. 1986. Hydrologic characteristics of vegetation types as affected by livestock grazing systems, Edwards Plateau, Texas. J. Range Manage. **39**: 505–509.

Topp, G. C., Galganov, Y. T., Ball, B. C. and Carter, M. R. 1993. Soil water desorption curves. Pages 569–579 *in* M. R. Carter, ed. Soil sampling and methods of analysis. CSSS. Lewis Publishers, Boca Raton, FL.

Twerdoff, D. A. 1996. Soil compaction and soil water under rotational grazing of annual and perennial forages. M.Sc. thesis, Department of Renewable Resources, University of Alberta. Edmonton, AB. 89 pp.

Twerdoff, D. A., Chanasyk, D. S., Naeth, M. A., Baron, V. S. and Mapfumo, E. 1999. Soil water regimes of rotationally grazed perennial and annual forages. Can. J. Soil Sci. **79**: 627–637.