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Soil Compaction and Soil Water Under Rotational Grazing of Annual and Perennial Forages

by

Dennis Allan Twerdoff ©

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled SOIL COMPACTION AND SOIL WATER UNDER ROTATIONAL GRAZING OF ANNUAL AND PERENNIAL FORAGES submitted by Dennis Allan Twerdoff in partial fulfillment of requirements for the degree Master of Science in Water and Land Resources.

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ABSTRACT

The impacts of intensive grazing management under specific forage types and grazing intensities on near-surface bulk density and soil water were measured in a completely randomized block design of 4 forages x 3 grazing intensities over 4 replicates at Lacombe, Alberta.

Near-surface bulk density (DB) increased with increased grazing intensity similarly under both annuals and perennials and increased most in the first summer. DB also increased over-winter while over the second summer, it decreased in some treatments. Cultivation mitigated increases in bulk density only slightly.

Seasonal soil water was highest in spring. Surface soil water was generally highest under heavy grazing and annuals. Soil water under perennials was lower than annuals from mid April until early August, but similar thereafter. Wetting fronts were larger under annuals than perennials. Evapotranspiration was higher under perennials than annuals from May until late June while the opposite occurred from late June until early August.

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I. INTRODUCTION

Background

In Canada, more and more farmers are diversifying their management schemes to incorporate beef production or to increase the production of existing beef operations. Economic factors continue to favor the production of Alberta beef as global population increases, the cost of trade decreases and the high quality of Alberta beef is maintained within the global market. Increased demand for beef is forcing the cattle industry to expand from arid and semiarid rangelands and to utilize more humid ecosystems, traditionally used for grain farming. In other regions, grazing is used to improve marginal or lower quality land. The Parkland Ecoregion of Alberta contains 700,000 ha of improved pasture, 41 % of the provincial total (Statistics Canada, 1991). Most of this pasture is used by the beef cattle industry, which annually adds $1.5 billion to the provincial economy (Statistics Canada, 1991). Fluctuating cattle prices from year to year result in fluctuating cattle numbers which creates fluctuating demand for pasture on a yearly basis. Flexibility in the number of hectares in pasture is therefore an important competitive tool for Alberta beef producers.

Soil water is one of the most important factors affecting range productivity (Houston, 1965). Infiltration is the hydrologic process that determines the partitioning of precipitation between soil water and surface runoff. Erosion removes topsoil and carries nutrients away from the land often into creeks and rivers undesirably affecting water quality. Soil structure degrades as organic matter declines and bare soil is exposed to raindrop impact leading to surface sealing and crusting. Since the soil surface controls the rate of water movement into the soil profile (Gray, 1970), range management strategies should involve soil water conservation and aim to reduce soil and nutrient losses through runoff and maintain soil structure through organic matter recharge. The most practical and economic means of realizing these objectives may be through manipulation of grazing animals (Naeth, 1988).

Interest in Alberta's rangeland hydrology, particularly the effects of grazing on soil physical properties and water processes, has intensified during the past few years because of the need to ensure sustainable management of soil and water resources while increasing productivity. Savory and Parsons (1983) suggested that rangeland conditions will improve under rotational grazing by breaking up soil crusts, incorporating organic matter into the soil and improving soil physical parameters. Dormaar et al. (1989) reported an increase in bulk density and a reduction in hydraulic conductivity under short duration intensive grazing (SDIG). Warren (1986a) reported increased soil bulk density, increased runoff and sediment yield and decreased infiltration rate under heavily grazed pastures compared to lightly grazed pastures under SDIG. SDIG is being implemented as a new management practice as farmers attempt to maximize their land resources (Dormaar et al., 1989).

Annual pastures are routinely used in other areas of the world as supplemental forage during times of reduced biomass production of perennial forages. Baron et al. (1993) reported that in Alberta's Aspen Parkland, many cool-season perennial forages produced 60 % of annual production before 1 July. As a result, livestock production was limited during late summer and fall. Intermittent frosts and low temperatures during September and October in temperate climates limit growth of most forages except winter cereals. The potential of using winter cereals to supplement perennial forage production could increase farmland use for up to six months of the year.

In the Aspen Parkland, traditional cereal production only utilizes four of six potential growth months: four months, from May to August, required for growth from seeding to ripening; and two months, when the land lies idle before winter freeze up. Cropping practices which utilize the entire growing season could provide additional pasture for livestock and reduce soil erosion (Baron et al., 1993). Hydrologic research has traditionally been focused on arid and semiarid zones and there is little information about hydrologic parameters in the cooler and more humid ecoregions of the Canadian Prairie. Little is known about the hydrology of SDIG in Alberta in which newly seeded perennial forages as well as annual forages are used.

Grazing has hydrologic impacts which result primarily from interactions of climate, vegetation, soil and intensity and duration of grazing (Blackburn, 1984; Naeth and Chanasyk, 1996). The scientific literature contains hydrologic studies on many range types in the United States which are summarized in reviews by Blackburn (1984) and Branson et al. (1981). Each ecoregion behaves uniquely, argue Taboada and Lavado (1988) and Blackburn (1984). The factors causing differences among past studies on rangeland hydrology are related to different soil properties, environmental conditions and grazing intensity so each ecoregion must be studied separately (Taboada and Lavado, 1988). In research studies, light and medium grazing intensities create small changes in hydrology while heavy grazing almost always decreases infiltration and increases bulk density. These deleterious changes are often confounded by range improvement activities (Naeth, 1988).

Soil parameters influencing rangeland hydrology under grazing

Many researchers have reviewed the effects of cattle trampling and vegetation removal by grazing animals on rangeland hydrology and soil physical properties (Warren et al., 1986a; Taboada and Lavado, 1988; Chanasyk and Naeth, 1996). Most researchers agree that heavy grazing of animals can alter surface watershed characteristics which increase runoff potential and subsequently, increase erosion potential, decrease infiltration, decrease surface-water quality (Warren, 1986a), decrease soil quality (Dormaar, 1989), and reduce forage production attributes (Heady, 1975). Under intensive grazing, vegetation defoliation, reduced litter and higher stocking rates compact soils (Chanasyk and Naeth, 1996). Compacted soils have reduced infiltration and macroporosity (Heinonen, 1986; Toboada and Lavado, 1988). Macropores act as conduits for precipitation within the soil. Rain drop impacts on bare soil can break down surface soil aggregates which clog existing surface pores and create soil surface crusts (Heady, 1975; Naeth and Chanasyk, 1996). Soil compaction is an important process in rangeland hydrology because it influences water intake and runoff (Branson et al., 1981). Soil compaction was defined by Gupta et al. (1989) as the compression of unsaturated soil particles, causing an increase in bulk density with a simultaneous reduction in fractional air volume. Except for high clay soils, increases in bulk density are commonly associated with soil compaction and the deleterious effects of grazing on soil structure and soil hydrologic responses

(Abdel-Magid et al., 1987; Dormaar et al., 1989; Chanasyk and Naeth, 1996) Degree of soil compaction depends on soil water, soil texture, grazing intensity, vegetation type and climatic regime (Toboado and Lavado, 1988; Chanasyk and Naeth, 1996).

There is a strong relationship between soil water and soil texture and grazing (Chanasyk and Naeth, 1996). Fine textured soils tend to hold more water than coarse textured soils and thus are more vulnerable to compaction especially when pastures are grazed under wet conditions (Chanasyk and Naeth, 1996). The greatest amount of soil compaction occurs at field soil moisture contents between wilting point and field capacity (Orr, 1960). Soils tend to compact more under moist conditions (Chanasyk and Naeth, 1996) because soil particles slide past each other with the lubrication of water (Hillel, 1982) while under dry conditions, soil aggregates can break down from cattle trampling to form a compacted surface soil layer (Warren et al., 1986b). Increases in bulk density due to grazing are shallow (Orr, 1960), with the greatest density increase in the 0 to 5 cm depth interval. Cultivation of annual pastures may mitigate increases in soil bulk density due to disturbance of near-surface soil.

Vegetation parameters influencing rangeland hydrology under grazing

Grazing affects hydrology of an area by altering plant species, plant density, and ground cover (Naeth, 1988). Heavy grazing often induces changes in vegetation species and plant density favoring less palatable species or more grazing tolerant species (Heady, 1975). Grazing reduces plant height and litter accumulation. A desired management system would include a proper balance of litter accumulation, vegetation removal by the grazing animal and the incorporation of organic matter into the soil to maintain soil structure and promote soil sustainability (Naeth, 1988).

Branson et al. (1981) stated that removal of plant material by grazing animals leads to soil compaction. Under deferred-rotational grazing, Wood and Blackburn (1984) reported higher bulk density under shrub zonal vegetation compared to midgrass and shortgrass vegetation. Under midgrass and shortgrass vegetation, soil bulk density was lower on rested pastures compared to grazed pastures suggesting soil recovery under rest. Heinonen (1986) suggested that some plant species may be better at mitigating increases in soil bulk density than other plant species. Smoliak et al. (1972) reported shallow rooted species replaced deeper rooted species in drier environments caused by heavy grazing. Rhizomatous rooting species may have an advantage over deeper rooted species in mitigating near-surface compaction because root penetration is most active in the zone of greatest compaction.

There is no definitive description or term for dead vegetative matter in range ecosystems. Naeth (1988) defined litter as all dead organic matter not incorporated within the mineral soil and occurring above soil mineral horizons. Soil organic matter was defined by the Canadian Department of Agriculture (1979) as the organic fraction of soil including plant and animal residues at various stages of decomposition, cells tissues of soil organisms and substances synthesized by the soil population.

Grazing may reduce soil organic matter by reducing the amount of above ground plant material (Smoliak et al., 1972; Dormaar et al., 1977; Naeth et al., 1991a) but in other studies, grazing increased soil organic matter (Dormaar et al., 1984) or had no effect on soil organic matter (Johnston et al., 1971; Dormaar et al., 1977).

Some researchers found the quantity of living plant matter and associated litter correlated better with infiltration than any other measurable parameter (Rauzi and Hanson, 1966; Rauzi and Smith, 1973; Naeth, 1988). Litter and vegetation increase infiltration rates by improving soil structure, decreasing the impact of raindrops which induce surface sealing, and by reducing and slowing down runoff which leads to erosion (Naeth, 1988). Litter can reduce evaporation losses from soil through reduction of wind velocity, stabilization and lowering of soil temperature, and increasing the diffusion gradient from soil to air which can increase soil water (Naeth, 1988).

Litter and vegetation can also reduce the amount of precipitation reaching the soil surface through interception and subsequent evaporation of absorbed water (Naeth et al., 1991). Interception varies with plant species and cropping system (Branson, 1982). Interception losses from small storms are often high while those from larger storms are small, ranging from 2 to 5% (Corbett and Crouse, 1968). The amount of water evaporated from litter is governed primarily by the volume of accumulated litter (Hevely and Patric, 1965), the water holding capacity of litter (Naeth et al., 1991b), and the evaporation potential before and after precipitation events (Corbett and Crouse, 1968). Water holding capacity of litter varies with vegetation type and particle size distribution of litter (Naeth et al., 1991b). Taller vegetation will increase the amount of interception through increased leaf area (Branson, 1982).

Perennial pastures are traditionally used for conservation and many are established in the Aspen Parkland as supplemental pasture or to be cropped as hay. Meadow bromegrass (*Bromus riparious Rehm.*) is adapted to the more moist and cooler areas of the Canadian Prairies (Knowles et al., 1993). It has a restricted creeping root habit and abundant basal leaves with rapid regrowth following clipping or grazing (Knowles et al., 1993). Meadow bromegrass has a bunch grass habit with a high litter producing potential and a moderate to high erosion reducing potential while smooth bromegrass is a rhizomatous perennial grass with a moderate litter forming potential and a high erosion reducing potential. Smooth bromegrass is a rhizomatous perennial grass with medium litter producing potential and high erosion reducing potential. It is slow to regrow because most or all tiller apices are removed by cutting (Barnes et al. 1995) and regrowth comes from crowns and underground rhizomes.

'Pika' Winter Triticale (X *Triticasecale* Wittmack) is a rust and snowmold resistant crop compared to varieties of rye and wheat grown in the Canadian Prairies (Salmon et al., 1992). Due to earlier maturity, Pika is more suited for seed production than spring triticale cultivars in the cool, short-season areas of Alberta (Salmon et al., 1992). Pika matures early and appears to have potential for spring-seeded forage either as a monocrop or in combination with barley (Salmon et al., 1992). Triticale is a winter cereal with low to moderate litter forming potential and moderate erosion reducing potential. A triticale/barley mix has a low litter forming potential and a moderate to low erosion reducing potential.

Study Objectives

To effectively manage grazing lands in a productive yet sustainable manner in Alberta, the impacts of grazing intensity on soil physical properties and hydrology must be quantified. To successfully quantify these characteristics, a knowledge of the interaction of soil, climate, vegetation and management decisions must be improved. Although much research on rangeland hydrology and soil compaction has been conducted in the United States Great Plains, extrapolation of results is not easy because of differing soils, climate and vegetation. The present study was intended to assess the hydrologic impacts of short duration intensive grazing at a pasture site in central Alberta Aspen Parkland. It was hypothesized that soil bulk density would increase with increased grazing intensity but increases would be mitigated under annual forages through cultivation. Soil water status would be controlled at the soil surface and would include effects of soil compaction, litter, vegetation and bare ground. The research was designed to compare the hydrologic response of crop by grazing factors under the same soil and climatic regimes. Special consideration was given to those parameters which influenced increases in soil bulk density and changes in soil water status.

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II. SURFACE SOIL COMPACTION UNDER ROTATIONAL GRAZING OF ANNUAL AND PERENNIAL FORAGES IN CENTRAL ALBERTA

Introduction

In many ecosystems around the world, researchers have reported soil compaction by grazing animals (Warren et al., 1986; Stephanson and Veigel, 1987; Toboado and Lavado, 1988; Chanasyk and Naeth, 1996). Soil compaction was defined by Gupta et al. (1989) as the compression of unsaturated soils, causing an increase in bulk density with a simultaneous reduction in fractional air volume. Except for high clay soils, increases in bulk density are commonly associated with soil compaction and the deleterious effects of grazing on soil structure and soil hydrologic responses (Abdel-Magid et al., 1987; Dormaar et al., 1989; Chanasyk and Naeth, 1996). Degree of soil compaction depends on soil texture, soil water, grazing intensity, vegetation type and climatic regime (Toboado and Lavado, 1988; Chanasyk and Naeth, 1996).

Fine textured soils tend to compact more than coarse-textured ones (van Haveren, 1983). In the Northern Great Plains, bulk density in clay, silty clay and sandy loam soils all increased under heavy grazing compared to light grazing (van Haveren, 1983) while in sandy soils, no increase in bulk density occurred with greater stocking density (Abdel-Magid et al., 1987).

There is a strong relationship between soil water and soil texture and grazing (Chanasyk and Naeth, 1996). Fine textured soils tend to hold more water than coarse textured soils and thus are more susceptible to compaction especially when pastures are grazed under wet conditions (Chanasyk and Naeth, 1996). The greatest amount of soil compaction occurs at field soil moisture content between wilting point and field capacity (Orr, 1960). Soils tend to compact more under moist conditions (Mulholland and Fullen, 1991; Chanasyk and Naeth, 1996) because soil particles slide past each other with the lubrication of water (Hillel, 1982). Dry soil aggregates can be pulverized from cattle trampling to subsequently form a compacted surface soil layer (Warren et al., 1986). Increases in bulk density due to grazing are shallow (Orr, 1960), with the greatest density increase in the 0 to 5 cm depth interval.

Branson et al. (1981) stated that removal of plant material by grazing animals can lead to soil compaction. Under deferred-rotational grazing, Wood and Blackburn (1984) reported higher bulk density under shrub zonal vegetation compared to midgrass and shortgrass vegetation. Soil bulk density under midgrass and shortgrass vegetation was lower on rested pastures compared to grazed pastures. Heinonen (1986) suggested some plant species may be better at mitigating increases in soil bulk density than other plant species. Smoliak et al. (1972) reported shallow rooted species replaced deeper rooted species in drier environments caused by heavy grazing. Rhizomatous rooting species may have an advantage over deeper rooted species in mitigating near-surface compaction because root penetration is most active in the zone of greatest compaction. Cultivation of annual pastures may also mitigate increases in soil bulk density due to disturbance of near-surface soil.

Few researchers have examined the influence of grazing intensity on soil bulk density for different forage types under the same soil and climatic regime. Grazing intensity is a subjective term that is usually quantified by stocking rate guidelines established for a certain area. Few researchers have quantified grazing intensity in terms of vegetation height at the beginning and end of grazing. In most past studies, the response of soil physical properties to continuous grazing of long-term pastures have been researched but little is known about soil response to rotational grazing. Short-duration-intensive-grazing (SDIG) is a relatively new management practice in Canada under research (Dormaar et al. 1989). With SDIG, farmers can control timed grazing of smaller pastures at increased stocking rates (Dormaar et al. 1989). Savory and Parsons (1983) hypothesized that soil physical conditions could be improved under SDIG through the breaking up of surface crusts by cattle trampling. However, Warren et al. (1986) reported increases in bulk density correlated with increasing stocking rate under SDIG under both moist and dry soil moisture conditions. Dormaar et al. (1989) also reported increased deterioration of soil quality under an already poor quality soil, using high-stocking rate SDIG.

Since the objective of most grazing management practices is to maximize livestock production per unit area while maintaining sustained forage resources (Dormaar et al., 1989), using annual forages as supplemental pastures may be an option for some managers. In the Southern Great Plains, hard red winter wheat is used as supplemental forage during fall and winter (Krenzer et al., 1989). In Central Alberta, perennial forages produced 60 % of total summer production before July 1 (Baron et al. 1993). Few researchers have studied the use of annual forages to extend the grazing season in the Northern Great Plains.

The objective of this study was to quantify the changes in near-surface bulk density (DB) under different forages and different grazing intensities at a site in central Alberta. It was hypothesized that DB would increase as grazing intensity increased. DB would be higher under perennial forages than under annual forage because soils under annual forages would be cultivated every year thereby mitigating increased DB associated with grazing. Finally, DB increases would be less under smooth bromegrass forages than under meadow bromegrass forages because smooth bromegrass has a rhizomotous rooting pattern which would more efficiently mitigate DB in the zone of greatest DB increase, than deeper rooted meadow bromegrass.

Materials and Methods

Study Site and Experimental Design

The study site was located at Lacombe, Alberta approximately 130 km south of Edmonton, Alberta at the Agriculture and Agri-Food Canada Research Centre (52°N 113°W). Research began in spring 1994 and ended in fall 1995. The climate is continental prairie which is slightly affected by Chinook winds most winters (Environment Canada, 1991). The moisture regime is sub-humid with 447.5 mm of annual precipitation (de St. Remy, 1990). The mean annual temperature is 2.4 °C with a January mean temperature of -13.8 °C and a July mean temperature of 16.1 °C (de St. Remy, 1990). The dominant soil on the study site is an Orthic Black Chernozem (Ponoka series) with a silty loam surface horizon texture and a variable loam texture in deeper horizons (Bowser et al., 1951; AAFC Lacombe Research, 1993). The thickness of the surface horizon is variable but averages 30 cm. Below lies a well developed AB horizon that is also variable in thickness and reaches a maximum depth of 60 cm in some areas. Soil on the study site was developed on glacio-lacustrine parent material characterized by bedded clays, silts and very fine sands (AAFC Lacombe Research, 1953; Stalker, 1960). Topography of the study area is undulating with a 1 to 6 % slope.

The study site was located on both east-facing sloped and flat land at an elevation ranging from 866 to 873 m. Prior to the study, the pasture was vegetated with smooth bromegrass (*Bromus inermis* L.,), quackgrass (*Agropyron repens* L.), and blue grass (*Poa praetensis* L.) and was grazed periodically each summer for approximately 15 years. In summer 1992, the study site was broken and fenced. Experimental plots were established, 48 in total, in 4 replicates of 12 plots each. Individual plots were 9 m wide and 33 m long. The four replicates were located above each other with the upper two replicates on a 4 to 6% east facing slope and the bottom two replicates on relatively flat land. Adjacent to the site, 3 unfenced benchmark plots (3% east facing), established on an open 25 year old pasture, with similar plot sampling dimensions, were established on a sward similar to that of previously unbroken land, to provide a long-term pasture comparison. The plots were left fallow until spring 1993 after cultivation in 1992. During the establishment of the forages in 1993, one plot was discarded due to operational problems.

Meteorological Conditions

A portable weather station was set up on the research site. Total daily precipitation, maximum temperature and minimum temperatures were measured from mid-April to late-October in 1994 and 1995. Data from the study years were compared to 85 year long-term data (1907-1992) from a weather station less than 2 km away.

Forage Factors

Four forages with differing grass morphology and litter forming capabilities were chosen for study under grazing. 'Paddock' Meadow bromegrass (*Bromus riparious* Rehm.) and 'Carlton' smooth bromegrass (*Bromus inermis* L.) used as perennial treatments, while 'Pika' winter triticale (*Triticosecale X* Wittmack) and triticale/barley (*Triticosecale X* /*Hordeum vulgare* var. AC Lacombe) mix were annual treatments. Meadow bromegrass is a bunch grass with a high litter producing potential and an assumed moderate to high erosion reducing potential while smooth bromegrass is a rhizomatous perennial grass with an assumed moderate litter forming potential and a high erosion reducing potential. Triticale is a winter cereal with low to moderate litter forming potential and moderate erosion reducing potential. The triticale/barley mix has a low litter forming potential and a moderate to low erosion reducing potential.

Perennial forages were seeded May 31, 1993. Seedbed preparation consisted of a fertilizer application (112 kg ha^{-1}), one pass with a rototiller, followed by a diamond spike harrow and then a crowfoot packer. Smooth bromegrass was seeded at 11.2 kg ha^{-1} and meadow bromegrass was seeded at 16.8 kg ha^{-1}. Alfalfa (*Medicago* *sativa* var. Spreader II) was seeded with each perennial forage at 1 kg ha^{-1}. Forages were broadcast seeded followed by one pass with a diamond harrow and one pass with a crowfoot packer. In 1994 and 1995, the perennial forages were fertilized in mid-April at 112 kg ha^{-1}.

In June 1993, annual plots were prepared by rototilling, harrowing and fertilizing at 112 kg ha^{-1}. Triticale was seeded at 135 kg ha^{-1} and a triticale/barley mix was seeded at a rate of 90 kg ha^{-1} triticale and 50 kg ha^{-1} barley. Plots were seeded with a plot seeder which had press wheels at the front and back of double disk openers. A final packing operation was performed with a crowfoot packer. In early May, 1994 and 1995 annual seedbeds were prepared in a similar manner to 1993 and seeding rates were the same.

Grazing Factors

One year old crossbred beef replacement heifers were used to graze plots. In 1993, unquantified but even light grazing was used to reduce forage on all treatments to an even height for study commencement in spring 1994.

In this study, grazing intensity was defined by forage height. Grazing started when forages reached a target maximum height and ceased when a target minimum height was reached. Target heights were set according to species morphology, desired litter, and bare ground appropriate for that treatment. Mean seasonal field heights were determined using an average of 10 ruler heights.

Grazing of heavily grazed perennial treatments commenced when they were 8 to 10 cm in height and ended at 2 to 5 cm; grazing of medium grazing began at 12 to

15 cm and ceased at 8 to 10 cm, while light grazing started at 20 to 25 cm and stopped at 12 to 15 cm. On annual forages, heavy grazing started at a forage height of 8 to 12 cm and ended at 2 to 5 cm, medium grazing was initiated at 12 to 15 cm and ceased at 8 to 10 cm, while light grazing started at a height of 15 to 20 cm and stopped at 12 to 15 cm.

For both annual and perennial forages, heavy grazing represented an over grazed condition with significant bare ground and minimum litter. Medium grazing represented near optimum conditions without excessive bare ground and with a moderate amount of litter. Light grazed forages reached an advanced stage of maturity with seedhead emergence where possible and was intended to maximize litter production.

Different amounts of rest for regrowth were required for different grazing intensities, therefore, the number of grazing events per season varied among treatments. On the perennial treatments, heavy, moderate and light grazing treatments were grazed approximately 7, 5 and 3 times per season, respectively, on average. On the annual treatments, heavy, moderate and light grazing treatments were grazed approximately 5, 4 and 2 times per season, respectively, on average.

Stocking rate is often used to characterize grazing intensity and the energy required to compact soil. In this study, cow-days were used as an indication of compactive energy imparted to the treatments. The reader can calculate stocking rate as cow-days per unit area. In each 9 x 33 m plot, pastures were usually grazed over one day, with more cattle as grazing intensity increased and the number of days per stocking rate was expressed as 1 cow-day. Treatment cow-days were averaged over replications for each grazing event.

Measurement of Near-Surface Bulk Density and Volumetric Moisture Content

In this study, near-surface refers to the top 10 cm of the surface mineral soil horizon. Two Campbell Pacific Nuclear probes, one MC1 and one MC3-82, were used to measure near-surface bulk density (DB) and near-surface volumetric moisture content (VMC) simultaneously. The MC1 probe was used with the MC3-82 for spring 1994 measurements but on all other measurement dates, the MC3-82 was used. In each treatment, three locations were selected in the middle of each third of each plot. Locations were chosen on smooth ground to maximize instrument accuracy. At the measurement location, litter and vegetation were removed to the mineral soil layer using electric clippers when necessary. In spring 1994, 5 readings in duplicate were taken at each location in an approximate 0.5-m-diameter circle. The measuring procedure was refined and changed thereafter. At each measuring location, two holes were punched on either side of a rectangle the size of the gauge bottom. Two readings at each hole were taken to a depth of 10 cm, i.e. 4 readings per location and 12 readings per treatment.

Measurement time for each reading was 16 s. Before and after sampling, standard counts were taken with each density/soil moisture gauge on a stand elevating the gauge 82 cm above the ground surface with the probe locked in the gauge shield. For each gauge, the mean standard count was the average of at least 10 standard accepted. For each gauge, DB and VMC were computed by placing gauge counts into a unique equation derived for each individual gauge. The DB equation used was the manufacturer's specified equation while the VMC equation was derived locally by calibrations with soil cores. Dry bulk density was obtained by subtracting the average volumetric moisture content at each measurement hole from the average wet bulk density at that hole.

Statistical Analyses

For each data collection date, bulk density and volumetric moisture content data were tested for homogeneity of variance using the Bartlett test (Steel and Torrie, 1980). The W test was used to test for normality of distribution (Shapiro and Wilk, 1965). A SAS two factor (forage x grazing) General Linear Model (GLM) with replication was used to analyze significant differences at a 5% level to test for factor effects and interactions. Using SAS, data with significant F values were further analyzed by estimating means and separating estimated means using Least Squared Difference (Petersen, 1985). A SAS single factor GLM was used to analyze treatment effects. Data with significant F values were further analyzed by estimating means and separating estimated means using Least Squared Difference (Steel and Torrie, 1980; Petersen 1985).

Results and Discussion

Meteorological Conditions

May to October 1994 precipitation was 36 % higher than the LTN. All study months in 1994 had higher precipitation than the LTN (Table 2.1). May to October 1995 precipitation was 15 % higher than the LTN. May, July and August 1995 precipitation was higher than the LTN while September precipitation was lower than the LTN. Over-winter snowpack was measured at the Lacombe Research Centre meteorological site: 76 and 47 cm with respective water equivalents of 89 mm and 30 mm for 1993-1994 and 1994-1995 respectively.

Monthly mean air temperatures (derived from Table 2.1) were generally higher than the LTN in 1994 and lower than the LTN in 1995. May, August and September 1994 mean monthly air temperatures were 1.5, 1.5 and 2.5 °C above the LTN, respectively; July and August 1995 air temperatures were 1.5 and 3.5 °C below the LTN, respectively. In September 1995, the monthly mean air temperature was 1 °C higher than the LTN. 1994 was characterized with above normal temperatures with many high intensity, short duration thunderstorms and periods of extended rain and high temperature. The study year 1995 was characterized by more consistent rainfall and cooler than normal July and August temperatures.

Quality of Data

The interactions of bulk density with soil moisture are minimized in soils with a low expandable clay content (Hillel, 1982) such as those at the study site. In a scatter plot for moisture content (range: 5-40%) versus bulk density (range: 0.90-1.35 Mg m^{-3}) data slope was 2% negative with a wide scatter; R^2 values were below 0.02, moisture need not be considered as a potential factor affecting

To test the accuracy of the sampling procedure, an independent experiment of over 35 trials compared MC3-82 readings to core density. Two 10-cm diameter cores, averaged along the base of the gauge to a depth of 0 to 10 cm, had similar densities as gauge readings. R^2 values were 0.93-0.98 for both density and volumetric moisture content (data not shown).

Many researchers consider the ambient surface soil moisture conditions before and during time of grazing in evaluating compaction. Since surface soil moisture measurements were taken only biweekly (Chapter 3), it was difficult to quantify the ambient soil moisture conditions at the time of each grazing event. Of 24 measurement dates in 1994 and 1995, surface soil moisture was well distributed and ranged from permanent wilting point to field capacity (Chapter 3). Precipitation was frequent and well distributed during both grazing seasons and grazing events occurred on an evenly distributed schedule. Hence, surface soil moisture was variable throughout the study.

Compactive Energy

In both years, cow-days under heavy grazing were at least twice those under light grazing, except for triticale/barley treatments in 1994 (Table 2.2). Over both summers, total cow-days under perennials were approximately twice those under annuals. As well, cow-days per grazing event were slightly higher under perennials than annuals.

Throughout the duration of the experiment, VMC among forages was generally not significantly different except at the beginning of the study (Table 2.3). At this time, soil moisture conditions were variable with no apparent trend (Table 2.4). Although not tested statistically, VMC in the benchmark site was numerically lower (except for May 1994) than the experimental plots (Table 2.3).

Grazing intensity

VMC was significantly different among grazing intensities, except at the beginning and end of the study (Table 2.3). Except on these dates, VMC was higher in lightly grazed plots compared to medium and heavily grazed plots. On the lightly grazed plots, lower DB (discussed in the next section) likely lead to higher infiltration through better soil structure, thereby increasing VMC. In the first fall, only annual and smooth bromegrass treatments were significantly different among respective treatments (Table 2.4). VMC in both lightly grazed annual treatments was higher than in medium and heavily grazed annual treatments, while in smooth bromegrass treatments, soil water was significantly higher under heavily grazed compared to medium grazed treatments. Except for meadow bromegrass, VMC in lightly grazed treatments was significantly higher than in medium and heavily grazed treatments during the spring of 1995. Higher amounts of standing litter in lightly grazed plots (not measured) may have trapped more snow over the winter compared to medium and heavily grazed plots leading to higher VMC in the spring. Even after cultivation in

Near-Surface Bulk Density

Forage type

DB was generally not significantly different among forages except at the end of the first grazing season (Table 2.5). On October 8, 1994, DB was significantly higher under meadow bromegrass than under annuals. Fewer grazing events throughout the first summer likely kept DB lower under annual forages than under perennial forages at all grazing levels (the number of cow-days for annuals was approximately half that of perennials, Table 2.2).

The relationship between compaction (DB) and cow-days was predictable. When the means of DB values for fall 1994 and 1995 were regressed against cow-days, equations of the trend, $y = 1.056 + 0.003x - 1.709x^2$ for perennials and $y = 1.060 + 0.003x - 1.321x^2$ for annuals, fit well (Figure 2.1).

DB changed most over the first year of grazing, while in the second year DB decreased in most treatments (Table 2.6). Some researchers have reported greatest compaction occurs under the first pass with farm machinery and less compaction occurs on subsequent passes (Heinonen, 1986). The effect of grazing may be analogous to that under vehicular traffic in that the greatest compaction occurred over the first summer of grazing. Above normal precipitation during 1994 (+56 %) could have left soils more susceptible to compaction compared to 1995 when precipitation was only 15 % above normal. In the second summer, DB could have been lowered

Over the two years, DB increased more under perennial [illegible]

(Table 2.5). Cow-days under perennials were twice those of annuals so there was twice the compacting energy imparted to the perennial forages (Table 2.2). DB among perennial forages increased most under meadow bromegrass although DB under smooth bromegrass also increased to a higher level than that under annual forages (Table 2.5). Change in DB under triticale was closer to that for perennials compared to triticale/barley. DB under smooth bromegrass was lower than under meadow bromegrass indicating smooth bromegrass may be better at mitigating increases in bulk density because of its rhizomotous rooting habit which grows within the zone of greatest compaction Table 2.5).

In all annual treatments, DB increased after one season of grazing (Table 2.5). Cultivation in spring 1995, after one season of grazing, slightly decreased DB under annual forages (0.01-0.07 Mg m^{-3}), especially under heavily grazed treatments (Table 2.6). Cultivation did not lower DB to equivalent levels to the beginning of the study. Considering DB averaged over all annual treatments, cultivation decreased DB only 3 %. There were no significant differences in DB among triticale and triticale/barley (Table 2.5).

Grazing intensity

DB was significantly different among grazing intensities on all measurement dates after grazing was established excluding after cultivation (Table 2.5). Except for under medium grazed treatments was between [illegible]

grazing. Cow-days under heavy grazing were approximately twice those of light grazing (Table 2.2). More cow-days and bare ground, along with less litter and less forage recovery time between grazing events, likely caused DB to be higher under heavy grazing compared to light grazing and medium grazing. Root development under heavy grazing may have been inhibited by defoliation so density amelioration through root penetration may have been less under this treatment.

In October 1994, DB was significantly higher under heavily grazed smooth bromegrass than lightly grazed treatments (Table 2.6). In October 1995, DB under heavily grazed triticale, as well as under heavily grazed perennials, was significantly higher than under lightly grazed treatments (Table 2.6).

Surface soil moisture was highest under heavy grazing on all dates that surface soil moisture was significantly different (10 of 23 dates) (Chapter 3). Higher surface soil moisture conditions would likely leave heavily grazed plots even more susceptible to compaction compared to lighter grazing.

The change in DB was most dramatic under all heavily grazed treatments after the first season while the change in DB under medium and light grazing increased only slightly after the first season (Table 2.6). Generally, light and medium grazing caused similar increases in DB in 1994. In 1995, DB under both medium and light grazing decreased while DB under heavy grazing did not change (Table 2.6). Roots likely

After one season of grazing, DB increased over the winter in all treatments (0.02-0.07 Mg m^{-3}) (Table 2.5), indicating lack of over-winter freeze-thaw mitigation. Kay et al. (1985) reported DB was not mitigated due to freeze-thaw action over the winter. The researchers suggested that macroporosity was reduced by the expansive growth of ice lenses and that DB increased subsequent to settling of soil particles after spring thaw. An increase in DB for all plots could also indicate a deterioration of soil structure after just one season of grazing through the deterioration of soil organic matter and physical trampling. Deleterious changes to soil structure could have caused freeze/thaw action to break up soil aggregates causing more soil settling. DB plots increased most over the winter in the medium grazed plots and to levels similar to that of heavily grazed treatments under all forages except under meadow bromegrass. DB under medium grazing in spring 1995 was similar to that under heavy grazing but in the previous fall, DB under medium grazing was similar to light grazing.

Significant differences in DB among treatments occurred in the fall of both years (Table 2.6). In October 1994, DB under heavily grazed smooth bromegrass treatments was significantly higher than under lightly grazed treatments. DB under heavily grazed meadow bromegrass treatments was significantly higher than that in medium grazed treatments. In 1994, there were no significant differences among

Measurements in this study were from 0 to 10 cm. Soil cores from some of the experimental plots in the fall 1995 (data not shown) had a higher DB for the 0 to 5 cm than the 5 to 10 cm depth interval (Mapfumo, 1996). Thus, 10-cm probe readings may average DB over too great an interval to detect differences in DB among treatments. The duration of this study was also short so the depth of compaction may increase over the long-term. It is important to quantify the depth of compaction so coring may still be [illegible] most accurate measurement of DB in grazing studies. However, for many tr[illegible] in this study, coring would be extremely labor intensive compared to [illegible], ease of use and accuracy of the surface moisture/density gauge. In this experiment, readings provided significant differences among grazing intensities but only once among forages. By using cores, differences in DB, at the 0 to 5 cm depth interval, among forages are likely to be greater. The soil in the study area is one of Alberta's best quality soils so changes in DB could be deeper and more dramatic if this study had been conducted on a lower quality soil.

Conclusions

DB increased under all treatments over the two-year study, especially in the first year of grazing. DB increased most in the first year under both annuals and perennials. DB under perennials was higher than that under annuals. DB under annual forages increased at a similar rate to that under perennial forages. Cultivation reduced DB under annual forages by only 3 % and lowered it under heavily grazed annual treatments most. DB was lower under smooth bromegrass than under meadow bromegrass likely because of smooth bromegrass's rhizomatous rooting habit which helped mitigate increased DB from grazing in the zone of greatest compaction.

DB was highest under heavy grazing, followed by medium and light grazing, respectively. VMC in the spring after grazing was highest under light grazing likely because of increased infiltration through lower DB and higher standing litter which trapped more snow.

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Table 2.1. Meteorological data for Lacombe Research Station

	Precipitation (mm)			Average Max. Temp.(°C)			Average Min.Temp. (°C)		
Date	LTN	1994	1995	LTN	1994	1995	LTN	1994	1995
May	50	86	61	17	18	17	2	4	2
June	82	102	83	21	21	22	7	7	8
July	78	87	112	24	24	22	9	10	9
August	64	151	104	22	22	19	7	10	6
September	42	68	9	18	21	21	3	5	2
October	19	29	17	12	11	12	-3	-2	-3
May to October	335	523	386	19	19	19	4	6	4

Table 2.2. Cow-days per grazing event for all forage x grazing treatments during 1994 and 1995.

	Meadow Brome			Smooth Brome			Triticale			Triticale/Barley		
	Light	Medium	Heavy	Light	Medium	Heavy	Light	Medium	Heavy	Light	Medium	Heavy
1994	7.4	7.0	6.4	7.4	7.3	6.8	5.1	4.8	5.2	5.5	5.0	5.9
	2.8	3.6	5.9	6.5	4.2	6.0	4.2	2.5	5.7	4.3	2.6	5.5
	5.1	3.9	5.2	4.6	6.3	6.4		1.8	3.9		2.2	5.3
		3.9	5.2		2.0	7.7			3.9		1.5	
		1.1	10.0		1.6	5.3						
			4.0			7.2						
						5.6						
Seasonal total	15.3	19.6	36.7	18.4	21.4	45.0	9.3	9.1	18.7	9.8	11.3	16.7
	Meadow Brome			Smooth Brome			Triticale			Triticale/Barley		
	Light	Medium	Heavy	Light	Medium	Heavy	Light	Medium	Heavy	Light	Medium	Heavy
1995	7.5	6.4	5.4	7.9	4.4	5.6	4.0	2.8	4.7	3.6	4.0	5.0
	3.9	3.6	4.7	4.2	3.8	3.7	2.2	4.9	5.9	2.9	3.3	6.1
	3.8	1.8	2.5	3.7	3.1	5.3	2.7	3.7	5.2	0.7	2.5	5.1
		4.7	4.8		3.8	5.5		1.9	5.5		1.4	3.0
		3.7	6.1		2.8	5.2			4.2			4.1
		3.7	6.2			4.7						
			9.5			5.0						
			4.2									
Seasonal total	15.1	24.0	43.4	15.9	17.8	35.0	8.9	13.3	25.5	7.2	11.2	23.4
2 year average	15.2	21.8	40.1	17.2	19.6	40.0	9.1	11.2	22.1	8.5	11.3	20.0
	Perennial Average			16.2	20.7	40.0	Annual Average			8.8	11.2	21.1

Table 2.3. Near-surface volumetric moisture content (0-10 cm) ($cm^3/cm^3 \times 100$) for all forages and grazing factors.

Forage	May 94	AC*	Oct 94	May 95	AC*	Oct 95
meadow brome	19.0 b	-	28.1 a	26.2 a	-	19.0 a
smooth brome	19.5 ab	-	30.3 a	26.8 a	-	19.7 a
triticale	22.1 ab	19.3 a	27.6 a	25.5 a	28.8 a	18.6 a
triticale/barley	23.7 a	20.3 a	30.4 a	26.5 a	28.5 a	20.8 a
benchmark site	21.6	-	15.7	15.3	-	11.4
Grazing Intensity						
light	21.7 a	20.9 a	31.3 a	29.9 a	30.3 a	20.4 a
medium	19.8 a	18.4 b	27.8 b	23.8 b	27.3 b	17.9 a
heavy	21.7 a	20.0 ab	28.2 b	25.1 b	27.9 b	20.3 a

*AC is after spring cultivation and seeding of annual forages.

Means among the same factor (forage or grazing), within each column and followed by the same letter, are not significantly different ($P \leq 0.05$).

Table 2.4. Near-surface volumetric moisture content (0-10 cm) (cm^3/cm^3) for all forage x grazing treatments.

Forage	Grazing Intensity	May 94	AC*	Oct. 94	May 95	AC*	Oct. 95
meadow brome	light	17.3 cd	-	28.2 bcd	28.5 abc	-	18.1 a
	medium	21.3 bcd	-	26.9 de	24.3 de	-	20.4 a
	heavy	18.5 cd	-	29.3 bcd	25.8 cde	-	18.6 a
smooth brome	light	22.3 abd	-	31.0 bcd	30.0 a	-	19.3 a
	medium	17.2 cd	-	29.8 d	23.9 de	-	18.5 a
	heavy	19.0 bcd	-	32.2 a	26.5 bcd	-	21.3 a
triticale	light	20.3 bcd	20.5 a	31.8 ab	29.5 ab	31.5 a	22.7 a
	medium	15.5 d	17.3 a	25.5 d	22.5 e	26.8 a	14.5 a
	heavy	28.5 a	20.3 a	25.5 d	24.5 de	28.0 a	18.7 a
triticale/barley	light	25.0 ab	21.3 a	34.4 a	31.5 a	30.3 a	21.8 a
	medium	25.3 ab	19.5 a	29.0 bcd	24.8 de	27.8 a	18.2 a
	heavy	20.8 bcd	20.0 a	27.8 bcd	23.8 de	27.8 a	22.5 a

*AC is after spring cultivation and seeding of annual forages.

Means within the same column and followed by the same letter are not significantly different ($P \leq 0.05$).

Table 2.5. Near-surface bulk density (0-10 cm) (Mg m^{-3}) for all forage and grazing factors.

Forage	May 94	AC*	Oct 94	May 95	AC*	Oct 95	ΔDB 94	ΔDB 95	Σ ΔDB
meadow brome	1.07 a	-	1.15 a	1.17 a	-	1.17 a	+0.08	0.00	+0.10
smooth brome	1.05 a	-	1.13 ab	1.18 a	-	1.15 a	+0.08	-0.03	+0.10
triticale	1.05 a	1.04 a	1.09 b	1.16 a	1.14 a	1.14 a	+0.04	-0.02	+0.09
triticale/barley	1.08 a	1.04 a	1.09 b	1.16 a	1.12 a	1.13 a	+0.01	-0.03	+0.05
benchmark site	1.08 a	-	1.09	1.14	-	1.15	+0.01	+0.01	+0.07
Grazing Intensity									
light	1.05 a	1.04 a	1.09 b	1.14 b	1.12 a	1.11 b	+0.04	-0.03	+0.06
medium	1.08 a	1.05 a	1.11 b	1.17 ab	1.13 a	1.15 b	+0.03	-0.02	+0.07
heavy	1.04 a	1.01 a	1.15 a	1.19 a	1.12 a	1.19 a	+0.11	0.00	+0.15

*AC is after spring cultivation and seeding of annual forages.

Means among the same factor (forage or grazing), within each column and followed by the same letter, are not significantly different ($P \leq 0.05$).

ΔDB is the change in near-surface bulk density from spring (before cultivation for annuals) to the fall of the same year.

Table 2.6. Near-surface bulk density (0-10 cm) (Mg m^{-3}) for all forage x grazing treatments.

Forage	Grazing Intensity	May 94	AC*	Oct. 94	May 95	AC*	Oct. 95	ΔDB 94	ΔDB 95
meadow brome	light	1.06 a	-	1.13 abc	1.14 a	-	1.14 bcd	+0.07	0.00
	medium	1.09 a	-	1.10 bc	1.15 a	-	1.15 abcd	+0.01	0.00
	heavy	1.04 a	-	1.19 a	1.21 a	-	1.22 a	+0.15	+0.01
smooth brome	light	1.02 a	-	1.09 cd	1.13 a	-	1.11 cd	+0.07	-0.02
	medium	1.06 a	-	1.14 abc	1.20 a	-	1.15 abcd	+0.08	-0.05
	heavy	1.06 a	-	1.17 ab	1.20 a	-	1.19 ab	+0.11	-0.01
triticale	light	1.06 a	1.05 a	1.07 cd	1.15 a	1.13 a	1.09 d	+0.01	-0.06
	medium	1.08 a	1.04 a	1.09 cd	1.16 a	1.15 a	1.16 abcd	+0.01	0.00
	heavy	1.01 a	1.01 a	1.12 bcd	1.17 a	1.13 a	1.17 abc	+0.11	0.00
triticale/barley	light	1.07 a	1.02 a	1.06 d	1.12 a	1.11 a	1.10 cd	-0.01	-0.02
	medium	1.10 a	1.06 a	1.10 cd	1.18 a	1.12 a	1.13 bcd	0.00	-0.05
	heavy	1.06 a	1.02 a	1.12 bcd	1.18 a	1.11 a	1.16 abcd	+0.06	-0.02

*AC is after spring cultivation and seeding of annual forages.

Means within the same column and followed by the same letter are not significantly different ($P \leq 0.05$).

ΔDB is the change in near-surface bulk density from spring (before cultivation for annuals) to the fall of the same year.

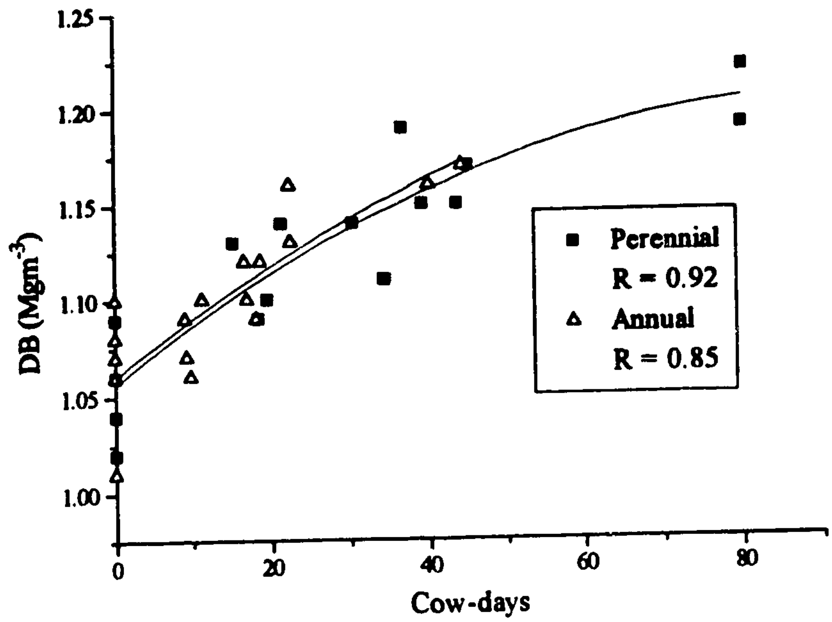

Figure 2.1. Near-surface bulk density (Mg m^{-3}) for May (before annual cultivation) and October 1994, and October 1995 versus cow-days for all treatments.

III. SOIL WATER RESPONSES TO ROTATIONAL GRAZING UNDER ANNUAL AND PERENNIAL FORAGES IN CENTRAL ALBERTA

Introduction

Grazing intensity and vegetation type interact to influence soil water through the deleterious effects of grazing on soil physical properties, through the reduction of vegetation and litter interception and through reduced forage evapotranspiration.

Infiltration rates generally decrease with increasing grazing intensity (Rauzi, 1963; Warren et al. 1986; Abdel-Magid et al. 1987; Naeth et al., 1990; Naeth and Chanasyk, 1996). Many researchers have reported increases in bulk density with increased grazing intensity (Warren et al. 1986; Naeth and Chanasyk, 1996) which can indicate surface soil compaction and reduced macroporosity, leading to reduced infiltration. In California, Liacos (1962) found that soil water was lower under heavy grazing than light grazing which he attributed differences to decreased infiltration. Near Fort Macleod, Alberta, Dormaar et al. (1989) reported lower soil water under short duration grazing compared to no grazing. They found bulk density increased and hydraulic conductivity decreased, hypothesizing infiltration was reduced by short duration grazing.

Litter and vegetation can reduce the amount of precipitation reaching the soil; this intercepted precipitation generally evaporates before it reaches mineral soil (Branson et al., 1981; Naeth et al., 1991a). Corbett and Crouse (1968) and Couturier and Ripley (1973) reported interception losses were generally high from small storms while for large storms, interception accounted for only 10 % of total storm capacity (Branson et al., 1981). However, in subhumid regions of the Northern Great Plains, many numerous small rainfall events occur; litter and vegetation may enhance interception losses significantly thereby affecting soil water. In many regions of the Canadian Northern Great Plains, soil water recharge is achieved from large storms and from spring snowmelt (Naeth and Chanasyk, 1996). Grazing management strategies which facilitate accumulations of litter may reduce soil water during the growing season yet increase snowmelt recharge in the spring (Naeth et al., 1991b).

In the Great Plains of South Dakota, Hanson and Lewis (1978) reported soil water increased as grazing level increased due to reduced interception loss by standing vegetation and mulch under heavy grazing. Naeth and Chanasyk (1996) found that surface soil water (0 to 7.5 cm) was higher under very heavy, compared to heavy, short duration grazing except under dry conditions. This they attributed to more bare ground, reduced litter and vegetation and reduced evapotranspiration under very heavy grazing brought on by defoliation. Litter and vegetation can retard runoff and therefore increase infiltration compared to bare soil (Branson et al. 1981). In Alberta, the most destructive sediment yielding erosion occurs during snowmelt rather than during summer storm events (Chanasyk and Woytowich, 1987; Naeth and Chanasyk, 1996). Grazing management strategies which promote over-winter litter accumulation likely reduce soil erosion by slowing runoff and increasing infiltration capacity.

Many researchers have considered the effect of defoliation and subsequent reduction in evapotranspiration of forages. In Utah, Buckhouse and Coltharp (1976) and alfalfa compared to medium or lightly clipped vegetation at a mid elevation study site. Evapotranspiration varies with plant species and grassland ecosystem (Branson et al. 1981, Naeth et al., 1991a). Depth of rooting (Buckhouse and Coltharp, 1976, Naeth et al., 1991a) and rooting morphology can influence where soil water is withdrawn up in the soil profile (Branson et al., 1981).

Short-duration-intensive grazing (SDIG) is a relatively new management practice in Canada (Dormaar et al., 1989). SDIG involves timed grazing of smaller pastures at increased stocking rates (Dormaar et al. 1989). Savory and Parsons (1983) hypothesized that soil physical conditions could be improved under SDIG through the breaking up of surface crusts through the action of cattle trampling. However, both Warren et al. (1986) and Abel-Magid et al. (1987) reported reduced infiltration which correlated with increasing stocking rate under SDIG. Dormaar et al. (1989) reported lower soil water under high-stocking rate SDIG compared to a non-grazed site. Naeth and Chanasyk (1996) found higher surface soil water under very heavy compared to heavy short duration grazing but below 30 cm, the relationship was opposite.

Annual pastures are routinely used in other areas of the world as supplemental forage during times of reduced biomass production of perennial forages. Baron et al. (1993) reported that in the Aspen Parkland of Alberta, many cool-season perennial forages produced 60 % of annual production before 1 July. As a result livestock production was limited during the late summer and fall. Intermittent frosts and low temperatures during September and October prevent growth of most forages except winter cereals. The potential for using winter cereals to supplement perennial forage production could permit farmland to be used for up to 6 months of the year.

In the Aspen Parkland, traditional cereal production only utilizes 4 of 6 potential growth months: from May to August, required for growth from seeding to ripening; and 2 months, when the land lies idle before winter freeze up. Cropping practices which utilize the entire growing season could provide additional pasture for livestock and reduce soil erosion (Baron et al , 1993). Hydrologic research has traditionally focused on arid and semiarid zones and there is little information about hydrologic parameters in the cooler and more humid ecoregions of the Canadian Prairie. Little is known about the hydrology of SDIG in Alberta which uses both newly seeded perennial forages as well as annual forages.

The most important factor controlling range productivity is soil water (Branson et al., 1981). The objective of this study was to identify how soil water was affected by crop and grazing management system in Central Alberta. It was hypothesized that soil water would be more responsive to forage type than to grazing intensity. Accumulated soil water would be highest under annual forages and under heavily grazed forages due to more bare ground, reduced evapotranspiration and litter and lower biomass and LAI. Different forage types would evapotranspire at different rates and at different periods within the summer but there would be little detectable difference in ET among grazing intensities.

Materials and Methods

Study Site and Experimental Design

Refer to Chapter 2 for details.

Meteorological Conditions

Conditions are the same as Chapter 2.

Forage Factors

Factors are the same as Chapter 2.

Grazing Factors

Factors are the same as Chapter 2.

Field Measurement of Soil Water

Within each of the 51 plots, 3 aluminum neutron probe access tubes were installed in mid August, 1993, to a depth of approximately 100 cm. The access tubes were installed along the centerline of the plot with one tube in the center and the other two halfway to the end fences, approximately 8 m apart from each other. A hand-auger was used to dig a 4.4-cm diameter hole to a depth of approximately 1 m. In the benchmark site, the tubes were set up on unfenced pseudo-plots with similar dimensions.

Using Campbell Pacific Nuclear (Model 503DR) neutron scattering hydroprobes, volumetric soil moisture (VMC) was measured once in mid April and then biweekly from May to mid October during 1994 and 1995. To avoid systematic errors, at least two probes per plot were used to measure soil moisture in either one or two of the three access tubes. The neutron probe readings started at 15 cm and continued at 10-cm depth intervals to a depth of 100 cm. At each depth increment, two 16-second readings were taken. To measure surface soil water (SSW), a polyethylene surface shield was placed on the neutron probe and then placed on the ground surface within 1 m from of each access tube (Chanasyk and Naeth, 1988). The surface-shield readings represented the top 7.5 cm of each access tube measurement. Two readings were taken adjacent to each tube and averaged. Profile soil water (SW) was calculated at each depth increment, as a volume percent from field recorded counts and then as a depth of water by multiplying this volume percent by the appropriate depth increment.

Before and after sampling the access tubes and surface moisture, standard counts were taken with each neutron probe on a stand elevating the gauge approximately 30 cm above the ground surface with the probe locked in the gauge shield. For each gauge, the mean standard count was the average of at least 10 standard counts which must have produced a chi value between 0.75 and 1.25 in order to be accepted. SW equations were derived from local calibrations. For each gauge, the count ratio for each depth in each tube was computed by dividing the sample count taken in the access tube, at that depth, by the mean standard count. Each count ratio was then entered into a unique equation derived for each gauge to determine volumetric moisture content at a given depth for a given tube. Accumulated soil water

(ASW) was calculated as a depth of water (mm) by summing incremental soil water measurements to 30, 50, 70 and 90 cm.

Statistical Analyses

For each data collection date, SSW and ASW data were tested for homogeneity of variance using the Bartlett test (Steel and Torrie, 1980). The W test was used to test the data for normality of distribution (Shapiro and Wilk, 1965). A SAS two factor (forage x grazing) General Linear Model (GLM) with replication was used to analyze significant differences at a 5% level to test for factor effects and interactions. Using SAS, data with significant F values were further analyzed by separating estimated means using Least Squared Difference (Petersen, 1985). Treatment effects were analyzed with a SAS single factor GLM. Data with significant F values were further analyzed by separating means using Least Squared Difference (Steel and Torrie, 1980; Petersen, 1985).

Evapotranspiration

Evapotranspiration was calculated from a soil water budget using the equation: ET = precipitation - change in soil water. Percolation and runoff were assumed to be zero. For total seasonal ET, the change in soil water was calculated by subtracting the amount of soil water on the last measurement date of a given season from that on the first. Precipitation was the total precipitation within the time interval between the two measurement dates. For biweekly ET, the change in soil water was calculated by subtracting the amount of soil water on the second measurement date from that on the first. Precipitation was the total precipitation between measurement dates. Daily ET, expressed in mm/day, was derived by dividing biweekly ET by the number of days between measurement dates.

Wilting Point and Field Capacity Derivation

Wilting point (WP) and field capacity (FC) were derived from a combination of field soil density measurements with depth and standard pressure plate analysis. WP was expressed as mm of soil water, for a given depth interval, at -1.5 MPa and FC was expressed as mm of soil water, for a given depth interval, at -0.33 MPa (Hillel, 1982). In situ soil density measurements were taken in 10-cm increments using a Campbell Pacific Nuclear (Model 501DR) depth moisture/density gauge. Procedures for obtaining readings and calculating density and moisture content were identical to field measurements of soil water using the Campbell Pacific Nuclear Scientific 503 probes except that density equations were those provided by the manufacturer. The calibration equation for VMC was derived using data from local sites. Bulk density at a given depth was determined by subtracting volumetric moisture content at that depth from the wet density at that depth calculated from the manufacturer's calibration curve. Standard counts were determined before and after each set of readings taken.

Results

Meteorological Conditions

Conditions were the same as discussed in Chapter 2.

Surface Soil Water (0 to 10 cm)

Crop factors

SSW varied among forages from mid June to late July in 1994 and on all measurement dates after early June in 1995 (Table 3.1a). In June and July of both years, SSW was higher under annual forages than under perennial forages, although not always statistically significant. During this period, perennial forages were well established while annual forages only grew from late May. SSW was significantly lower under annual forages than under perennial forages only on May 24, 1994, a period of very hot, windy weather, likely due to greater evaporation from bare ground between rows.

From early August to October 1995, SSW fluctuated but mostly under smooth bromegrass and especially under heavily grazed treatments (Table 3.1a). SSW was frequently higher under heavily grazed smooth bromegrass treatments than for other treatments (Table 3.2a). On many measurement dates, SSW was lowest under meadow bromegrass and was similar to that of the benchmark site (Table 3.1a).

Grazing Factors

SSW was significantly higher under heavy grazing compared to light or medium grazing on only 10 of 23 measurement dates (Table 3.1a). In 1994, SSW was significantly lowest under medium grazing (8 of 12 measurement dates). From mid June until early August of both years, SSW was significantly higher under heavily grazed perennial treatments compared to lightly grazed ones (Table 3.2a).

SSW was not significantly different among grazing intensities from mid August until September 1994 and from early August until late September 1995 but SSW under heavily grazed treatments was [illegible]

3.1a). During this period, SSW under heavily grazed annual and perennial treatments was higher than that under the respective lightly grazed treatments (Table 3.2a).

Accumulated Soil Water (ASW) 0 to 30, 0 to 50, 0 to 70 and 0 to 90 cm

ASW for depth intervals of 0 to 7.5, 0 to 30, 0 to 50, 0 to 70 and 0 to 90 cm is given in Tables 3.1a-e, inclusive. WP for each depth interval was 10, 29, 46, 63 and 81 mm, respectively, while FC for them was 30, 65, 98, 136, and 173 mm, respectively.

Crop factors

From early May to late July of both years, ASW (0 to 30, 0 to 50, 0 to 70 and 0 to 90 cm) was higher under annual forages than under perennial forages (Tables 3.1b-e, respectively). ASW was similar among annuals and perennials by mid August.

There were generally no significant differences in ASW among forages after early August 1994. At this time, soil water was extremely low (Table 3.1c). High precipitation, immediately after and continuing for the next month, caused soil water to be recharged by mid September 1994 to levels comparable to those in the spring. Precipitation in 1995 was again higher than the LTN but not as high as in 1994 (Table 2.1), especially in September. After mid August 1995, differences in ASW were apparent among forage treatments (Table 3.1b-e). At all depth intervals, except 0 to 50 cm, ASW under triticale/barley treatments was generally highest and ASW under meadow bromegrass was generally lowest (Table 3.1b-e).

highest under smooth bromegrass and generally lowest in annual forages (Table 3.1c). On September 12 and 26, 1995, ASW (0 to 50 cm) under perennials was higher than that in the annual plots.

ASW among annual forages was generally similar for all depth intervals, except for 0 to 30 cm where ASW under triticale/barley was significantly higher than under triticale for 5 of 13 dates in 1995 (Table 3.1b).

ASW under meadow bromegrass was consistently lower, although not always significantly, than that under other forages and it was, at times, similar to ASW levels in the benchmark (Table 3.1c).

Grazing Factors

On 11 of 13 measurement dates in 1994, ASW (0-30 cm) was significantly higher under heavy grazing compared to either light or medium grazing (Table 3.1b). For greater depth intervals, 0-50, 0-70 and 0-90 cm, ASW was again significantly higher under heavy than light or medium grazing but only on 5, 6 and 3 measurement dates respectively (Table 3.1c-e). Differences in ASW among grazing intensities at greater depth intervals occurred from late June to mid August 1994. In 1995, ASW among grazing intensities was similar (Tables 3.1b-e).

Seasonal Soil Water

Soil water levels were highest in spring of both years and greater than field capacity (FC) at this time for all treatments (Figures 3.2a-d; Tables 3.1a-e). In early wilting point (WP) (Figures 3.2a-3.2d; Tables 3.1a-e). End of season water was near WP but only in 1995 (Table 3.1c).

In 1994, with above normal precipitation and temperatures, soil water levels were both extremely high and low (Table 3.1c). Above normal precipitation in 1994 recharged soil water (0 to 30 cm) to near spring soil water levels on three measurement dates (Table 3.1b): on May 24, July 6 and September 12, with approximate biweekly precipitation of 78, 78 and 65 mm respectively and with approximate monthly precipitation of 85, 110 and 159 mm respectively. More precipitation was required to recharge soil water (0 to 30 cm) in early September compared to May and July. After one season of grazing, spring soil water among grazing intensities was not different.

Profile Soil Water

Data from two early summer measurement dates, which coincided over the two years (June 9, 1994 and June 8 1995), were good examples portraying typical differences in profile soil water between annuals and perennials. Wetting fronts under annual treatments were larger compared to those of perennial treatments (Figure 3.1a-d). On some measurement dates, wetting fronts were not visible under perennial forages but were under annual forages (Figure 3.2a-b). Under perennial forages, soil water tended to be held near the surface and declined rapidly with depth.

Soil water was almost always higher in the uppermost 0 to 30 cm than deeper in the profile (Figures 3.1 a-d, 3.2 a-b). Soil water below 40 cm was often uniform

3.1 a-d, 3.2 a-b).

Evapotranspiration

Total season ET among treatments ranged from 528-550 mm in 1994 and 441-467 mm in 1995. The total period covered was 182 days in 1994 and 178 days in 1995 so seasonal daily ET ranged from 2.9-3.0 mm/day in 1994 and 2.5-2.6 mm/day in 1995.

In both springs, calculated ET was approximately 1.6-2.6 mm/day for perennials and 1.2-2.2 mm/day for annuals. Perennials evapotranspired more than annuals until early June. From late May to late August of both years, calculated ET fluctuated between 2-6 mm/day, depending on soil water conditions. In September of both years, ET dropped from summer levels, especially in 1995, when soil water conditions were low.

Discussion

In June and July of both years, SSW under annuals was higher than under perennials. During this period, perennials were well established compared to annuals so perennials may have evapotranspired more than annuals therefore reducing soil water. Gill (1996) found more bare ground between rows on annual plots which likely reduced interception and allowed more precipitation to reach the soil surface, and infiltrate, increasing SSW. Later in the summer when annuals were well established, SSW was similar among forages. On many measurement dates, SSW was lowest

On many measurement dates, SSW was higher under heavy compared to medium and light grazing. This may have occurred due to either reduced interception or reduced rooting (reduced ET) under heavily grazed treatments.

ASW, from May to late July of both summers, was lower under perennial forages. During this period, perennial forages were well established compared to annual forages so perennial forages likely evapotranspired more, therefore, lowering ASW. Perennial forages likely grew and evapotranspired vigorously early in the season (April and May) while annual forages only began growing in late May.

In 1994, ASW after mid August was similar among forages but in 1995, ASW was often different among forages. Differences between years may have resulted from differenced in precipitation patterns. In this study, above normal precipitation in September 1994 recharged soil water so differences among forages could have been masked. In 1995, when precipitation in August and September was closer to normal, differences in ASW among forages were evident.

After mid August 1995, ASW was generally highest under triticale/barley and lowest under meadow bromegrass for all depth intervals except 0-50 cm (Tables 3.1 b-e). Higher soil water under triticale/barley than under a monocrop of triticale could indicate lower productivity under the mix as found by Baron et al. (1993). ASW (0-50 cm) was often highest under smooth bromegrass and lowest under annual forages. Annual forages may consume water from the 30-50 cm depth interval late in the water at this time in an attempt to set seed under grazing stress.

Meadow bromegrass may evapotranspire more than other forage types. Differences in soil moisture among meadow bromegrass and annual forages became more pronounced in the second study year because meadow bromegrass likely continued to root more and deeper. Conversely, annual forages grow for only one season so rooting depth is determined by plant growth over that growing season. Smooth bromegrass is rhizomatous and is shallow rooting. Therefore, its ASW, later in the summer, was often similar to that under annual forages (Table 3.1b-e) whose rooting depth was also relatively shallow compared to that of meadow bromegrass. ASW at all depths, except 0 to 50 cm, was much lower under meadow bromegrass than under shallower rooted species.

On many measurement dates in 1994, ASW under heavy grazing was higher than under either light or medium grazing. However, in 1995 there were few differences. In 1994, grazing effects on ASW could have been more pronounced because pastures were newly established. Differences among grazing intensities in 1994 could have been due to interception, reduced evapotranspiration through defoliation and limited root growth. The lack of differences in ASW in 1995 could be due to greater effects on ASW from forages so grazing differences could be masked.

Interception was not measured in this study but an arbitrary amount of precipitation per day could be used to characterize it. In this study 12 mm of precipitation was less than 12 mm. Thus most rainfall events were small and differences in interception likely caused differences in ASW among grazing intensities.

Defoliation under heavy grazing may have caused limited root growth and reduced evapotranspiration. In 1994, ASW was often highest under heavy grazing so evapotranspiration by vegetation may have been less, resulting in higher ASW under heavy grazing. Less foliage on heavily grazed plots likely meant lower evapotranspiration compared to medium and lightly grazed plots. Root mass under heavily grazed forages was likely limited so plant evapotranspiration was likely reduced compared to that of other grazing intensities. However, this effect was not evident in ASW, profile soil water (SW) or evapotranspiration (ET) (latter two discussed later). In 1995, ASW was generally not significantly different among grazing intensities, perhaps masked by greater differences in ASW among forage types.

In spring both years, ASW was seasonally highest for all depth intervals. Naeth and Chanasyk (1996) stressed the importance of snowmelt for soil water recharge in a prairie grassland ecoregion. In this study, snowmelt also recharged soil water to the highest levels of the year. Snowmelt recharge would likely be reduced under heavy grazing because of reduced infiltration. However, this was not evident in this study even though near-surface bulk density was highest under heavy grazing (Chapter 2). Summer recharge occurred during periods of high precipitation but ASW

(Gill, 1996), likely caused larger wetting fronts under annuals. Reduced interception likely caused more precipitation to reach the soil under annuals than under perennials even in the fall when annual forages were well established.

ET under perennial forages was generally highest during May of both years. From June to early August, annual forages had high evapotranspiration rates during early growth. There were no differences in ET among annual forages. ET appeared to be dependent on soil water and was generally highest under high soil water conditions. Calculated ET was likely overestimated during high soil water conditions. During these times percolation would not be negeligible, as assumed. More runoff occurred in 1994 than in 1995 (Gill, 1996) so calculated ET values in 1994 were likely overestimated due to non-negligible runoff.

Grazing intensity had little effect on average daily ET. Forage type affected ET slightly with ET under perennial forages higher than that under annual forages (Table 3.3). Perennial forages started evapotranspiring earlier in the season compared to annual forages but in both years from late June to early August, ET under perennial forages dropped below that of annual forages. During this latter time interval, meadow bromegrass evapotranspired more than smooth bromegrass although not always significantly. By mid August and for the remainder of both summers, ET was similar among all forages.

Conclusions

Surface soil water was more responsive to grazing intensity than accumulated soil water, with heavy grazing generally having the highest surface soil water. Accumulated soil water was affected more by forage type than grazing intensity, as hypothesized, with large differences in accumulated soil water between annual and perennial forages. Accumulated soil water was lower under perennial than annual forages until August 1994 and for most of 1995.

Soil water was generally highest in the spring and declined throughout the summer. Differences in ET at this study site were evident among forages but not among grazing intensities. Perennial forages had high evapotranspiration in the spring but evapotranspiration by annuals was higher from late June to early August, resulting in similar ASW among forages during this time period. Expected lower evapotranspiration under heavy grazing did not occur.

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Table 3 1a. Surface soil water (0-7.5 cm) (mm) for all forage and grazing factors.

Date	*Ppt. (mm)	Forage				Grazing Intensity			Benchmark site
		meadow brome	smooth brome	triticale	triticale/barley	light	medium	heavy	
12-Apr-94	-	15.8 a	16.6 a	17.9 a	19.0 a	18.1 a	15.7 a	18.2 a	8.8
9-May-94	7	10.6 b	11.5 b	13.1 a	13.2 a	12.5 a	11.7 a	12.1 a	6.7
24-May-94	78	22.3 a	22.2 a	18.8 c	20.1 bc	21.2 a	20.8 a	20.6 a	13.7
9-Jun-94	43	12.9 a	14.8 a	14.4 a	14.6 a	14.0 a	13.6 a	14.8 a	11.4
24-Jun-94	32	11.9 b	12.7 b	13.4 ab	14.6 a	13.2 ab	12.4 b	13.9 a	8.2
6-Jul-94	78	24.6 a	19.8 c	21.1 b	24.6 a	21.3 b	21.9 b	24.4 a	18.1
19-Jul-94	20	15.3 c	17.9 b	20.1 a	18.7 ab	17.6 b	16.8 b	19.6 a	12.8
2-Aug-94	8	7.7 a	8.0 a	9.4 a	8.9 a	8.1 b	7.8 b	9.6 a	5.3
15-Aug-94	57	12.4 a	14.0 a	13.0 a	12.9 a	13.1 a	12.2 a	13.4 a	8.5
30-Aug-94	94	-	-	-	-	-	-	-	-
12-Sep-94	65	19.5 a	19.7 a	19.1 a	18.6 a	17.2 b	19.8 a	20.7 a	16.0
26-Sep-94	3	16.2 a	16.9 a	13.8 a	16.2 a	14.5 b	15.8 ab	17.0 a	12.2
11-Oct-94	16	20.0 a	19.9 a	17.9 a	17.7 a	18.1 a	18.1 a	20.4 a	15.7
19-Apr-95	-	23.4 a	27.1 a	23.9 a	25.0 a	24.2 a	24.2 a	25.5 a	19.2
9-May-95	20	21.4 a	21.7 a	20.8 a	22.5 a	21.3 a	21.5 a	22.0 a	18.5
23-May-95	39	22.4 a	22.4 a	21.8 a	22.1 a	21.9 a	22.2 a	22.4 a	16.6
8-Jun-95	41	17.6 c	19.7 b	19.8 b	21.7 a	19.2 b	18.7 b	21.2 a	14.6
23-Jun-95	38	17.6 b	20.1 a	21.1 a	20.7 a	19.8 a	19.9 a	19.9 a	16.8
10-Jul-95	64	19.7 c	20.6 bc	21.6 ab	22.5 a	19.6 c	21.2 b	22.5 a	17.9
18-Jul-95	23	-	-	-	-	-	-	-	-
3-Aug-95	35	16.5 c	19.0 a	17.8 b	18.6 ab	17.1 b	17.6 b	19.2 a	14.2
15-Aug-95	58	22.8 ab	20.8 c	21.6 bc	23.3 a	21.7 a	21.9 a	22.8 a	19.5
29-Aug-95	39	16.6 b	20.1 a	17.6 b	17.0 b	17.0 a	17.6 a	18.8 a	17.0
12-Sep-95	1	13.8 ab	15.3 a	11.7 b	13.2 ab	12.9 a	12.9 a	14.6 a	13.1
26-Sep-95	9	13.2 b	14.8 a	12.3 c	13.9 b	12.3 c	13.4 b	14.6 a	10.0
14-Oct-94	9	-	-	-	-	-	-	-	-

Means among the same factor (forage or grazing intensity) followed by the same letter and within the same row are not significantly different ($P \leq 0.05$).
* Precipitation since last measurement date, (-) is missing data. WP = 10 mm, FC = 30 mm.

Table 3.1b. Accumulated soil water (0-30 cm) (mm) for all forage and grazing factors.

Date	*Ppt. (mm)	Forage				Grazing Intensity			Benchmark site
		meadow brome	smooth brome	triticale	triticale/barley	light	medium	heavy	
12-Apr-94	-	77 b	80 b	86 a	89 a	85 ab	79 b	87 a	56
9-May-94	7	46 b	51 b	68 a	69 a	61 a	55 b	60 a	33
24-May-94	78	79 b	80 b	91 a	93 a	86 b	83 b	89 a	65
9-Jun-94	43	56 b	61 b	87 a	87 a	72 ab	69 b	77 a	48
24-Jun-94	32	44 b	50 b	65 a	65 a	56 b	51 b	62 a	30
6-Jul-94	78	66 c	73 b	80 a	81 a	72 b	70 b	82 a	62
19-Jul-94	20	47 c	52 b	60 a	61 a	54 b	50 b	62 a	36
2-Aug-94	8	30 c	33 bc	38 a	36 ab	34 b	32 b	38 a	17
15-Aug-94	57	52 a	57 a	57 a	56 a	55 a	54 a	57 a	49
30-Aug-94	94	77 a	75 a	76 a	77 a	74 a	78 a	77 a	65
12-Sep-94	65	83 a	83 a	84 a	86 a	81 b	84 ab	87 a	64
26-Sep-94	3	59 a	61 a	62 a	67 a	60 b	60 b	68 a	43
11-Oct-94	16	58 a	60 a	63 a	65 a	61 b	57 b	67 a	44
19-Apr-95	-	89 b	98 ab	96 ab	103 a	99 a	94 a	97 a	83
9-May-95	20	72 c	77 bc	84 ab	87 a	84 a	76 b	78 ab	64
23-May-95	39	63 b	67 b	88 a	90 a	80 a	74 a	77 a	55
8-Jun-95	41	55 b	59 b	84 a	87 a	72 a	69 a	73 a	51
23-Jun-95	38	48 b	53 b	74 a	75 a	64 a	61 a	63 a	35
10-Jul-95	64	58 c	60 c	70 b	78 a	65 a	66 a	69 a	47
18-Jul-95	23	48 c	49 c	59 b	69 a	55 a	55 a	59 a	-
3-Aug-95	35	41 c	44 bc	48 b	54 a	45 a	45 a	51 a	24
15-Aug-95	58	56 b	55 b	61 b	70 a	59 a	59 a	63 a	44
29-Aug-95	39	52 c	56 bc	60 ab	66 a	56 a	59 a	61 a	48
12-Sep-95	1	38 c	41 b	41 bc	48 a	42 a	40 a	45 a	26
26-Sep-95	9	35 a	39 a	39 a	44 a	38 ab	37 b	42 a	21
14-Oct-95	9	34 b	37 ab	41 ab	45 a	39 a	38 a	40 a	17

Means among the same factor (forage or grazing intensity) followed by the same letter and within the same row are not significantly different ($P \leq 0.05$).
* Precipitation since last measurement date, (-) is missing data. WP = 29 mm, FC = 65 mm.

Table 3.1c. Accumulated soil water (0-50 cm) (mm) for all forage and grazing factors.

Date	*Ppt. (mm)	Forage				Grazing Intensity			Benchmark site
		meadow brome	smooth brome	triticale	triticale/barley	light	medium	heavy	
12-Apr-94	-	118 b	120 b	134 a	135 a	129 a	119 a	131 a	86
9-May-94	7	72 b	81 b	109 a	110 a	96 a	87 a	96 a	54
24-May-94	78	104 b	107 b	137 a	141 a	123 a	118 a	127 a	93
9-Jun-94	43	80 b	87 b	134 a	133 a	108 a	104 a	114 a	67
24-Jun-94	32	66 b	75 b	104 a	102 a	86 ab	80 b	94 a	44
6-Jul-94	78	87 c	98 b	110 a	112 a	97 a	96 a	112 a	84
19-Jul-94	20	67 c	76 b	88 a	88 a	77 b	74 b	89 a	51
2-Aug-94	8	47 b	53 ab	59 a	58 a	53 b	51 b	59 a	26
15-Aug-94	57	76 a	83 a	82 a	81 a	80 a	80 a	82 a	71
30-Aug-94	94	101 a	101 a	103 a	105 a	99 a	104 a	104 a	88
12-Sep-94	65	112 a	113 a	116 a	122 a	110 b	116 ab	121 a	92
26-Sep-94	3	84 a	88 a	92 a	99 a	85 b	88 ab	98 a	63
11-Oct-94	16	80 a	85 a	90 a	96 a	85 a	84 a	95 a	62
19-Apr-95	-	124 b	137 ab	139 ab	151 a	142 a	133 a	138 a	125
9-May-95	20	99 b	107 b	122 a	127 a	120 a	108 a	113 a	90
23-May-95	39	84 b	92 b	127 a	131 a	113 a	105 a	108 a	77
8-Jun-95	41	75 b	81 b	122 a	128 a	103 a	98 a	103 a	75
23-Jun-95	38	66 b	74 b	107 a	109 a	91 a	87 a	89 a	45
10-Jul-95	64	77 b	81 b	98 a	107 a	89 a	91 a	93 a	57
18-Jul-95	23	64 c	68 c	84 b	98 a	78 a	78 a	80 a	-
3-Aug-95	35	57 b	62 ab	69 a	62 ab	65 a	65 a	71 a	30
15-Aug-95	58	69 a	79 a	73 a	76 a	80 a	81 a	85 a	52
29-Aug-95	39	83 ab	95 a	71 b	77 b	78 a	83 a	85 a	63
12-Sep-95	1	84 b	96 a	55 c	61 c	62 a	61 a	67 a	35
26-Sep-95	9	63 b	74 a	52 c	58 bc	58 a	56 a	63 a	28
14-Oct-95	9	50 b	54 ab	60 ab	69 a	59 a	57 a	60 a	23

Means among the same factor (forage or grazing intensity) followed by the same letter and within the

Table 3.1d. Accumulated soil water (0-70 cm) (mm) for all grazing and forage factors.

Date	*Ppt. (mm)	Forage: meadow brome	smooth brome	triticale	triticale/barley	Grazing Intensity: light	medium	heavy	Benchmark site
12-Apr-94	-	154 b	162 ab	181 a	180 a	171 a	159 a	177 a	110
9-May-94	7	99 c	115 b	146 a	148 a	130 a	119 a	133 a	73
24-May-94	78	128 b	138 b	176 a	180 a	156 a	149 a	162 a	112
9-Jun-94	43	104 c	117 b	174 a	172 a	141 a	136 a	149 a	84
24-Jun-94	32	89 c	104 b	142 a	140 a	117 ab	112 b	128 a	58
6-Jul-94	78	108 c	125 b	141 a	144 a	123 b	124 b	143 a	104
19-Jul-94	20	88 c	102 b	117 a	119 a	101 b	100 b	119 a	65
2-Aug-94	8	66 b	78 a	81 a	81 a	73 b	72 b	84 a	37
15-Aug-94	57	98 a	111 a	106 a	106 a	103 a	105 a	109 a	92
30-Aug-94	94	122 a	127 a	126 a	131 a	121 a	129 a	129 a	107
12-Sep-94	65	133 a	138 a	140 a	148 a	131 b	140 ab	147 a	109
26-Sep-94	3	104 a	113 a	114 a	125 a	107 b	111 b	125 a	80
11-Oct-94	16	100 a	109 a	113 a	122 a	106 a	107 a	120 a	77
19-Apr-95	-	152 b	172 ab	172 ab	192 a	176 a	166 a	174 a	159
9-May-95	20	121 c	135 bc	150 ab	159 a	148 a	135 a	142 a	110
23-May-95	39	105 b	118 b	156 a	163 a	140 a	130 a	137 a	94
8-Jun-95	41	94 b	104 b	152 a	159 a	129 a	123 a	130 a	97
23-Jun-95	38	84 b	97 b	136 a	139 a	116 a	111 a	115 a	55
10-Jul-95	64	96 b	103 b	124 a	137 a	113 a	115 a	118 a	67
18-Jul-95	23	83 c	90 bc	109 ab	126 a	102 a	101 a	104 a	-
3-Aug-95	35	74 c	84 bc	92 ab	104 a	85 a	86 a	94 a	38
15-Aug-95	58	91 c	98 bc	106 b	122 a	100 a	103 a	110 a	61
29-Aug-95	39	90 c	99 bc	108 ab	123 a	99 a	106 a	109 a	74
12-Sep-95	1	73 b	83 b	85 ab	101 a	83 a	83 a	91 a	43
26-Sep-95	9	69 c	79 b	81 b	93 a	78 a	78 a	86 a	36
14-Oct-95	9	66 b	75 ab	83 ab	97 a	79 a	79 a	82 a	31

Means among the same factor (forage or grazing intensity) followed by the same letter and within the

Table 3.1e. Accumulated soil water (0-90 cm) (mm) for all forage and grazing factors.

Date	*Ppt. (mm)	Forage				Grazing Intensity			Benchmark site
		meadow brome	smooth brome	triticale	triticale/barley	light	medium	heavy	
12-Apr-94	-	197 b	217 ab	234 a	225 a	218 a	208 a	228 a	143
9-May-94	7	131 c	157 b	192 a	188 a	169 a	158 a	174 a	93
24-May-94	78	157 c	177 b	222 a	221 a	194 a	188 a	200 a	138
9-Jun-94	43	132 c	153 b	220 a	213 a	178 a	174 a	187 a	107
24-Jun-94	32	114 b	119 b	188 a	181 a	153 a	149 a	165 a	79
6-Jul-94	78	133 c	158 b	182 a	184 a	157 b	160 b	178 a	133
19-Jul-94	20	111 c	133 b	157 a	155 a	133 b	131 b	153 a	88
2-Aug-94	8	83 b	101 a	110 a	110 a	96 b	96 b	111 a	56
15-Aug-94	57	122 b	141 a	136 ab	133 ab	129 a	134 a	137 a	110
30-Aug-94	94	145 a	154 a	156 a	164 a	147 a	160 a	157 a	129
12-Sep-94	65	156 a	167 a	169 a	174 a	156 a	170 a	174 a	135
26-Sep-94	3	125 a	140 a	143 a	152 a	132 a	137 a	152 a	102
11-Oct-94	16	121 a	134 a	140 a	148 a	129 a	132 a	146 a	98
19-Apr-95	-	182 a	212 a	209 a	227 a	210 a	206 a	208 a	196
9-May-95	20	147 b	167 ab	183 a	187 a	177 a	164 a	172 a	131
23-May-95	39	126 b	145 b	189 a	195 a	169 a	157 a	165 a	117
8-Jun-95	41	112 b	129 b	187 a	190 a	157 a	150 a	157 a	124
23-Jun-95	38	103 b	122 b	168 a	167 a	144 a	135 a	140 a	74
10-Jul-95	64	117 b	127 b	156 a	170 a	140 a	144 a	144 a	85
18-Jul-95	23	98 b	113 b	141 a	148 a	124 a	123 a	128 a	-
3-Aug-95	35	93 c	109 bc	123 ab	134 a	113 a	114 a	117 a	54
15-Aug-95	58	110 c	125 bc	141 ab	154 a	130 a	129 a	138 a	76
29-Aug-95	39	112 c	126 bc	136 ab	150 a	126 a	132 a	135 a	89
12-Sep-95	1	92 b	108 b	113 ab	130 a	106 a	110 a	116 a	58
26-Sep-95	9	89 c	101 bc	108 ab	121 a	102 a	103 a	109 a	52
14-Oct-95	9	73 b	99 ab	114 ab	133 a	94 a	107 a	114 a	35

Means among the same factor (forage or grazing intensity) followed by the same letter and within the

Table 3.2a. Surface soil water (0-7.5 cm) (mm) for all forage x grazing treatments.

Date	meadow brome			smooth brome			triticale/barley			triticale		
	light	medium	heavy	light	medium	heavy	light	medium	heavy	light	medium	hea[illegible]
12-Apr-94	14 a	16 a	17 a	18 a	15 a	18 a	20 a	17 a	20 a	20 a	16 a	18
9-May-94	10 e	10 e	11 de	11 de	11 de	12 cde	14 ab	13 abc	13 bcd	15 a	12 bcd	13
24-May-94	23 ab	23 a	21 abcd	23 a	22 abcd	22 abc	20 abcd	20 [illegible]	20 bcde	19 de	18 e	19
9-Jun-94	12 a	13 a	14 a	15 a	13 a	16 a	15 a	15 [illegible]	14 a	14 a	14 a	1[illegible]
24-Jun-94	11 cd	11 d	14 abc	13 abcd	11 d	14 ab	14 ab	15 a	15 a	15 ab	13 bcd	1[illegible]
6-Jul-94	17 g	20 de	22 cd	20 ef	19 fg	25 ab	24 ab	25 ab	25 ab	24 ab	23 bc	2[illegible]
19-Jul-94	15 ef	14 f	17 cde	16 def	17 cde	21 ab	17 cde	18 bcd	21 ab	23 a	18 bcd	2[illegible]
2-Aug-94	7 a	7 a	9 a	6 a	7 a	10 a	[illegible]	8 a	10 a	10 a	9 a	[illegible]
15-Aug-94	12 c	12 c	12 c	12 c	14 abc	16 a	[illegible]	12 c	13 bc	15 ab	12 c	1[illegible]
30-Aug-94	-	-	-	-	-	-	-	-	-	-	-	
12-Sep-94	19 bc	20 ab	20 ab	16 c	20 ab	23 a	16 c	20 b	[illegible]	18 bc	20 b	2[illegible]
26-Sep-94	14 c	17 abc	18 ab	14 c	16 bc	20 a	16 bc	16 bc	[illegible]	14 c	14 c	1[illegible]
11-Oct-94	19 a	19 a	22 a	17 a	19 a	24 a	17 a	17 a	[illegible]	20 a	16 a	1[illegible]
19-Apr-95	21 a	24 a	25 a	23 a	29 a	29 a	25 a	24 a	25 a	27 a	23 a	2[illegible]
9-May-95	22 a	21 a	22 a	20 a	20 a	24 a	22 a	24 a	21 a	21 a	20 a	2[illegible]
23-May-95	23 a	22 a	23 a	20 a	24 a	23 a	22 a	22 a	22 a	22 a	21 a	2[illegible]
8-Jun-95	16 e	17 de	21 bc	17 de	20 bc	22 abc	23 ab	19 cd	24 a	21 abc	19 cd	1[illegible]
23-Jun-95	17 bc	20 a	16 c	20 ab	19 abc	22 a	21 a	22 a	20 a	22 a	19 abc	2[illegible]
10-Jul-95	18 d	20 cd	21 abc	18 d	21 abc	23 a	23 ab	22 abc	23 a	20 bc	22 abc	2[illegible]
18-Jul-95	-	-	-	-	-	-	-	-	-	-	-	
3-Aug-95	15 e	17 de	18 cd	18 bcd	18 bcd	20 a	18 cd	18 cd	20 ab	17 cd	17 cd	1[illegible]
15-Aug-95	21 c	24 ab	24 a	20 c	20 c	23 abc	23 abc	23 abc	23 abc	23 abc	21 c	2[illegible]
29-Aug-95	16 d	17 cd	17 bcd	18 abcd	21 ab	22 a	15 d	15 d	20 abc	19 abcd	18 bcd	1[illegible]
12-Sep-95	14 a	13 a	15 a	15 a	14 a	17 a	11 a	13 a	15 a	12 a	11 a	1[illegible]
26-Sep-95	11 f	14 b	14 b	13 cde	14 bc	16 a	14 bc	13 bcd	14 b	11 ef	12 def	1[illegible]
14-Oct-95	-	-	-	-	-	-	-	-	-	-	-	

Means followed by the same letter within the same row are not significantly different ($P \leq 0.05$).
(-) is missing data.

Table 3.2b. Accumlated soil water (mm) (0-30 cm) for all forage x grazing treatments.

Date	meadow brome			smooth brome			triticale/barley			triticale		
	light	medium	heavy	light	medium	heavy	light	medium	heavy	light	medium	he
12-Apr-94	69 d	79 bcd	83 abcd	84 abc	73 cd	83 abcd	93 a	84 abc	91 ab	93 a	80 abcd	
9-May-94	44 d	45 d	50 d	54 cd	47 d	52 cd	72 a	66 ab	69 ab	73 a	62 bc	
24-May-94	75 e	79 de	82 cde	81 de	74 e	84 cde	96 a	91 abc	95 a	94 ab	85 bcd	
9-Jun-94	51 d	55 cd	62 bc	60 bcd	55 cd	67 b	90 a	83 a	88 a	88 a	83 a	
24-Jun-94	40 g	43 fg	51 def	52 def	45 efg	54 de	65 abc	57 cd	73 a	67 abc	59 bcd	
6-Jul-94	60 g	67 efg	71 def	73 def	65 fg	81 bc	79 cd	75 cde	90 a	79 bcd	74 cde	
19-Jul-94	44 g	46 fg	53 def	51 defg	49 efg	57 cde	59 bcd	52 def	72 a	62 bc	53 def	
2-Aug-94	28 d	31 cd	32 cd	33 cd	31 cd	37 abc	36 bc	31 cd	42 a	39 ab	34 bcd	
15-Aug-94	49 a	55 a	52 a	57 a	55 a	58 a	57 a	51 a	61 a	57 a	55 a	
30-Aug-94	70 a	86 a	77 a	76 a	70 a	78 a	76 a	80 a	75 a	76 a	75 a	
12-Sep-94	78 a	89 a	83 a	79 a	80 a	90 a	84 a	84 a	91 a	83 a	84 a	
26-Sep-94	52 d	63 abc	64 abc	57 cd	56 cd	71 a	68 ab	62 abc	71 a	62 abc	59 bcd	
11-Oct-94	53 a	56 a	63 a	56 a	55 a	69 a	66 a	60 a	70 a	66 a	58 a	
19-Apr-95	86 a	91 a	90 a	97 a	95 a	100 a	108 a	96 a	105 a	105 a	91 a	
9-May-95	74 cd	70 d	71 d	83 abc	70 d	79 abcd	90 a	85 abc	85 abc	90 ab	78 bcd	
23-May-95	64 b	63 b	62 b	70 b	64 b	67 b	92 a	87 a	91 a	94 a	84 a	
8-Jun-95	51 d	58 cd	57 cd	58 cd	57 cd	61 c	91 a	82 ab	89 a	90 a	77 b	
23-Jun-95	45 c	51 c	48 c	54 c	50 c	55 c	77 a	75 ab	72 ab	79 a	66 b	
10-Jul-95	52 f	63 cdef	59 def	57 ef	58 def	65 bcde	79 a	79 a	76 ab	70 abcd	64 bcde	
18-Jul-95	45 c	50 bc	48 bc	46 bc	49 bc	51 bc	70 a	69 a	70 a	59 ab	53 bc	
3-Aug-95	37 f	44 cdef	41 ef	45 cdef	42 def	47 bcde	53 abc	52 abcd	59 a	48 abcd	41 def	
15-Aug-95	52 ef	61 bcde	55 def	56 cdef	51 f	60 bcde	66 abc	70 ab	73 a	63 abcd	55 def	
29-Aug-95	48 d	58 bcd	50 cd	55 bcd	56 bcd	57 bcd	62 ab	62 abc	74 a	60 bc	58 bcd	
12-Sep-95	35 d	40 bcd	38 bcd	43 bcd	38 bcd	44 abcd	47 ab	44 bcd	53 a	42 bcd	36 cd	
26-Sep-95	32 f	39 bcde	36 def	38 cde	36 def	42 abcd	45 ab	39 bcde	47 a	39 bcde	33 ef	
14-Oct-95	29 a	41 a	31 a	40 a	33 a	38 a	45 a	44 a	46 a	43 a	33 a	

Means followed by the same letter within the same row are not significantly different ($P \leq 0.05$).

Table 3.2c. Accumulated soil water (mm) (0-50 cm) for all treatments.

Date	meadow brome			smooth brome			triticale/barley			triticale	
	light	medium	heavy	light	medium	heavy	light	medium	heavy	light	medium
12-Apr-94	107 a	119 a	127 a	125 a	109 a	126 a	142 a	129 a	135 a	143 a	122 a
9-May-94	67 d	71 d	79 cd	85 cd	75 d	83 cd	114 ab	105 ab	110 ab	118 a	97 bc
24-May-94	96 c	104 c	111 bc	108 c	100 c	113 bc	143 a	138 a	142 a	143 a	128 ab
9-Jun-94	72 d	80 cd	88 bc	85 bcd	81 cd	96 b	136 a	129 a	133 a	138 a	127 a
24-Jun-94	58 e	65 de	74 de	75 d	68 de	81 cd	103 ab	94 bc	111 a	108 ab	95 bc
6-Jul-94	78 g	89 fg	93 def	95 cdef	91 efg	109 bc	106 bcd	105 cde	124 a	108 bc	101 cdef
19-Jul-94	61 f	67 ef	74 def	72 def	72 def	83 bcd	85 bcd	78 cde	103 a	89 abc	78 cde
2-Aug-94	43 e	49 de	50 de	52 bcde	50 cde	59 abcd	55 bcde	51 bcde	66 a	62 ab	53 bcde
15-Aug-94	71 a	82 a	74 a	83 a	81 a	86 a	83 a	75 a	87 a	83 a	81 a
30-Aug-94	91 a	112 a	101 a	102 a	96 a	105 a	103 a	108 a	103 a	101 a	101 a
12-Sep-94	104 a	123 a	110 a	105 a	108 a	125 a	118 a	117 a	130 a	113 a	116 a
26-Sep-94	72 c	91 abc	90 abc	80 bc	81 bc	104 a	99 ab	94 ab	105 a	91 abc	87 abc
11-Oct-94	72 a	82 a	87 a	78 a	78 a	99 a	95 a	91 a	102 a	94 a	84 a
[illegible]-Apr-95	116 a	129 a	126 a	138 a	131 a	142 a	160 a	141 a	152 a	156 a	131 a
9-May-95	99 cd	99 cd	98 cd	114 abcd	96 d	111 bcd	133 a	124 ab	124 ab	134 a	114 abcd
23-May-95	83 b	86 b	84 b	96 b	87 b	94 b	136 a	126 a	131 a	138 a	120 a
8-Jun-95	68 d	81 cd	77 cd	79 cd	78 cd	85 c	134 a	121 ab	127 ab	133 a	113 b
23-Jun-95	61 c	71 c	66 c	74 c	70 c	77 c	113 ab	109 ab	104 ab	117 a	96 b
10-Jul-95	68 c	87 bc	77 c	77 c	78 c	87 bc	111 a	110 a	104 ab	102 ab	89 abc
18-Jul-95	60 d	71 cd	62 d	65 d	68 cd	72 cd	99 a	98 a	96 ab	88 abc	73 bcd
3-Aug-95	51 d	63 bcd	57 cd	61 bcd	59 bcd	67 abcd	77 ab	76 ab	83 a	71 abc	60 bcd
15-Aug-95	67 d	81 abcd	71 cd	74 bcd	70 cd	83 abcd	91 ab	96 a	99 a	86 abc	75 bcd
29-Aug-95	63 d	83 abcd	68 cd	73 bcd	76 bcd	81 bcd	91 ab	93 ab	103 a	84 abcd	80 bcd
12-Sep-95	50 a	60 a	54 a	60 a	57 a	66 a	74 a	70 a	79 a	64 a	56 a
26-Sep-95	46 c	58 abc	51 bc	56 abc	54 abc	63 abc	69 ab	62 abc	70 a	61 abc	51 bc
14-Oct-95	43 a	62 a	44 a	57 a	47 a	59 a	69 a	68 a	70 a	65 a	50 a

Means followed by the same letter within the same row are not significantly different ($P \leq 0.05$).

Table 3.2d. Accumulated soil water (mm) (0-70 cm) for all treatments

Date	meadow brome			smooth brome			triticale/barley			triticale	
	light	medium	heavy	light	medium	heavy	light	medium	heavy	light	medium
12-Apr-94	138 a	151 a	173 a	166 a	147 a	172 a	188 a	173 a	180 a	194 a	164 a
9-May-94	90 f	96 ef	112 def	119 cde	106 def	120 cde	152 ab	143 abc	148 ab	159 a	131 bcd
24-May-94	117 d	127 cd	139 bcd	137 cd	129 cd	147 bc	183 a	178 a	180 a	185 a	164 ab
9-Jun-94	93 d	102 cd	116 bc	112 bcd	109 bcd	130 b	176 a	169 a	172 a	181 a	164 a
24-Jun-94	78 d	87 d	101 cd	100 cd	96 cd	115 bc	140 a	133 ab	149 a	149 a	130 ab
6-Jul-94	96 f	109 ef	117 cdef	118 cde	116 def	142 ab	136 bcd	139 abc	158 a	141 ab	131 bcd
19-Jul-94	79 g	88 fg	98 defg	95 efg	97 defg	116 abcd	112 bcde	109 bcde	135 a	120 abc	105 cde
2-Aug-94	59 d	68 cd	70 cd	72 bcd	72 bcd	89 ab	75 abcd	75 abcd	92 a	85 abc	74 abc
15-Aug-94	91 a	107 a	97 a	107 a	108 a	118 a	106 a	99 a	112 a	106 a	105 a
30-Aug-94	108 a	134 a	124 a	125 a	122 a	134 a	127 a	135 a	130 a	125 a	125 a
12-Sep-94	121 a	146 a	132 a	127 a	131 a	156 a	141 a	144 a	158 a	136 a	139 a
26-Sep-94	89 a	112 a	112 a	101 a	104 a	134 a	122 a	120 a	133 a	114 a	109 a
11-Oct-94	88 a	104 a	108 a	99 a	100 a	128 a	118 a	118 a	129 a	117 a	106 a
19-Apr-95	140 a	157 a	160 a	172 a	162 a	181 a	201 a	181 a	194 a	191 a	162 a
9-May-95	119 b	121 b	124 b	140 ab	121 b	144 ab	165 a	156 a	155 a	167 a	141 ab
23-May-95	101 c	106 c	107 c	119 c	110 c	126 bc	168 a	158 a	163 a	172 a	147 ab
8-Jun-95	83 d	101 cd	98 cd	99 cd	99 cd	114 c	165 ab	153 ab	159 ab	167 a	140 b
23-Jun-95	77 e	89 de	87 de	93 de	92 de	105 cd	143 ab	140 ab	134 ab	151 a	123 bc
10-Jul-95	84 d	108 bcd	96 cd	96 d	99 cd	115 abcd	139 ab	140 a	132 ab	132 ab	113 ab
18-Jul-95	76 e	91 cde	80 e	84 de	90 cde	97 abcd	129 a	125 ab	124 ab	117 abc	95 bc
3-Aug-95	64 d	82 abcd	75 cd	79 bcd	79 bcd	92 abc	101 abc	103 ab	109 a	96 abc	81 bc
15-Aug-95	82 c	102 abc	90 bc	93 bc	91 bc	110 ab	115 ab	125 a	127 a	112 ab	95 bc
29-Aug-95	80 d	104 abcd	87 cd	93 bcd	97 bcd	107 abcd	117 abc	123 ab	131 a	108 abcd	102 ab
12-Sep-95	66 a	80 a	73 a	79 a	78 a	92 a	99 a	98 a	105 a	87 a	77 a
26-Sep-95	60 d	78 bc	69 cd	75 bcd	73 bcd	88 ab	94 a	88 ab	95 a	83 abc	71 cd
14-Oct-95	57 a	82 a	58 a	76 a	64 a	86 a	94 a	99 a	97 a	89 a	70 a

Means followed by the same letter within the same row are not significantly different ($P \leq 0.05$).

Table 3.2e. Accumulated soil water (mm) (0-90 cm) for all treatments.

Date	meadow brome			smooth brome			triticale/barley			triticale	
	light	medium	heavy	light	medium	heavy	light	medium	heavy	light	medium
12-Apr-94	179 a	193 a	219 a	213 a	201 a	236 a	230 a	222 a	223 a	251 a	215 a
9-May-94	122 e	128 e	143 de	153 cde	146 de	171 bcd	190 ab	187 abc	187 abc	211 a	173 bc
24-May-94	144 e	157 e	170 de	173 cde	166 de	191 bcd	222 ab	223 ab	217 ab	237 a	206 ab
9-Jun-94	119 c	131 c	146 bc	145 bc	141 c	173 b	215 a	215 a	208 a	231 a	207 a
24-Jun-94	104 d	111 d	126 d	128 cd	133 cd	158 bc	178 ab	178 ab	185 ab	200 a	173 ab
6-Jul-94	123 d	137 cd	140 bcd	145 bcd	146 bcd	188 a	173 ab	187 a	192 a	185 a	169 ab
19-Jul-94	103 e	108 e	120 de	121 cde	125 bcde	154 ab	146 abcd	149 abc	170 a	163 a	143 ab
2-Aug-94	74 e	87 de	88 de	91 bcde	91 cde	120 a	103 abcd	106 abcd	122 a	116 ab	101 ab
15-Aug-94	116 a	135 a	114 a	132 a	136 a	156 a	128 a	131 a	141 a	138 a	134 a
30-Aug-94	130 a	159 a	147 a	150 a	149 a	163 a	152 a	177 a	162 a	155 a	155 a
12-Sep-94	143 a	171 a	155 a	151 a	159 a	190 a	165 a	180 a	177 a	166 a	168 a
26-Sep-94	111 a	137 a	129 a	128 a	124 a	168 a	145 a	152 a	161 a	143 a	136 a
11-Oct-94	109 a	126 a	127 a	122 a	124 a	157 a	140 a	148 a	156 a	145 a	130 a
19-Apr-95	169 a	198 a	180 a	204 a	207 a	225 a	239 a	211 a	230 a	227 a	206 a
9-May-95	142 a	152 a	148 a	172 a	146 a	184 a	191 a	186 a	185 a	204 a	172 a
23-May-95	125 d	127 d	127 d	147 cd	130 d	158 bcd	196 a	194 ab	195 ab	210 a	178 ab
8-Jun-95	102 e	126 de	110 de	124 de	115 de	147 cd	193 ab	189 ab	189 ab	209 a	171 bc
23-Jun-95	97 d	113 d	99 d	119 cd	111 d	135 bc	171 ab	167 ab	163 ab	188 a	152 ab
10-Jul-95	104 c	134 abc	114 c	115 c	124 bc	141 abc	172 a	175 a	163 ab	169 a	142 ab
18-Jul-95	86 c	111 abc	97 bc	104 bc	111 abc	123 abc	154 a	140 ab	151 a	152 a	130 ab
3-Aug-95	87 a	107 a	85 a	102 a	107 a	117 a	130 a	134 a	137 a	132 a	107 a
15-Aug-95	106 de	125 abcd	101 e	123 bcde	109 cde	142 abcd	144 abcd	155 ab	163 a	148 ab	128 ab
29-Aug-95	102 a	129 a	105 a	117 a	124 a	136 a	143 a	148 a	160 a	142 a	128 a
12-Sep-95	85 a	105 a	87 a	101 a	103 a	120 a	124 a	132 a	134 a	115 a	102 a
26-Sep-95	83 e	102 abcd	83 e	93 de	96 bcde	113 abcd	121 a	118 ab	123 a	112 abcd	96 c
14-Oct-95	64 d	91 cd	63 d	90 cd	83 cd	124 abc	94 bcd	153 a	147 a	127 abc	94 b

Means followed by the same letter within the same row are not significantly different ($P \leq 0.05$).

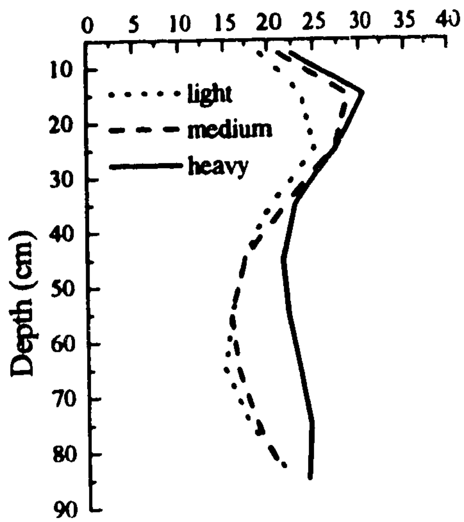
Table 3.3. Calculated average daily evapotranspiration (0-50 cm) (mm/day).

Date	*Ppt. (mm)	Forage: mbrome	SW_i	sbrome	SW_i	triticale	SW_i	trit/barl	SW_i	Grazing Intensity: light	SW_i	medium	SW_i	heavy	SW
9-May-94	7	1.9 a	118	1.6 b	120	1.2 c	134	1.2 c	135	1.5 a	129	1.5 a	119	1.6 a	13
24-May-94	78	3.1 a	72	3.3 a	81	3.1 a	109	3.3 a	110	3.4 a	96	3.1 a	87	3.2 a	9
9-Jun-94	43	4.2 a	104	3.6 b	107	3.2 c	137	2.9 c	141	3.6 a	123	3.5 a	118	3.5 a	12
24-Jun-94	32	3.1 c	80	3.5 b	87	4.2 a	134	4.1 a	133	3.6 ab	108	3.7 a	104	3.5 b	11
6-Jul-94	78	4.8 b	66	5.0 b	75	5.7 a	104	6.0 a	102	5.6 a	86	5.2 b	80	5.0 b	9
19-Jul-94	20	3.0 a	87	3.2 a	98	3.3 a	110	3.2 a	112	3.1 b	97	3.3 a	96	3.3 a	11
2-Aug-94	8	2.0 c	67	2.3 b	76	2.8 a	88	2.6 a	88	2.3 b	77	2.2 b	74	2.7 a	8
15-Aug-94	57	2.2 a	47	2.2 a	53	2.6 a	59	2.6 a	58	2.3 a	53	2.2 a	51	2.6 a	5
30-Aug-94	94	4.5 c	76	5.0 a	83	4.7 bc	82	4.9 ab	81	5.0 a	80	4.6 a	80	4.8 a	8
12-Sep-94	65	4.2 a	101	3.8 a	101	3.7 a	103	4.0 a	105	4.2 a	99	4.1 a	104	3.7 a	10
26-Sep-94	3	2.2 a	112	1.8 a	113	1.8 a	116	2.0 a	122	2.0 a	110	2.2 a	116	1.8 a	1
11-Oct-94	16	1.3 a	84	1.3 a	88	1.3 a	92	1.1 a	99	1.1 a	85	1.4 a	88	1.3 a	9
9-May-95	20	2.2 a	124	2.6 a	137	2.2 a	139	1.9 a	151	2.1 a	142	2.2 a	133	2.2 a	1
23-May-95	39	3.8 a	99	3.3 b	107	2.5 c	122	2.4 c	127	3.3 a	120	3.0 a	108	3.1 a	1
8-Jun-95	41	3.1 a	84	3.0 ab	92	2.8 b	127	2.9 ab	131	3.2 a	113	3.0 a	105	2.9 a	1
23-Jun-95	38	3.2 c	75	3.3 bc	81	3.8 a	122	3.5 b	128	3.3 a	103	3.3 a	98	3.4 a	1
10-Jul-95	64	3.1 c	66	3.5 b	74	3.8 b	107	4.3 a	109	3.9 a	91	3.5 a	87	3.6 a	
18-Jul-95	23	4.5 a	77	4.4 a	81	4.2 a	98	4.6 a	107	4.3 a	89	4.6 a	91	4.5 a	
3-Aug-95	35	2.7 c	64	2.9 bc	68	3.4 a	84	3.1 ab	98	3.0 a	79	3.0 a	78	2.7 a	
15-Aug-95	58	3.5 a	57	3.7 a	62	3.4 a	69	3.7 a	62	3.6 a	65	3.5 a	65	3.7 a	
29-Aug-95	39	2.9 a	69	2.7 a	79	2.8 a	73	2.7 a	76	2.9 a	80	2.6 a	81	2.8 a	
12-Sep-95	1	1.2 b	83	1.3 ab	95	1.6 a	71	1.6 a	77	1.2 b	78	1.7 a	83	1.4 b	
26-Sep-95	9	0.9 a	84	0.9 a	96	1.1 a	55	0.9 a	61	0.9 a	62	1.0 a	61	0.9 a	
14-Oct-95	9	0.6 a	63	0.7 a	74	0.4 a	52	0.5 a	58	0.5 a	58	0.5 a	56	0.6 a	

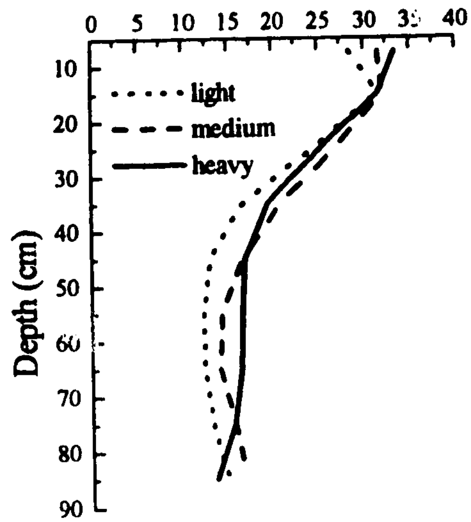
* Precipitation since last measurement date, SW_i is accumulated soil water (0-50 cm) at start of period.
Evapotranspiration = (difference in accumulated soil water between date in question and preceding date + Precipitation

(i) Dates with high soil moisture content

April 12, 1994

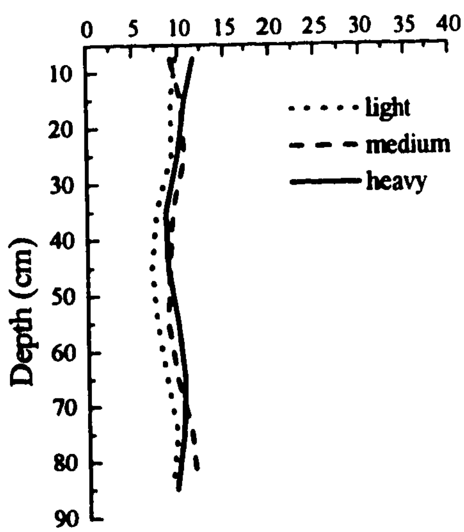


April 19, 1995



(ii) Dates with low soil moisture content

August 2, 1994



August 3, 1995

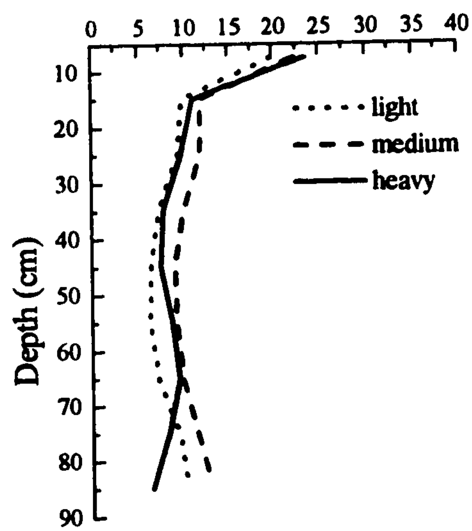


Figure 3.1a. Profile volumetric moisture content (cm^3/cm^3 x 100) under meadow bromegrass treatments: (i) dates with high soil moisture content; (ii) dates with low soil moisture content.

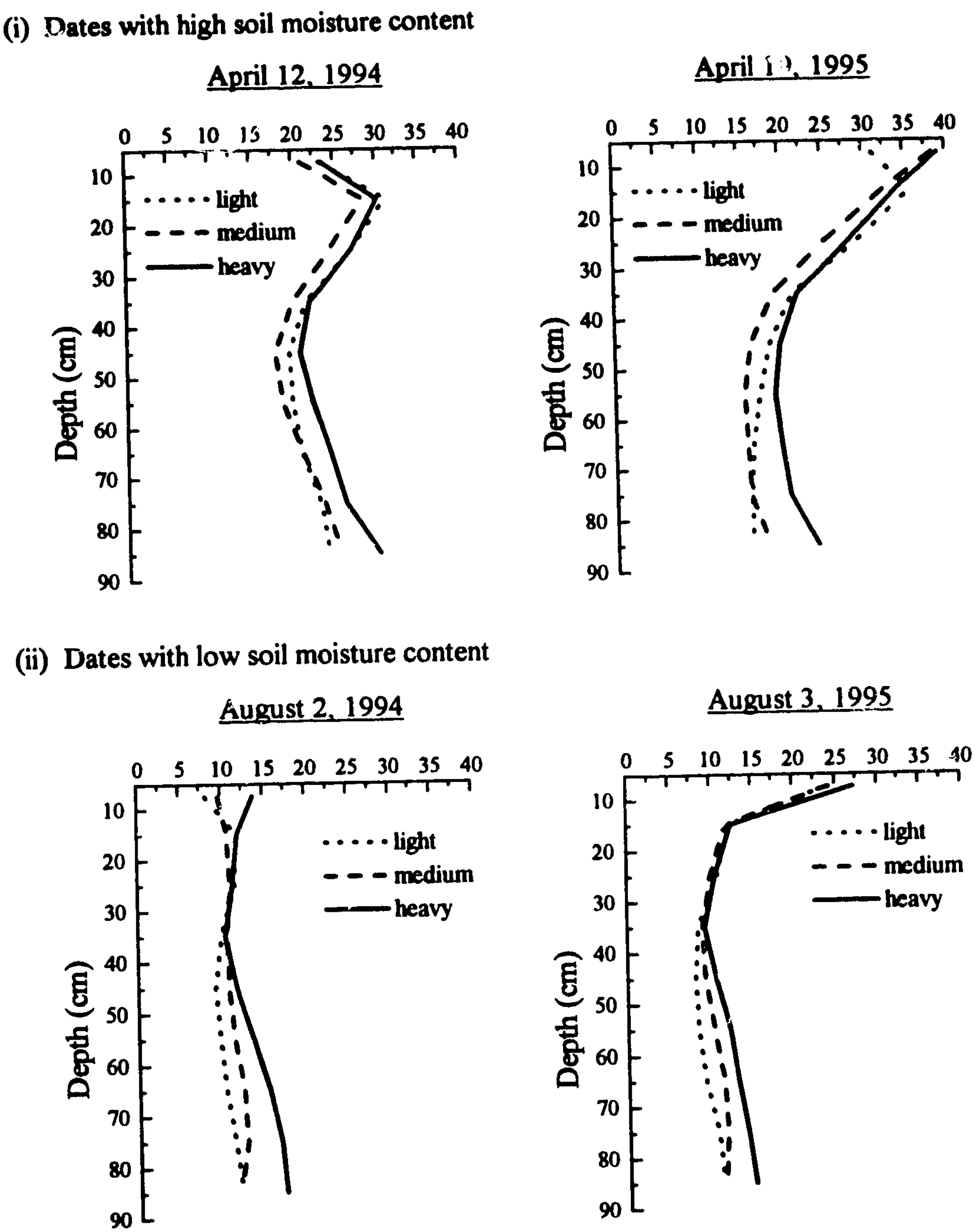
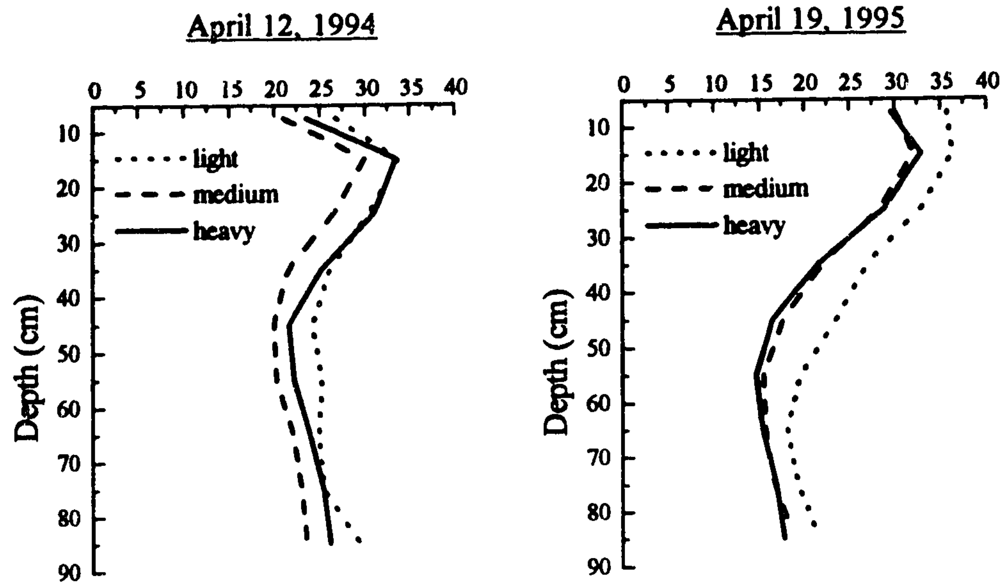


Figure 3.1b. Profile volumetric moisture content ($cm^3/cm^3 \times 100$) under smooth bromegrass treatments: (i) dates with high soil moisture content; (ii) dates with low soil moisture content.

(i) Dates with high soil moisture content



(ii) Date with low soil moisture content

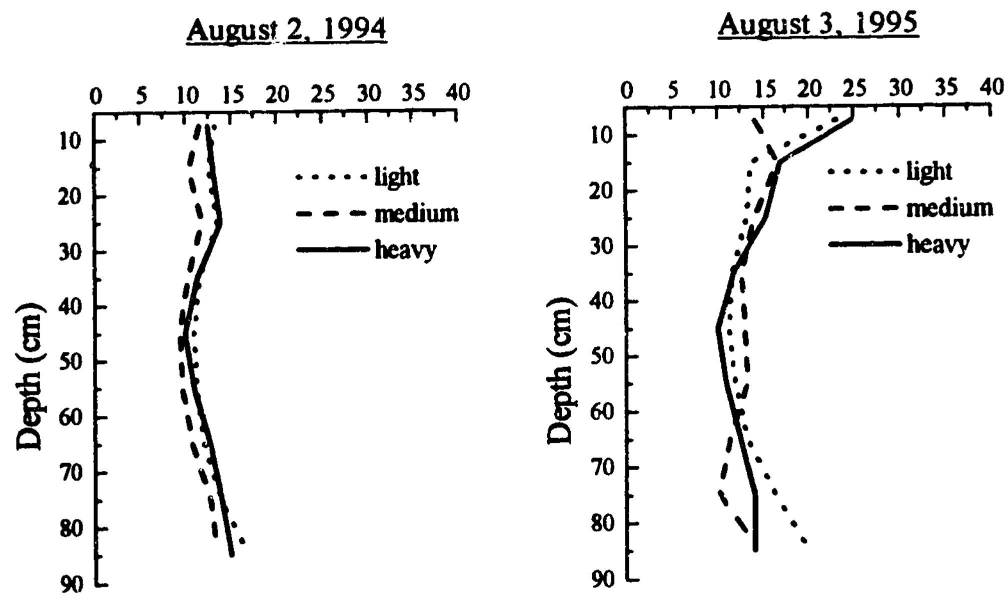
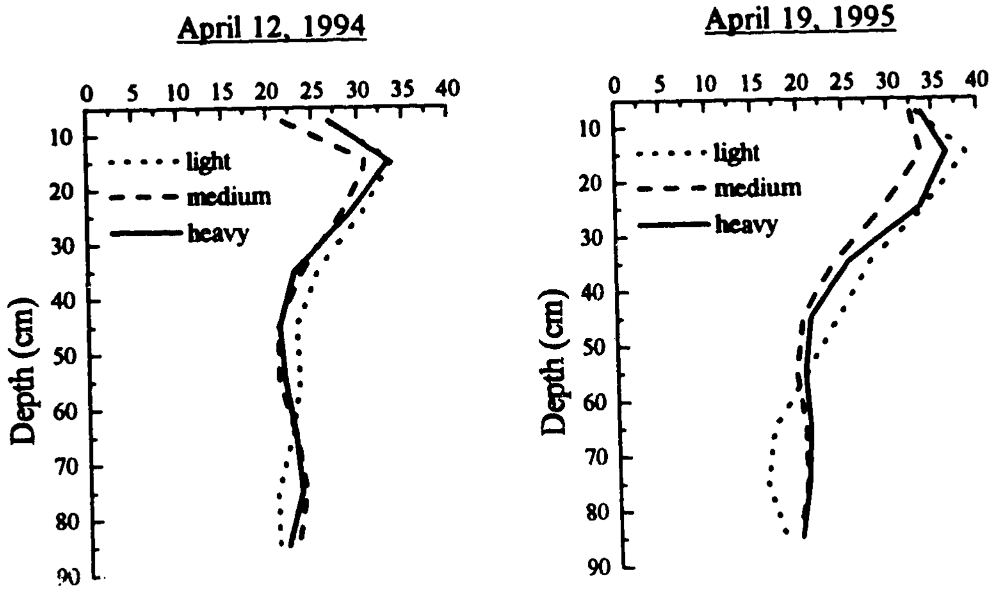


Figure 3.1c. Profile volumetric moisture content (cm^3/cm^3 x 100) under triticale treatments: (i) dates with high soil moisture content; (ii) dates with low soil moisture content.

(i) Dates with high soil moisture content



(ii) Date with low soil moisture content

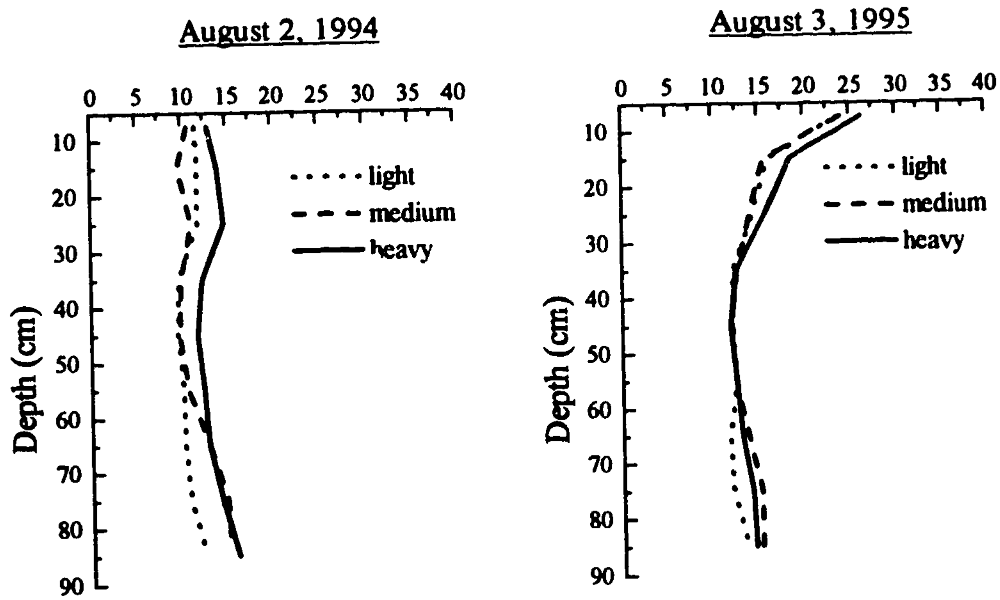


Figure 3.1d. Profile volumetric moisture content (cm^3/cm^3 x 100) under triticale/barley treatments: (i) dates with high soil moisture content; (ii) dates with low soil moisture content.

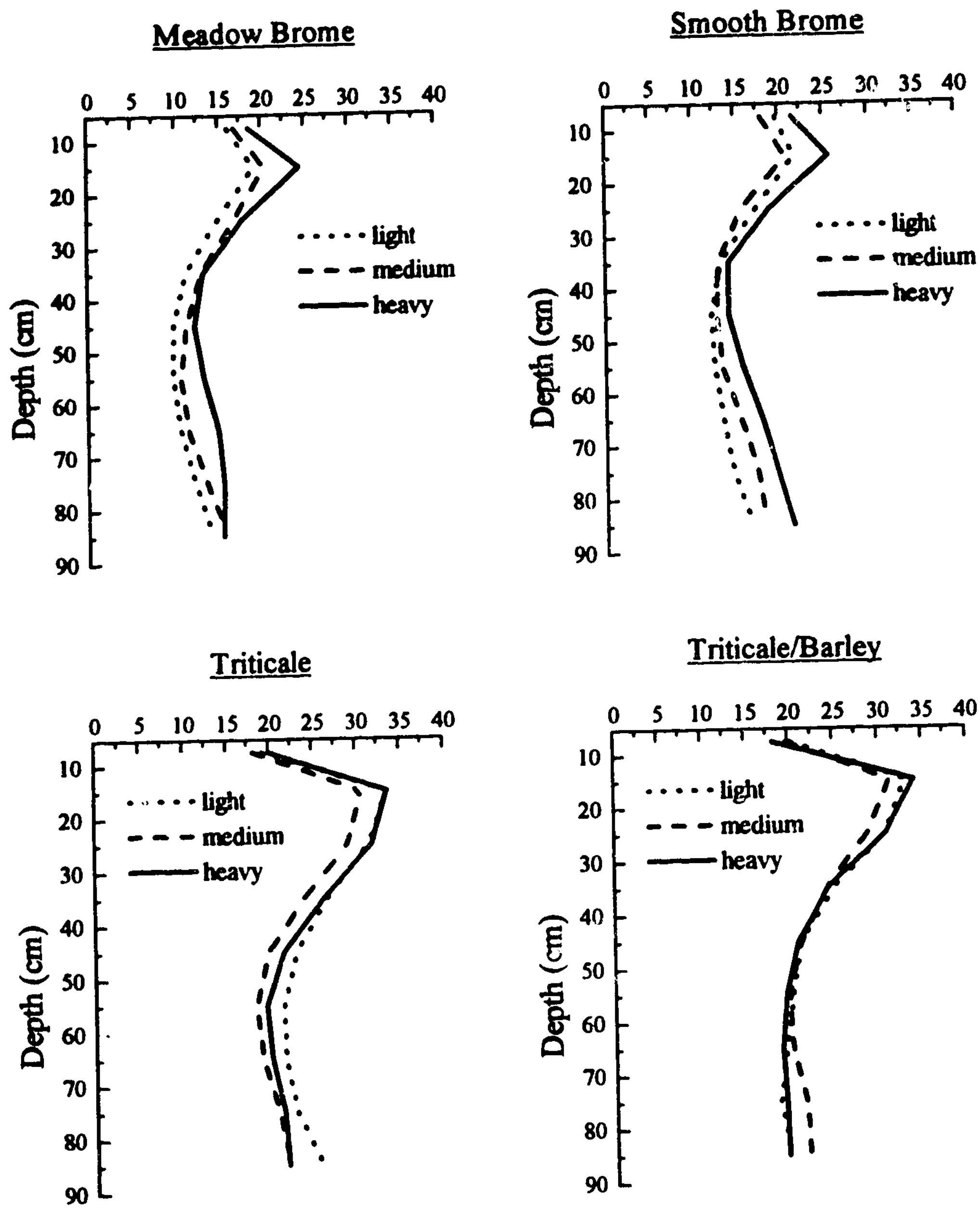


Figure 3.2a. Profile volumetric moisture content (cm^3/cm^3 x 100) for all treatments on June 9, 1994.

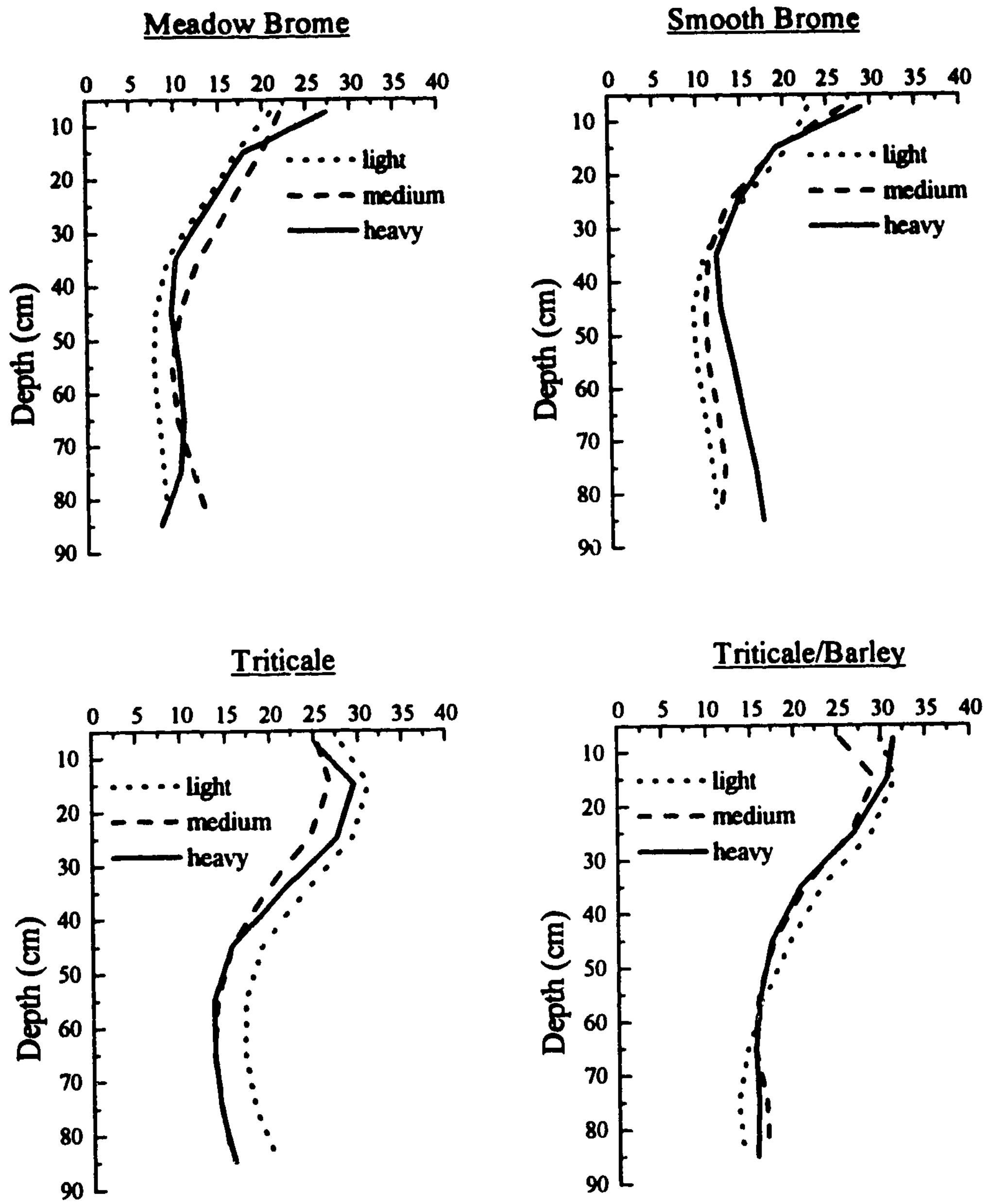


Figure 3.2b. Profile volumetric moisture content ($cm^3/cm^3 \times 100$) for all treatments on June 8, 1995.

IV. SYNTHESIS

This study was designed to determine the hydrologic impact of short-duration-intensive grazing (SDIG) in central Alberta under both annual and perennial forages. Few researchers have compared the hydrologic response of grazed annual forages to that of perennial forages. Most changes in soil and vegetation caused by grazing occur at or just below the soil surface. Near-surface bulk density and soil water measurements were used to help characterize hydrologic changes from SDIG on annual and perennial pastures.

Near-Surface Compaction

Grazing compacted soils in all treatments. Bulk density (DB) increased linearly with compactive energy (as proxied by cow-hours of grazing) over the first season of grazing under both annual and perennial forages. Cow-days, averaged over 2 years, under heavily grazed perennials were almost twice those of medium and lightly grazed perennials. DB under annual forages increased at a similar rate as perennial forages under a given amount of cow-days. However, soil under perennial forages compacted more than those under annual forages in total. DB was well correlated to both first-year cow-days and the two-year average cow-days. DB under heavily grazed annual forages appeared to be mitigated most by cultivation compared to that under lightly and medium grazed annuals, although cultivation in general reduced DB only very slightly.

DB was expected to decrease from the mitigating action of freeze/thaw cycles. Instead, DB increased over-winter, which could suggest a deterioration of soil structure from grazing, especially under annual forages since bulk density increased most over-winter under annual forages. Soil structure may have deteriorated more under annual forages compared to perennial forages. Over-winter bulk density also increased most under medium grazing.

DB declined over the second summer likely from root penetration among all forages but most under annual forages and more under smooth bromegrass compared to meadow bromegrass. Root penetration and cultivation mitigated increases in DB brought on by grazing but only under medium and lightly grazed treatments. Heavy grazing may have limited root penetration. Another possible explanation could be that the land initially deteriorated under the shock of a new landuse scheme, but stabilized in the second season.

Soil Water Regime

Surface soil water was often higher under heavy grazing than under light and medium grazing. Interception was likely less under heavy grazing so more precipitation reached the soil. Generally, surface soil water was highest under heavy grazing but these total season results contradict those for only the spring and fall. In the spring and after the first fall, surface soil moisture was lowest under heavily grazed treatments. Since surface soil moisture in the DB study was only measured in the spring and fall of both years, differences in surface soil water trends among studies are

likely due to the time of measurement
and fall may not reflect actual trends over time between the two measurement dates.

Differences in soil water among treatments were attributed to differences in interception, evapotranspiration and depth of water uptake by plants. More bare ground and less evapotranspiration under annual forages in April, May and June likely caused higher spring-summer soil water compared to perennial forages. Until early June of both years, soil water under perennial forages was lower than that under annual forages. Soil water under annual forages remained higher than under perennial forages until mid August even though ET was generally higher under annual forages until mid August. ET among forages was similar for the rest of the summer, yet in 1995 soil water under annual forages still remained higher than under meadow bromegrass. More bare ground under annual forages likely caused more water to infiltrate through less interception compared to perennial forages late in the summer causing higher soil water under annual forages even in the fall. It had been hypothesized that soil water would not be affected by reduced ET due to defoliation of vegetation and the study confirmed these results. Differences due to defoliation are likely masked by the larger differences among forage types.

Perennial forages could use soil water during vigorous growth in early summer and use less soil water as growth diminishes later in the season. Also, higher soil water under triticale/barley than under a monocrop of triticale could indicate lower productivity under the mix.

Soil water profiles, [illegible]

LAI and litter. Even late in the summer, wetting fronts appeared larger under annual forages compared to perennial forages. Annuals had bare space between rows and Gill (1996) also reported much more bare ground under annual forages than under perennial forages. On most measurement dates, profile soil water trends among forages were similar in that meadow bromegrass always used soil water deeper in the profile and used more soil water overall than all other forages. Smooth bromegrass extracted water close to the soil surface and annual forages seemed to use water from 30-50 cm.

Soil water under the benchmark site was always lower than under all treatments either because it was further away from a wind break, interception played a huge role, or numerous gopher holes resulting in unrepresentive readings. Soil water under the benchmark site was often near wilting point compared to all treatments. It almost appears the benchmark has reached a particular species compostion which uses all available soil water but only to the extent contributed to by precipitation.

This study provides an important contribution to the literature as management regimes change from the use of long-term pastures to the flexibility of short term pastures manipulated under short duration intensive grazing. Grazing annual forages appears to be a productive and viable management practice especially under triticale. DB under heavily grazed annual forages was slightly mitigated by cultivation but increased more per cow-day than perennials. Smooth bromegrass seemed to mitigate of smooth bromegrass was in the zone of greatest compaction.

Future Research Needs

This study was only 2 years in duration and represented the early phases of SDIG. A longer term study is required to assess the full impact of SDIG on sustainablity and productivity of rangelands.

Continued soil water monitoring would permit researchers to gain more information about the hydrologic changes from SDIG and which parameters influence soil water most. Equilibrium has likely not been reached after only 2 years.

DB should continue to be measured to monitor possible clues to the deterioration of soil quality and influences to hydrology. Depth of measurement can remain 0-10 cm but greater resolution could be achieved through small depth increment coring to define zones of greatest compaction. Also, the depth of compaction may change as the study continues and this change should be monitored.

Model Development

The hydrologic response of grazing in this study did not specifically differ from that found in past research, instead it provided researchers valuable high resolution data on the interaction of climate, vegetation, soil and grazing intensity. The large data set would allow researchers to validate simulation models. The study is valuable for sensitivity analysis in model development and it provides information which can help researchers better understand how parameters interact. Many multifaceted provide the required data. The information in this study along with that of Gill (199[illegible]) and AAFC Lacombe provide a large information set for modeling.

Gill, S. E. 1996. Grazing effects on runoff and erosion in annual and perennial pastures in the parkland ecoregion of Alberta. M.Sc. Thesis. Department of Renewable Resources, University of Alberta Edmonton, AB.